National Aeronautics and
Space Administration

FY 2021

BUDGET ESTIMATES

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National Aeronautics and Space Administration

FY 2021 PRESIDENT'S BUDGET REQUEST SUMMARY

Budget Authority ($ in millions)	Op Plan 2019	Enacted 2020	Request 2021	Fiscal Year 2022	2023	2024	2025
NASA Total	21,500.0	22,559.0	25,246.0	27,159.6	28,628.0	28,088.1	26,308.3
Deep Space Exploration Systems	5,044.8	6,017.6	8,761.7	10,299.7	11,605.1	10,887.7	8,962.2
Exploration Systems Development	4,086.8	4,582.6	4,042.3	4,011.2	4,071.7	3,767.7	3,634.8
Exploration Research & Development	958.0	1,435.0	4,719.4	6,288.5	7,533.4	7,120.0	5,327.4
Exploration Technology	926.9	1,100.0	1,578.3	1,765.4	1,906.2	1,954.2	2,038.2
LEO and Spaceflight Operations	4,640.4	4,140.2	4,187.3	4,147.3	4,147.3	4,147.3	4,147.3
International Space Station	1,490.3	--	1,400.7	1,390.7	1,338.4	1,314.1	1,319.2
Space Transportation	2,109.7	--	1,877.8	1,771.4	1,826.8	1,848.7	1,843.4
Space and Flight Support (SFS)	1,000.4	--	758.7	810.2	782.1	784.5	784.7
Commercial LEO Development	40.0	--	150.0	175.0	200.0	200.0	200.0
Science	6,886.6	7,138.9	6,306.5	6,553.5	6,575.7	6,705.2	6,766.9
Earth Science	1,931.0	1,971.8	1,768.1	1,878.2	1,846.1	1,834.5	1,984.6
Planetary Science	2,746.7	2,713.4	2,659.6	2,800.9	2,714.9	2,904.8	2,830.7
James Webb Space Telescope	305.1	423.0	414.7	175.4	172.0	172.0	172.0
Astrophysics	1,191.1	1,306.2	831.0	891.2	1,000.9	959.7	975.5
Heliophysics	712.7	724.5	633.1	807.8	841.8	834.1	804.1
Aeronautics	724.8	783.9	819.0	820.7	820.7	820.7	820.7
STEM Engagement	110.0	120.0	--	--	--	--	--
Safety, Security, and Mission Services	2,755.0	2,913.3	3,009.9	2,998.5	2,998.5	2,998.5	2,998.5
Mission Services & Capabilities	1,729.3	--	1,952.0	1,940.6	1,940.6	1,940.6	1,940.6
Engineering, Safety, & Operations	1,025.7	--	1,057.9	1,057.9	1,057.9	1,057.9	1,057.9
Construction and Environmental Compliance and Restoration	372.2	373.4	539.1	530.3	530.3	530.3	530.3
Construction of Facilities	297.3	--	464.4	455.6	455.6	455.6	455.6
Environmental Compliance and Restoration	74.9	--	74.7	74.7	74.7	74.7	74.7
Inspector General	39.3	41.7	44.2	44.2	44.2	44.2	44.2
less rescission, P.L. 116- 93	--	-70.0	--	--	--	--	--
NASA Total	21,500.0	22,559.0	25,246.0	27,159.6	28,628.0	28,088.1	26,308.3

FY 2020 reflects net discretionary funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, which rescinded $70M in FY 2019 unobligated balances from the Science account. Per OMB Circular A-11, Appendix A, the rescission is scored in the year it was enacted.

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

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The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Beginning in FY 2021, SSMS has a revised budget account structure. FY 2019 reflects budget values that have been re-cast into the new SSMS budget structure.

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	Fiscal Year						
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NASA Total	**21,500.0**	**22,559.0**	**25,246.0**	**27,159.6**	**28,628.0**	**28,088.1**	**26,308.3**
Deep Space Exploration Systems	**5,044.8**	**6,017.6**	**8,761.7**	**10,299.7**	**11,605.1**	**10,887.7**	**8,962.2**
Exploration Systems Development	**4,086.8**	**4,582.6**	**4,042.3**	**4,011.2**	**4,071.7**	**3,767.7**	**3,634.8**
Orion Program	**1,350.0**	**1,406.7**	**1,400.5**	**1,322.3**	**1,391.0**	**1,239.9**	**1,084.7**
Crew Vehicle Development	1,339.5	1,396.2	1,390.0	1,311.8	1,378.9	1,229.9	1,064.7
Orion Program Integration and Support	10.5	--	10.5	10.5	12.1	10.0	20.0
Space Launch System	**2,144.0**	**2,585.9**	**2,257.1**	**2,238.3**	**2,249.2**	**2,091.8**	**2,087.1**
Launch Vehicle Development	2,093.1	2,525.8	2,200.2	2,177.0	2,188.0	2,035.8	2,001.1
SLS Program Integration and Support	50.9	--	56.9	61.3	61.1	56.0	86.0
Exploration Ground Systems	**592.8**	**590.0**	**384.7**	**450.6**	**431.6**	**436.0**	**463.0**
Exploration Ground Systems Development	586.6	558.7	377.0	447.0	428.0	436.0	443.0
EGS Program Integration and Support	6.2	--	7.7	3.6	3.6	--	20.0
Exploration Research & Development	**958.0**	**1,435.0**	**4,719.4**	**6,288.5**	**7,533.4**	**7,120.0**	**5,327.4**
Advanced Exploration Systems	**348.9**	**--**	**258.2**	**226.9**	**146.7**	**130.1**	**130.1**
Advanced Cislunar and Surface Capabilities	**132.1**	**--**	**212.1**	**821.4**	**1,664.5**	**1,502.1**	**1,152.6**
Gateway	**332.0**	**--**	**739.3**	**712.1**	**481.8**	**376.5**	**476.4**
Human Landing System	**--**	**--**	**3,369.8**	**4,388.1**	**5,100.4**	**4,971.3**	**3,428.3**
Human Research Program	**145.0**	**--**	**140.0**	**140.0**	**140.0**	**140.0**	**140.0**
Exploration Technology	**926.9**	**1,100.0**	**1,578.3**	**1,765.4**	**1,906.2**	**1,954.2**	**2,038.2**
Early Stage Innovation and Partnerships	**101.7**	**--**	**169.2**	**179.2**	**196.2**	**196.2**	**196.2**
Agency Technology and Innovation	8.8	--	9.4	9.4	9.4	9.4	9.4
Early Stage Innovation	66.5	--	123.4	133.4	150.4	150.4	150.4
Partnerships and Technology Transfer	26.4	--	36.4	36.4	36.4	36.4	36.4
Technology Maturation	**201.2**	**--**	**469.1**	**551.5**	**654.1**	**748.4**	**835.8**
Technology Demonstration	**416.8**	**--**	**537.2**	**556.0**	**513.4**	**464.8**	**525.1**
Laser Comm Relay Demo (LCRD)	17.2	30.0	13.6	--	--	--	--
Solar Electric Propulsion (SEP)	48.1	48.1	48.7	25.4	9.0	5.8	--
Restore & SPIDER (OSAM-1)	192.8	227.2	133.5	117.2	59.4	14.6	--
Small Spacecraft, Flight Opportunities & Other Tech Demo	158.7	--	341.4	413.4	445.0	444.5	525.1
SBIR and STTR	**207.2**	**--**	**402.8**	**478.7**	**542.6**	**544.8**	**481.1**
LEO and Spaceflight Operations	**4,640.4**	**4,140.2**	**4,187.3**	**4,147.3**	**4,147.3**	**4,147.3**	**4,147.3**
International Space Station	**1,490.3**	**--**	**1,400.7**	**1,390.7**	**1,338.4**	**1,314.1**	**1,319.2**
International Space Station Program	**1,490.3**	**--**	**1,400.7**	**1,390.7**	**1,338.4**	**1,314.1**	**1,319.2**
ISS Systems Operations and Maintenance	1,085.3	--	1,049.8	1,047.8	1,007.5	983.1	983.1
ISS Research	405.0	--	350.9	342.9	330.9	331.0	336.1
Space Transportation	**2,109.7**	**--**	**1,877.8**	**1,771.4**	**1,826.8**	**1,848.7**	**1,843.4**

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Budget Authority ($ in millions)	Op Plan 2019	Enacted 2020	Request 2021	2022	2023	2024	2025
Crew and Cargo Program	**1,895.6**	**--**	**1,778.1**	**1,708.1**	**1,763.6**	**1,784.1**	**1,778.7**
Commercial Crew Program	**214.1**	**--**	**99.7**	**63.2**	**63.2**	**64.6**	**64.6**
Space and Flight Support (SFS)	**1,000.4**	**--**	**758.7**	**810.2**	**782.1**	**784.5**	**784.7**
Space Communications and Navigation	**602.5**	**--**	**506.0**	**517.4**	**487.1**	**481.1**	**481.1**
Space Communications Networks	499.0	--	388.2	388.6	372.6	372.6	372.6
Space Communications Support	103.5	--	117.8	128.8	114.5	108.5	108.5
Human Space Flight Operations	**133.1**	**--**	**89.9**	**101.1**	**103.7**	**104.6**	**104.8**
Launch Services	**88.4**	**--**	**91.9**	**101.9**	**92.2**	**92.2**	**92.2**
Rocket Propulsion Test	**60.0**	**--**	**47.6**	**47.8**	**47.8**	**47.8**	**47.8**
Communications Services Program	**101.9**	**--**	**23.4**	**42.0**	**51.2**	**58.9**	**58.9**
21st Century Space Launch Complex	**14.5**	**--**	**--**	**--**	**--**	**--**	**--**
Commercial LEO Development	**40.0**	**--**	**150.0**	**175.0**	**200.0**	**200.0**	**200.0**
Science	**6,886.6**	**7,138.9**	**6,306.5**	**6,553.5**	**6,575.7**	**6,705.2**	**6,766.9**
Earth Science	**1,931.0**	**1,971.8**	**1,768.1**	**1,878.2**	**1,846.1**	**1,834.5**	**1,984.6**
Earth Science Research	**454.1**	**--**	**447.3**	**471.9**	**494.1**	**528.5**	**530.3**
Earth Science Research and Analysis	316.5	--	309.9	321.7	324.0	327.4	327.2
Computing and Management	137.6	--	137.4	150.2	170.1	201.1	203.1
Earth Systematic Missions	**932.7**	**--**	**608.3**	**706.1**	**695.6**	**640.7**	**797.3**
Surface Water and Ocean Topography Mission (SWOT)	109.1	82.2	63.9	32.8	11.5	9.5	9.5
NASA-ISRO Synthetic Aperture Radar (NISAR)	134.6	136.0	59.7	73.5	34.4	24.3	19.7
Landsat 9	137.4	108.9	86.5	2.8	2.9	3.0	3.0
Sentinel-6	70.4	59.5	20.4	14.9	35.3	52.9	68.0
Other Missions and Data Analysis	481.2	--	377.8	582.2	611.5	551.1	697.1
Earth System Science Pathfinder	**223.8**	**--**	**338.9**	**301.2**	**251.6**	**241.8**	**234.4**
Venture Class Missions	163.5	--	263.6	230.8	183.6	176.9	169.4
Other Missions and Data Analysis	60.2	--	75.3	70.4	68.0	64.9	64.9
Earth Science Data Systems	**202.0**	**--**	**245.4**	**259.9**	**263.2**	**278.7**	**277.7**
Earth Science Technology	**63.4**	**--**	**74.2**	**82.8**	**84.6**	**86.4**	**86.4**
Applied Sciences	**55.1**	**--**	**53.9**	**56.3**	**57.0**	**58.5**	**58.5**
Planetary Science	**2,746.7**	**2,713.4**	**2,659.6**	**2,800.9**	**2,714.9**	**2,904.8**	**2,830.7**
Planetary Science Research	**276.6**	**--**	**305.4**	**288.6**	**285.1**	**295.2**	**286.7**
Planetary Science Research and Analysis	195.7	--	223.0	206.2	204.4	207.1	204.4
Other Missions and Data Analysis	80.9	--	82.4	82.4	80.7	88.1	82.3
Planetary Defense	**150.0**	**--**	**150.0**	**147.2**	**97.6**	**98.0**	**98.0**
DART	98.0	72.4	66.4	9.1	4.5	--	--
Other Missions and Data Analysis	52.0	--	83.6	138.1	93.1	98.0	98.0
Lunar Discovery and Exploration	**188.0**	**--**	**451.5**	**517.3**	**491.3**	**458.3**	**458.3**
Discovery	**409.5**	**--**	**484.3**	**424.4**	**434.8**	**570.1**	**505.8**
Lucy	165.5	210.8	153.4	63.7	16.5	18.6	22.9
Psyche	174.2	219.3	187.4	152.4	28.7	29.0	32.0
Other Missions and Data Analysis	69.8	--	143.5	208.3	389.6	522.5	450.9
New Frontiers	**93.0**	**--**	**179.0**	**314.3**	**332.8**	**326.9**	**285.0**

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Budget Authority ($ in millions)	Op Plan 2019	Enacted 2020	Request 2021	2022	2023	2024	2025
			Fiscal Year				
Dragonfly	8.0	--	95.8	198.8	291.4	288.7	208.9
Other Missions and Data Analysis	85.0	--	83.2	115.5	41.4	38.2	76.1
Mars Exploration	**712.7**	**--**	**528.5**	**588.4**	**671.2**	**798.7**	**855.3**
Mars Rover 2020	502.6	318.7	162.3	97.0	33.0	--	--
Other Missions and Data Analysis	210.1	--	366.2	491.4	638.2	798.7	855.3
Outer Planets and Ocean Worlds	**793.6**	**--**	**414.4**	**370.7**	**239.4**	**192.3**	**171.7**
Jupiter Europa	732.4	592.6	403.5	351.8	224.9	180.8	160.1
Other Missions and Data Analysis	61.2	--	10.9	18.9	14.5	11.5	11.7
Radioisotope Power	**123.3**	**--**	**146.3**	**150.1**	**162.8**	**165.4**	**169.8**
James Webb Space Telescope	**305.1**	**423.0**	**414.7**	**175.4**	**172.0**	**172.0**	**172.0**
Astrophysics	**1,191.1**	**1,306.2**	**831.0**	**891.2**	**1,000.9**	**959.7**	**975.5**
Astrophysics Research	**222.8**	**--**	**269.7**	**279.1**	**327.2**	**314.9**	**331.1**
Astrophysics Research and Analysis	83.4	--	90.2	92.2	94.2	94.2	94.2
Balloon Project	40.2	--	44.8	45.8	45.7	46.3	46.3
Science Activation	45.0	--	45.6	45.6	45.6	45.6	45.6
Other Missions and Data Analysis	54.2	--	89.1	95.5	141.7	128.8	145.0
Cosmic Origins	**222.8**	**--**	**124.0**	**123.2**	**120.0**	**122.4**	**122.4**
Hubble Space Telescope Operations	98.3	--	88.3	98.3	98.3	98.3	98.3
Stratospheric Observatory for Infrared Astronomy (SOFIA)	85.2	--	12.0	--	--	--	--
Other Missions and Data Analysis	39.3	--	23.7	24.9	21.7	24.1	24.1
Physics of the Cosmos	**151.2**	**--**	**143.9**	**160.8**	**155.3**	**169.8**	**154.1**
Exoplanet Exploration	**367.9**	**--**	**47.2**	**50.4**	**47.6**	**51.6**	**52.2**
Other Missions and Data Analysis	367.9	--	47.2	50.4	47.6	51.6	52.2
Astrophysics Explorer	**226.5**	**--**	**246.2**	**277.7**	**350.8**	**301.0**	**315.6**
Heliophysics	**712.7**	**724.5**	**633.1**	**807.8**	**841.8**	**834.1**	**804.1**
Heliophysics Research	**248.9**	**--**	**230.5**	**218.7**	**225.2**	**224.0**	**224.5**
Heliophysics Research and Analysis	71.2	--	58.6	58.6	58.6	58.6	58.6
Sounding Rockets	61.1	--	71.6	60.1	65.1	65.1	65.1
Research Range	30.0	--	27.4	26.4	26.8	26.9	26.9
Other Missions and Data Analysis	86.7	--	73.0	73.5	74.7	73.4	73.9
Living with a Star	**135.3**	**--**	**127.9**	**134.5**	**246.4**	**225.5**	**233.3**
Solar Orbiter Collaboration	27.1	12.8	8.1	8.2	8.1	8.2	8.2
Other Missions and Data Analysis	108.2	--	119.7	126.3	238.2	217.3	225.0
Solar Terrestrial Probes	**180.5**	**--**	**126.3**	**262.2**	**202.6**	**195.6**	**115.5**
Other Missions and Data Analysis	180.5	--	126.3	262.2	202.6	195.6	115.5
Heliophysics Explorer Program	**147.9**	**--**	**148.4**	**192.4**	**167.6**	**189.0**	**230.8**
Other Missions and Data Analysis	147.9	--	148.4	192.4	167.6	189.0	230.8
Aeronautics	**724.8**	**783.9**	**819.0**	**820.7**	**820.7**	**820.7**	**820.7**
Aeronautics	**724.8**	**783.9**	**819.0**	**820.7**	**820.7**	**820.7**	**820.7**
Airspace Operations and Safety Program	**105.7**	**--**	**90.4**	**92.6**	**94.4**	**96.2**	**96.2**
Advanced Air Vehicles Program	**272.1**	**--**	**212.7**	**222.2**	**230.3**	**261.2**	**266.2**
Integrated Aviation Systems Program	**209.6**	**--**	**269.0**	**256.4**	**244.4**	**209.5**	**204.5**
Low Boom Flight Demonstrator	105.9	103.5	79.1	75.5	13.8	3.8	--

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Integrated Aviation Systems Program	103.7	--	190.0	180.9	230.6	205.7	204.5
Transformative Aero Concepts Program	**137.4**	**--**	**129.9**	**132.3**	**134.6**	**136.7**	**136.7**
Aerosciences Evaluation and Test Capabilities	**--**	**--**	**117.0**	**117.1**	**117.1**	**117.1**	**117.1**
Aerosciences Eval. & Test Capabilities Program	--	--	117.0	117.1	117.1	117.1	117.1
STEM Engagement	**110.0**	**120.0**	**--**	**--**	**--**	**--**	**--**
Safety, Security, and Mission Services	**2,755.0**	**2,913.3**	**3,009.9**	**2,998.5**	**2,998.5**	**2,998.5**	**2,998.5**
Mission Services & Capabilities	**1,729.3**	**--**	**1,952.0**	**1,940.6**	**1,940.6**	**1,940.6**	**1,940.6**
Information Technology (IT)	**501.8**	**--**	**553.9**	**553.9**	**553.9**	**553.9**	**553.9**
Mission Enabling Services	**690.8**	**--**	**705.0**	**693.7**	**693.7**	**693.7**	**693.7**
Infrastructure & Technical Capabilities	**536.8**	**--**	**693.1**	**693.0**	**693.0**	**693.0**	**693.0**
Engineering, Safety, & Operations	**1,025.7**	**--**	**1,057.9**	**1,057.9**	**1,057.9**	**1,057.9**	**1,057.9**
Agency Technical Authority	**175.3**	**--**	**184.0**	**184.0**	**184.0**	**184.0**	**184.0**
Center Engineering, Safety, & Operations	**850.4**	**--**	**873.9**	**873.9**	**873.9**	**873.9**	**873.9**
Construction and Environmental Compliance and Restoration	**372.2**	**373.4**	**539.1**	**530.3**	**530.3**	**530.3**	**530.3**
Construction of Facilities	**297.3**	**--**	**464.4**	**455.6**	**455.6**	**455.6**	**455.6**
Institutional CoF	**218.9**	**--**	**395.1**	**455.6**	**455.6**	**455.6**	**455.6**
Exploration CoF	**31.9**	**--**	**22.3**	**--**	**--**	**--**	**--**
Space Operations CoF	**17.6**	**--**	**23.9**	**--**	**--**	**--**	**--**
Science CoF	**19.7**	**--**	**23.1**	**--**	**--**	**--**	**--**
Aeronautics CoF	**9.2**	**--**	**--**	**--**	**--**	**--**	**--**
Environmental Compliance and Restoration	**74.9**	**--**	**74.7**	**74.7**	**74.7**	**74.7**	**74.7**
Inspector General	**39.3**	**41.7**	**44.2**	**44.2**	**44.2**	**44.2**	**44.2**
Inspector General	39.3	41.7	44.2	44.2	44.2	44.2	44.2
less rescission, P.L. 116- 93	**--**	**-70.0**	**--**	**--**	**--**	**--**	**--**
NASA Total	**21,500.0**	**22,559.0**	**25,246.0**	**27,159.6**	**28,628.0**	**28,088.1**	**26,308.3**

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MESSAGE FROM THE ADMINISTRATOR

President Donald Trump's Fiscal Year 2021 Budget for NASA is worthy of 21st century space exploration. The President's Budget invests more than $25 billion in NASA to reinforce our innovative human space exploration program while maintaining strong support for NASA's full suite of science, aeronautics, and technology work.

The 2021 NASA Budget constitutes a nearly 12 percent increase over the previous fiscal year. Our Agency knows this comes at a time of constrained resources for the Federal Government, and demonstrates the Nation's commitment to NASA at the dawn of a new, dynamic spaceflight era. Every dollar spent in space development technologies is meant to improve life here on Earth. Past investments in NASA have helped profoundly improve American life. I am fully confident that this fiscal year's investment will continue to empower our Agency's remarkable ability to elevate the human condition.

The resources extended to NASA in the FY 2021 Budget and outyears will enable our Nation to stay on the path to landing the first woman and the next man on the surface of the Moon in 2024 and build a sustainable lunar presence. It lays the foundations to eventually send human missions to Mars. Most noteworthy, through this Budget, the President has directed more than $3 billion toward development of a human landing system, the first time we have had direct funding for a human lander since the Apollo Program. This signals a significant national commitment to our American exploration campaign. This Budget's full support of the Space Launch System rocket, Orion spacecraft, the Gateway, and all systems, technologies, and science needed for the Artemis Program will safely deliver us to the lunar surface, Mars, and beyond.

Although our ultimate goal is far beyond low-Earth orbit (LEO), what we do there will expedite our exploration elsewhere. The President's Budget fully supports the International Space Station's critical missions to learn about human health in microgravity, demonstrate exploration technologies, and much more. Furthermore, this Budget aids NASA in broadening commercial activity in LEO to support ever greater private participation. Partnerships are the cornerstone of our approach to enabling human expansion across the solar system. American businesses currently resupply the space station and soon will launch American astronauts on American rockets from American soil - a capability we must never lose again.

The Budget also strongly positions NASA to continue focusing our energies on the exciting and new horizons emerging in science, aeronautics, and technology. In science, the Budget supports our decadal priorities, including history's first Mars sample return mission, the Europa Clipper, and development of new trailblazing Earth observation missions. In aeronautics, the Budget supports cutting-edge research on commercial use of supersonic aircraft and unmanned aerial system technologies that will make flying with commercial and private aircraft safer and more efficient in the 21st century. Lastly, we all know that advanced technology powers exploration, and the Budget invests in critical, reusable systems needed to get us to the Moon, Mars, and beyond, including next-generation robotics and crewhabitats.

The 2021 Budget empowers NASA to tirelessly continue developing civilization-changing technologies, execute era-defining exploration, and deepen humanity's scientific knowledge of our Earth and the universe. I am confident proper investment in our space priorities, coupled with the unmatched talents of American engineers and scientists, will strengthen our national posture for continued space supremacy and lead humanity into the next era of technical and scientific progress as the Artemis Generation.

Jim Bridenstine

Ad astra,
Jim Bridenstine

NOTES ON THE BUDGET

With the resources provided in the Fiscal Year 2021 Budget, NASA will: partner with commercial industry to build a Human Landing System, keeping NASA on track to land the first woman and the next American man on the lunar surface in 2024; launch American astronauts from American soil on American rockets to the International Space Station; and embark on missions that will yield great scientific discoveries further advancing humanity's knowledge of the universe.

The Administration's strong support and vision for NASA are reflected in the FY 2021 President's Budget, which reflects a 21st century budget to propel 21st century exploration and discovery. Building on Fiscal Year 2020's Budget, as amended, of $22.6 billion to enable a 2024 Moon landing, this year's budget request for NASA will place the Agency on the path to achieving the mission laid out by President Trump in Space Policy Directive One, and by Vice President Pence in his speech at NASA's Marshall Space Flight Center.

NASA's historic and enduring purpose is captured in four major strategic thrusts: Discover, Explore, Develop, and Enable. These correspond to our missions of scientific discovery of our world, of other worlds, and of the cosmos as a whole; missions of exploration in our solar system with humans and robotic probes that expand the frontiers of human experience; and missions that develop and advance new technologies in exploration and aeronautics that allow American industry to increase market share and create new markets, on Earth and the near-Earth region of space.

Discover

NASA's Science program epitomizes the Agency's history of momentous discovery and funds on-going discovery and exploration of our planet, other planets and planetary bodies, our star system in its entirety, our galaxy, and the universe beyond. Through the development of space observatories and probes, NASA will continue to inspire the next generation of scientists, engineers, and explorers, provide U.S. leadership in space, and expand human knowledge. NASA Science includes nearly 100 missions, many of which involve collaboration with international partners or other U.S. agencies. Over 30 of those missions are in the formulation and development stage, while more than 60 other missions continue operations.

This budget continues to reinvigorate robotic exploration of the solar system by providing $2.66 billion for Planetary Science. Early Commercial Lunar Payload Services (CLPS) lunar missions will enable important technology demonstrations that will inform the development of future landers and other exploration systems needed for NASA's Moon to Mars campaign. The budget request proposes to launch the Europa Clipper as early as 2024 on a commercial launch vehicle, which would save over $1.5 billion compared to using a Space Launch System rocket. This budget supports Discovery projects such as Lucy and Psyche, New Frontiers projects such as Dragonfly, as well as planetary defense measures to detect objects near Earth. The budget also supports a robust Mars exploration portfolio that includes the Mars 2020 Rover, the development of a Mars Sample Return mission, and planning for a future Mars Ice Mapper mission. Such Planetary missions will continue to inspire the next generation of explorers while aiding and informing a future sustained human presence in the solar system.

NASA missions continue to enhance our understanding of the Earth. This budget provides $1.77 billion for a focused, balanced Earth science portfolio that supports the priorities of the science and applications communities. The budget supports a robust Venture Class mission cadence and the launch of several upcoming missions, including Landsat-9, NASA-ISRO Synthetic Aperture Radar (NISAR), Surface Water and Ocean Topography (SWOT), and Sentinel-6. Consistent with prior budget requests, no funding is provided for the PACE and CLARREO Pathfinder missions given higher priorities for NASA funding.

NOTES ON THE BUDGET

This budget will complete the James Webb Space Telescope, planned for launch in March 2021. Providing $831 million for Astrophysics, the budget provides funding to continue such projects as IXPE, SPHEREx and GUSTO. The budget proposes to terminate funding for the Wide Field Infrared Survey Telescope (WFIRST) mission and the SOFIA mission, which have annual operating costs of over $80 million. The Administration is not ready to proceed with another multi-billion-dollar space telescope until Webb has been successfully launched and deployed. The SOFIA mission has not delivered high quality data products or science on par with other large science missions.

The budget provides $633 million for Heliophysics, continuing to support the Diversify, Realize, Integrate, Venture, Educate (DRIVE) initiative, the highest priority recommendation in the Heliophysics Decadal Survey. The budget also supports the IMAP mission and space weather-related interagency efforts.

The budget continues support of initiatives that use smaller, less expensive satellites and/or public-private partnerships to advance science. A targeted investment strategy focuses technology development on CubeSats/SmallSats in all four SMD science themes, and will provide novel partnership opportunities between commercial partners and NASA.

Explore

NASA is pursuing its Moon to Mars campaign to establish U.S. preeminence on the Moon through commercial and international partnerships, and using new procurement approaches to increase the sustainability of exploration. A vibrant landscape of American science, manufacturing and technology will create the investments necessary to support the first woman and next man on the Moon in 2024. This effort will leave many systems and assets in place, ensuring a strategic and sustainable American presence on the Moon, and serves to enable NASA with the skills, systems, and operational capabilities to support an eventual safe human mission to Mars.

The FY 2021 budget request includes more than $12 billion to pursue the Moon to Mars campaign, focusing on returning humans to the Moon and cislunar space, with eventual missions to Mars and beyond. NASA will evolve its core capabilities through continued technical advancements, and new approaches to industrial partnerships to maintain the U.S.'s leadership role in human spaceflight. The Agency has developed a phased approach for this activity, starting with robotic lunar landers and progressing to human activity in cislunar space, the lunar surface, then eventually to Mars and beyond.

The Lunar Discovery and Exploration program is supporting innovative approaches to achieve human and science exploration goals through Commercial Lunar Payload Services (CLPS), which allows NASA to focus on the development of instruments and exploration technology demonstrations to meet lunar science and exploration needs.

This budget is the first to specifically request funding for a Human Landing System since the Apollo era, and NASA is working with commercial partners to develop an integrated landing system that will transport crew to and from the lunar surface in 2024. The program will also support subsequent crewed missions to the lunar surface, and the capabilities developed will enable a sustainable long-term presence on the lunar surface in preparation for human missions to Mars.

The Exploration Systems Development programs are creating critical components of the Artemis flight architecture for human exploration beyond low Earth orbit. Orion will take humans to cislunar space atop the SLS, the heavy-lift rocket that is supported by Exploration Ground Systems (EGS) for integration and launch.

The Gateway architecture is focused on functional elements that will enable lunar landings and surface activities and lay the foundation for sustaining lunar operations on the Moon and human missions to Mars. Human lunar landers will dock with the Gateway and provide communications and logistics support for lunar surface missions.

To enable the Artemis initiative, Advanced Exploration System funding focuses on reducing operational risk, validating operational concepts, leveraging partner capabilities, and lowering lifecycle costs to help enable lunar and deep space missions. AES is employing a stepping-stone approach by testing on the ground, in LEO, and in cislunar space, with the ultimate goal being to conduct final validation of the entire habitation capability for long-duration exploration missions. NASA will conduct lunar missions to test systems and concepts, paving the way for long-duration human space exploration. Opening the space frontier requires expansion of technical and scientific knowledge to tackle complex problems and creative new solutions to meet demands never before encountered by humans.

NASA will continue to leverage its mission in low Earth orbit (LEO) to identify risks to human health, develop countermeasures, and test technologies that protect astronauts, while supporting National Laboratory research by private industry and other organizations, and working towards reducing operations and maintenance costs.NASA is making technological advances aboard ISS in autonomous rendezvous and docking, advanced communications systems, human health and behavior in space, life support systems for habitats, and space suit systems, as well as in basic research in biological and physical sciences. Over time, NASA has been and will continue to transition various aspects of human spaceflight operations in LEO to the private sector. This includes changes to the funding model supporting ISS and the use of commercial space stations, when they become available.

NASA will continue its partnership with the U.S. commercial space industry to operate safe, reliable and affordable transportation to and from the ISS, the Moon, and future commercial space stations in low Earth orbit. The Commercial LEO Development effort is stimulating the development of a commercial ecosystem in low Earth orbit. NASA's ISS and Commercial LEO Development efforts will lay the foundation for the emergence of an environment in LEO where a dynamic market exists, with NASA as an active participant. NASA will continue to purchase commercial crew and commercial cargo services in FY 2021, providing stability to NASA, the ISS and our international partners, the U.S. space transportation industry, and ensuring NASA's ability to launch astronauts from U.S. soil on American rockets.

Develop

NASA's discoveries re-write science textbooks and transform our knowledge of ourselves, our planet, the solar system, and the universe. Through its missions and sponsored research, NASA provides access to the farthest reaches of space, time, and essential information about our home planet. NASA seeks to solve the mysteries of the Universe and to better prepare for continued journeys beyond Earth. On the practical side, NASA research into the human body and cutting-edge developments are areas that have a direct correlation to our quality of life and economy. From scientific discovery, expanding human presence in space, to helping the nation in other ways, are all built upon developing new technologies that propel this exploration.

NOTES ON THE BUDGET

The Exploration Technology budget account, managed by the Space Technology Mission Directorate (STMD), is enabling technology research and development needs for human space exploration with a near-term prioritization of sustainable lunar exploration and an eye toward Mars in the long-term, while supporting technologies that have relevance to achieving future science exploration goals and commercial endeavors. New technology is critically needed to enable these goals, and STMD rapidly develops, demonstrates, and infuses revolutionary, high-payoff technologies through transparent, collaborative partnerships. These transformative technologies enable NASA's lunar and deep space exploration missions to meet human space exploration needs, as well as fostering commercial expansion in LEO, cislunar space and beyond.

NASA's investments continue to target technologies that benefit both human and robotic exploration, actively engaging with NASA Centers, industry, academia, and other Federal Government agencies to help define investment content. Under the Lunar Surface Innovation Initiative (LSII), STMD will develop and integrate systems used for in situ resource utilization, including oxygen, water, and hydrogen, reducing mission mass, cost, and risk. NASA is initiating a new nuclear program that will initially focus on developing a surface power system that would support long-duration crewed missions on the surface of the Moon. LSII will bring together the full range of stakeholders, including entrepreneurs, academia, small businesses, industry and the NASA workforce, to catalyze development of new technologies such as space weather monitoring tools and improve systems and components to allow survival and operation through the cold lunar night.

The Space Technology Mission Directorate contributes to growing the U.S. industrial and academic base, continuing the Nation's economic leadership, and strengthening our national security. STMD has developed a diverse portfolio of early-stage research and technology creating a technology pipeline to solve the Agency and Nation's most difficult exploration challenges by partnering with researchers across academia and industry. Public-private partnerships will enable NASA to share the risk and financial interest with private sector industry to better leverage government investments. For example, STMD is partnering with industry to demonstrate robotic manipulation of structures and remote manufacturing of structural trusses in space. These shared risks and gains include incentivizing technical performance and spurring future commercial markets in the process of developing new capabilities.

An additional important facet of NASA's development work is the air transportation system, a vital part of the U.S. and global economies. Air travel enhances our national security and the industrial base and provides a key catalyst to the nation's economic development and growth. NASA conducts aeronautics research to bring transformational advances in the safety, capacity, and efficiency of the air transportation system. NASA is also enabling breakthroughs in the speed and efficiency of transport aircraft that are the backbone of today's aviation system as well as in innovative new aircraft concepts and technologies that will enable new aviation markets.

With this budget, NASA will prepare the X-59 Low-Boom Flight Demonstrator for its first flight in FY 2022. The X-59 will demonstrate quiet supersonic flight and will deliver data to regulators who can change the rules to allow supersonic flight over land. NASA supports the efforts of U.S. industry to develop their next generation subsonic aircraft by developing new technologies to reduce fuel consumption, noise, and emissions. Electric aircraft propulsion is one of the most promising of these technologies and in cooperation with partners, NASA will be conducting flight tests of high power electric propulsion systems. From air traffic management to quiet verticle lift, NASA is working to eliminate key barriers to establish new Urban Air Mobility (UAM) markets. NASA will conduct a series of Grand Challenge events that will bring the UAM community together to demonstrate progress in the technologies needed to enable safe UAS operations in the National Airspace.

Technological leadership remains vital to our national security, economic prosperity, and global competitiveness. The Nation's continued economic leadership is, in part, due to the technological investments made in earlier years, through the work of the engineers, scientists, and policy makers who had the wisdom and foresight to make investments our country required to emerge as a global technological leader. That commitment accelerated the economy with the creation of new industries, products, and services that yielded lasting benefits. A technology-driven NASA will continue to help fuel our Nation's economic engine for decades to come, while also providing valuable breakthroughs for NASA's Moon to Mars campaign.

Enable

NASA's Space Communication and Navigation networks provide secure, reliable, and adaptable communication services to NASA missions, as well as external customers who rely on space communications services on a daily basis. The Launch Services Program ensures access to space for the Nation's civil sector satellite and robotic planetary missions. NASA is also developing the first long-period optical communications project that will demonstrate benefits for both deep space and near-Earth missions. Human exploration of the Moon requires robust communications links to and from the Moon to support high-resolution video, telemedicine, and advanced instruments to locate and identify exploitable resources on the Moon, such as subsurface ice.

NASA's Mission Support Directorate directly enables NASA's portfolio of missions in space exploration, science and aeronautics. The Safety, Security, and Mission Services account funds the essential day-to-day technical and business operations required to safely operate and maintain NASA centers and facilities and the independent technical authority required to reduce risk to life and program objectives for all missions. These mission support activities provide the proper services, tools, and equipment to complete essential tasks, protect and maintain the security and integrity of information and assets, and ensure that personnel work under safe and healthy conditions.

Planning, operating, and sustaining this infrastructure and our essential services requires a number of critical institutional capabilities including management of: human capital; finance; information technology; infrastructure; acquisitions; security; real and personnel property; occupational health and safety; equal employment opportunity and diversity; small business programs; external relations; strategic internal and external communications; stakeholder engagement; and other essential corporate functions. In FY 2021, NASA will strengthen cybersecurity capabilities, safeguarding critical systems and data serving the Moon to Mars campaign and the Artemis program. Increased funding for the Health and Medical Technical Authority will also strengthen independent oversight to mitigate risks in these programs. NASA will continue to provide strategic and operational planning and management over a wide range of services to help NASA operate in a more efficient and sustainable manner.

The Construction and Environmental Compliance and Restoration account enables NASA to manage the Agency's facilities with a focus on reducing infrastructure burdens, implementing high performance upgrades to increase efficiency, and prioritizing repairs to achieve the greatest return on investment. In FY 2021, NASA continues to consolidate facilities via institutional construction projects to achieve greater operational efficiency, replacing old, obsolete, costly facilities with fewer, high performance facilities. Programmatic construction of facilities projects provide the specialized technical facilities required by the missions. To protect human health and the environment, and to preserve natural resources for future missions, environmental compliance and restoration projects will clean up pollutants released into the environment during prior NASA activities.

NASA’s workforce continues to be its greatest asset for enabling missions in space and on Earth. The civil service staffing levels proposed in the FY 2021 Budget support NASA’s scientists, engineers, researchers, managers, technicians, and business professionals. NASA’s workforce includes civil service personnel at NASA Centers, Headquarters, and NASA-operated facilities. The mix of skills and distribution of workforce across the Agency is, however, necessarily changing. In order to maintain flexibility in its workforce, NASA is finding efficiencies in hiring and exploring the use of non-permanent employment to fill short-term or mission-specific needs. The Agency will apply the valued civil service workforce to priority and enduring mission work, adjusting the mix of skills where appropriate. Centers will use a range of tools available to reshape the workforce, and to identify, recruit, and retain a multi-generational workforce of employees who possess skills critical to the Agency.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

The FY 2020 Operating Plan was not approved at the time this budget was prepared. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

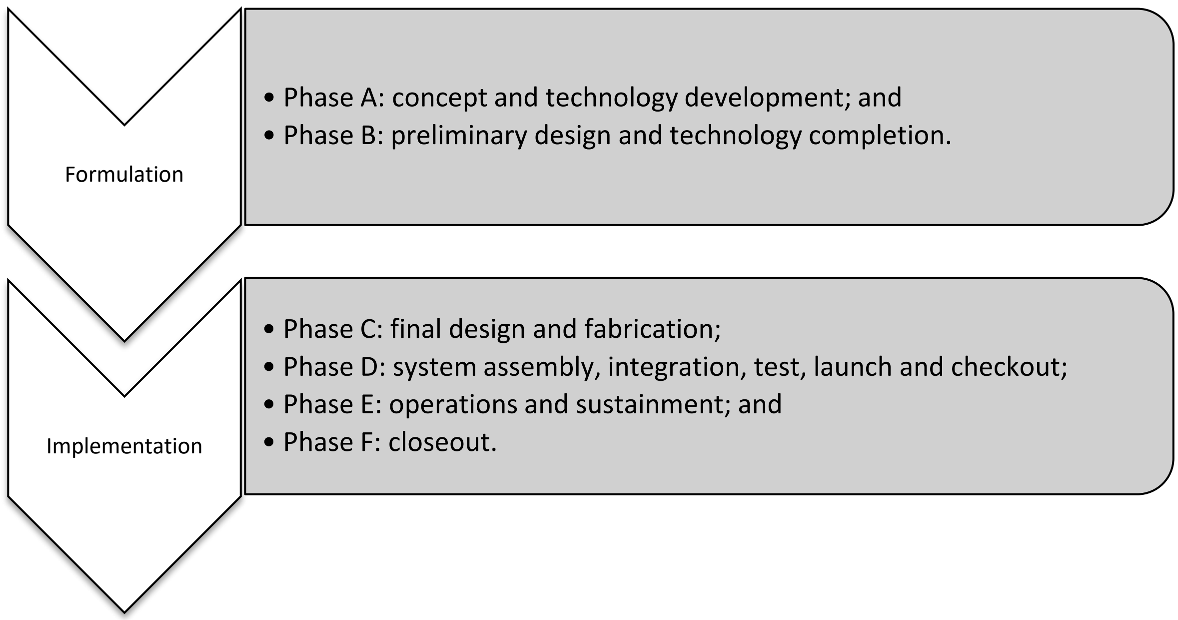
FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

FY 2020 reflects net discretionary funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, which recinded $70 million in FY 2019 unobligated balances from the Science account. Per OMB Circular A-11, Appendix A, the recission is scored in the year it was enacted.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

EXPLANATION OF PROJECT SCHEDULE COMMITMENTS AND KEY MILESTONES

Programs and projects follow their appropriate life cycle. The life cycle is divided into phases. Transition from one phase to another requires management approval at Key Decision Points (KDPs). The phases in program and project life cycles include one or more life-cycle reviews, which are considered major milestone events.



A life-cycle review is designed to provide the program or project with an opportunity to ensure that it has completed the work of that phase and an independent assessment of a program's or project's technical and programmatic status and health. The final life-cycle review in a given life-cycle phase provides essential information for the KDP that marks the end of that life-cycle phase and transition to the next phase if successfully passed. As such, KDPs serve as gates through which programs and projects must pass to continue.

The KDP decision to authorize a program or project's transition to the next life-cycle phase is based on a number of factors, including technical maturity; continued relevance to Agency strategic goals; adequacy of cost and schedule estimates; associated probabilities of meeting those estimates (confidence levels); continued affordability with respect to the Agency's resources; maturity and the readiness to proceed to the next phase; and remaining program or project risk (safety, cost, schedule, technical, management, and programmatic). At the KDP, the key program or project cost, schedule, and content parameters that govern the remaining life-cycle activities are established.

For reference, a description of schedule commitments and milestones is listed below for projects in Formulation and Implementation. A list of common terms used in mission planning is also included.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

Formulation

NASA places significant emphasis on project Formulation to ensure adequate preparation of project concepts and plans and mitigation of high-risk aspects of the project essential to position the project for the highest probability of mission success. During Formulation, the project explores the full range of implementation options, defines an affordable project concept to meet requirements, and develops needed technologies. The activities in these phases include developing the system architecture; completing mission and preliminary system designs; acquisition planning; conducting safety, technical, cost, and schedule risk trades; developing time-phased cost and schedule estimates and documenting the basis of these estimates; and preparing the Project Plan for Implementation.

Formulation Milestone	Explanation
KDP-A	The lifecycle gate at which the decision authority determines the readiness of a program or project to transition into Phase A and authorizes Formulation of the project. Phase A is the first phase of Formulation and means that: • The project addresses a critical NASA need; • The proposed mission concept(s) is feasible; • The associated planning is sufficiently mature to begin activities defined for formulation; and • The mission can likely be achieved as conceived.
System Requirements Review (SRR)	The lifecycle review in which the decision authority evaluates whether the functional and performance requirements defined for the system are responsive to the program's requirements on the project and represent achievable capabilities
System Definition Review or Mission Definition Review	The lifecycle review in which the decision authority evaluates the credibility and responsiveness of the proposed mission/system architecture to the program requirements and constraints on the project, including available resources, and determines whether the maturity of the project's mission/system definition and associated plans are sufficient to begin the next phase, Phase B.
KDP-B	The lifecycle gate at which the decision authority determines the readiness of a program or project to transition from Phase A to Phase B. Phase B is the second phase of Formulation and means that: • The proposed mission/system architecture is credible and responsive to program requirements and constraints, including resources; • The maturity of the project's mission/system definition and associated plans is sufficient to begin Phase B; and • The mission can likely be achieved within available resources with acceptable risk.
Preliminary Design Review (PDR)	The lifecycle review in which the decision authority evaluates the completeness/consistency of the planning, technical, cost, and schedule baselines developed during Formulation. This review also assesses compliance of the preliminary design with applicable requirements and determines if the project is sufficiently mature to begin Phase C.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

Implementation

Implementation occurs when Agency management establishes baseline cost and schedule commitments for projects at KDP-C. The projects maintain the baseline commitment through the end of the mission. Projects are baselined for cost, schedule, and programmatic and technical parameters. Under Implementation, projects are able to execute approved plans development and operations.

Implementation Milestone	Explanation
KDP-C	The lifecycle gate at which the decision authority determines the readiness of a program or project to begin the first stage of development and transition to Phase C and authorizes the Implementation of the project. Phase C is first stage of development and means that: • The project's planning, technical, cost, and schedule baselines developed during Formulation are complete and consistent; • The preliminary design complies with mission requirements; • The project is sufficiently mature to begin Phase C; and • The cost and schedule are adequate to enable mission success with acceptable risk.
Critical Design Review (CDR)	The lifecycle review in which the decision authority evaluates the integrity of the project design and its ability to meet mission requirements with appropriate margins and acceptable risk within defined project constraints, including available resources. This review also determines if the design is appropriately mature to continue with the final design and fabrication phase.
System Integration Review (SIR)	The lifecycle review in which the decision authority evaluates the readiness of the project and associated supporting infrastructure to begin system assembly, integration, and test. The lifecycle review also evaluates whether the remaining project development can be completed within available resources, and determine if the project is sufficiently mature to begin Phase D.
KDP-D	The lifecycle gate at which the decision authority determines the readiness of a project to continue in Implementation and transition from Phase C to Phase D. Phase D is a second phase in Implementation; the project continues in development and means that: • The project is still on plan; • The risk is commensurate with the project's payload classification; and • The project is ready for assembly, integration and test with acceptable risk within its Agency baseline commitment.
Launch Readiness Date (LRD)	The date at which the project and its ground, hardware, and software systems are ready for launch.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

Other Common Terms for Mission Planning

Term	Definition
Decision Authority	The individual authorized by the Agency to make important decisions on programs and projects under their authority.
Formulation Authorization Document	The document that authorizes the formulation of a program whose goals will fulfill part of the Agency's Strategic Plan and Mission Directorate strategies. This document establishes the expectations and constraints for activity in the Formulation phase.
Key Decision Point (KDP)	The lifecycle gate at which the decision authority determines the readiness of a program or project to progress to the next phase of the life cycle. The KDP also establishes the content, cost, and schedule commitments for the ensuing phase(s).
Launch Manifest	A list that NASA publishes (the "NASA Flight Planning Board launch manifest") periodically, which includes the expected launch dates for NASA missions. The launch dates in the manifest are the desired launch dates approved by the NASA Flight Planning Board, and are not typically the same as the Agency Baseline Commitment schedule dates. A launch manifest is a dynamic schedule that is affected by real world operational activities conducted by NASA and multiple other entities. It reflects the results of a complex process that requires the coordination and cooperation by multiple users for the use of launch range and launch contractor assets. Moreover, the launch dates are a mixture of "confirmed" range dates for missions launching within approximately six months, and contractual/planning dates for the missions beyond six months from launch. The NASA Flight Planning Board launch manifest date is typically earlier than the Agency Baseline Commitment schedule date to allow for the operationally driven delays to the launch schedule that may be outside of the project's control.
Operational Readiness Review	The lifecycle review in which the decision authority evaluates the readiness of the project, including its ground systems, personnel, procedures, and user documentation, to operate the flight system and associated ground system(s), in compliance with defined project requirements and constraints during the operations phase.
Mission Readiness Review or Flight Readiness Review (FRR)	The lifecycle review in which the decision authority evaluates the readiness of the project, ground systems, personnel and procedures for a safe and successful launch and flight/mission.
KDP-E	The lifecycle gate at which the decision authority determines the readiness of a project to continue in Implementation and transition from Phase D to Phase E. Phase E is a third phase in Implementation and means that the project and all supporting systems are ready for safe, successful launch and early operations with acceptable risk.
Decommissioning Review	The lifecycle review in which the decision authority evaluates the readiness of the project to conduct closeout activities. The review includes final delivery of all remaining project deliverables and safe decommissioning of space flight systems and other project assets.
KDP-F	The lifecycle gate at which the decision authority determines the readiness of the project's decommissioning. Passage through this gate means the project has met its program objectives and is ready for safe decommissioning of its assets and closeout of activities. Scientific data analysis may continue after this period.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

For further details, go to:

- NASA Procedural Requirement 7102.5E NASA Space Flight Program and Project Management Requirements: http://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=7120&s=5E.
- NASA Procedural Requirement NPR 7123.1B - NASA Systems Engineering Processes and Requirements: http://nodis3.gsfc.nasa.gov/npg_img/N_PR_7123_001B_/N_PR_7123_001B_.pdf.
- NASA Launch Services Web site: http://www.nasa.gov/directorates/heo/launch_services/index.html.

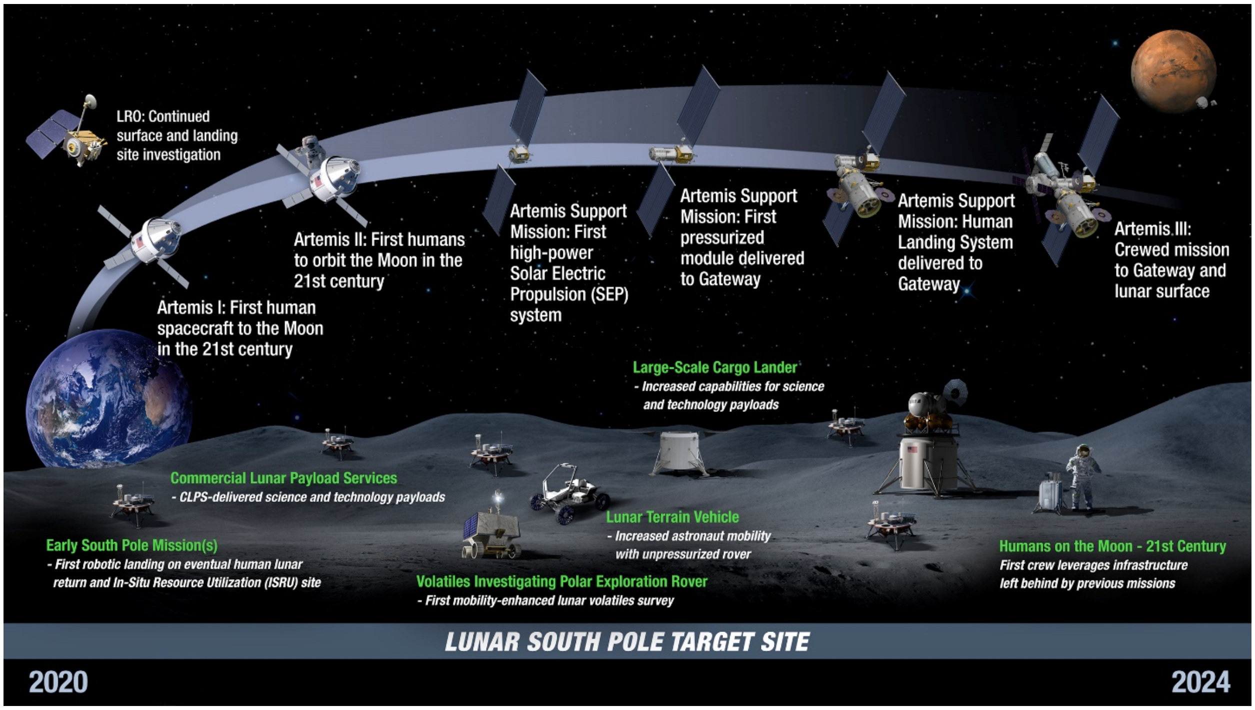
MOON TO MARS

FY 2021 Budget

Budget Authority (in $ millions)	*Actual* FY 2019	*Enacted* FY 2020	*Request* FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Moon to Mars TOTAL	**$7,558**	**$8,828**	**$12,371**	**$14,268**	**$15,839**	**$15,308**	**$13,489**
Deep Space Exploration Systems	$5,045	$6,018	$8,762	$10,300	$11,605	$10,888	$8,962
Exploration Technology	$464	$596	$1,211	$1,442	$1,658	$1,756	$1,854
Science	$721	$711	$847	$1,020	$1,075	$1,172	$1,233
SSMS	$1,239	$1,311	$1,375	$1,361	$1,356	$1,347	$1,335
CECR	$89	$192	$176	$145	$145	$145	$105

Space Policy Directive 1 and 2, and NASA's Strategic Goal 2 charge the United States to lead the return of humans to the Moon for long-term, sustainable exploration and utilization, followed by human missions to Mars and other destinations. The FY 2021 President's Budget proposes significant funding increases in support of these objectives. With the funding requested in FY 2021 and outyears, NASA seeks to send the first woman and the next man to the surface of the Moon by 2024, returning Americans to the lunar surface for scientific research, exploration, and technology demonstration.

NASA's Moon to Mars campaign will develop and test systems and plan a cadence of human spaceflight missions to lunar orbit and the lunar surface, eventually leading to Mars. Through programs across the Agency, including the Human Exploration & Operations Mission Directorate's Advanced Cislunar and Surface Capabilities (ACSC) program, and the Science Mission Directorate's Lunar Discovery and Exploration Program (LDEP), among others, NASA will develop strategies and technologies to feed into the lunar surface systems, promote innovative approaches to lunar robotics, develop sustaining operations and In-Situ Resource Utilization, and promote lunar landing capabilities. This approach will enable NASA to develop the skills, capabilities, and operational expertise to support a future mission to Mars.



The FY 2021 Budget provides NASA the ability to demonstrate industry-led lunar landing systems, transporting American astronauts to and from the surface of the Moon. The Budget also will enable us to:

- Fully support integration, testing, and the first flights of the Space Launch System (SLS) and Orion crew capsule, NASA-developed systems required to get to the Moon quickly and safely;
- Complete assembly of the U.S. elements of, and begin supplying and operating from, the Lunar Gateway - establishing the exploration infrastructure orbiting the Moon;
- Demonstrate key exploration technologies, including precision landing, cryogenic fluid management, in-situ resource utilization, and surface nuclear power to support sustainable lunar exploration and future missions to Mars;
- Utilize commercial lunar landers to deliver NASA science instruments and exploration technology demonstration payloads to the lunar surface;
- Launch a Mars Sample Return mission as early as 2026 and initiate a Mars Ice Mapper mission; and
- Ensure investments in the required capabilities, workforce, and facilities needed to guarantee safety and mission success.

The FY 2021 Budget Request maintains the existing budget structure for the Moon to Mars campaign, which will continue to be a cross-functional effort at Headquarters and across the Centers. NASA continues to integrate across the multiple mission directorates involved to ensure proper organizational structures are aligned to achieve mission success.

MOON TO MARS

Deep Space Exploration Systems

The Human Landing System program will utilize commercial partnerships to develop and jointly deploy an integrated landing system to transport humans to and from the lunar surface. NASA expects its commercial partners will heavily leverage NASA technology and expertise throughout the development process, leading to an integrated lunar transportation system that will deliver humans to the lunar surface in 2024, and develop and demonstrate a more sustainable HLS for subsequent crewed missions.

NASA is leading the way by preparing to carry humans farther into deep space than ever before. The Space Launch System (SLS), the Orion Crew Capsule, and Exploration Ground Systems (EGS) together represent a critical piece of the Moon to Mars campaign, and the Artemis program. All three programs will conduct readiness reviews prior to the potential launch of Artemis I, while preparing and upgrading necessary systems for the launches of Artemis II and III.

NASA will continue to develop the Gateway, conducting project level design reviews of the Power and Propulsion Element (PPE) and the Habitation and Logistics Outpost (HALO), and continuing development of program-level functions such as avionics, flight software, and future capabilities such as in-space refueling. NASA will use the Gateway infrastructure as part of a broader strategy to enable long-term exploration and utilization of the Moon and its surface.

Advanced Cislunar and Surface Capabilities and Advanced Exploration Systems will focus on supporting lunar technology development efforts, including flight and surface elements, life support systems, and crew health improvement.

Exploration Technology

Research and development of new technologies and capabilities lays the groundwork for enhancing and enabling lunar and deep space exploration. Exploration Technology will continue to focus its activities toward lunar and deep space exploration, enabling NASA’s workforce, in concert with industry and academia, to develop innovative ways to further humankind’s space exploration from conception to testing to spaceflight.

The Exploration Technology request supports the Lunar Surface Innovation Initiative as well as other technology research and development projects along the entire Technology Readiness Level spectrum that align with NASA exploration needs and support commercial expansion in space. The Lunar Surface Innovation Initiative serves as a catalyst for lunar surface technology development priorities such as: surface power, in situ resource utilization (ISRU), autonomous operations, and extreme environment technology. During 2021, the Space Technology Mission Directorate (STMD) aims to deliver the Solar Electric Propulsion in support of the Power and Propulsion Element of Gateway, to complete testing and initiate a flight demonstration of the Laser Communications Relay Demonstration mission, and to continue to advance Space Nuclear technologies to support the Moon to Mars campaign.

Scientific Exploration

Another critical element of exploration comes from NASA’s Science Mission Directorate (SMD), which will continue its efforts to explore and enhance scientific discovery. The Moon to Mars effort within Science is made up of the Lunar Development and Exploration Program (LDEP), the Mars 2020 rover, and future Mars robotic missions including the Mars Sample Return mission and Mars Ice Mapper. Future Mars robotic exploration will support decadal science objectives as well as lay the groundwork for future manned missions to Mars.

NASA is developing a series of instruments, experiments, and other payloads for robotic lunar missions to the surface of the Moon, which will launch using the Commercial Lunar Payload Services (CLPS) project. NASA is utilizing innovative acquisition approaches to engage U.S. industry capabilities as the Agency moves toward human exploration of the lunar surface. NASA intends to also work with international partners in this endeavor, delivering meaningful scientific exploration and technology development work in a cost-effective way.

Mission Support

NASA will fund the critical Agency-wide capabilities, workforce, and facilities that will enable the success of the Moon to Mars campaign, allowing NASA to achieve the Nation's space policy priorities. NASA's infrastructure and assets must be safe, secure, environmentally sound, appropriately sized, and operated efficiently so as not to hamper or delay the Moon to Mars campaign.

The technology capabilities and processes pioneered by the Artemis effort will enable the first intrepid crews of the new space age to travel safely to and from the surface of the Moon, mature sustainability on the Moon, and land on the surface of Mars. This will enable new scientific discoveries and promote new technologies, research, and the systems needed to sustain living in deep space for the benefit of all humankind. It will serve as an inspiration to the world and solidify the United States' preeminence in space exploration, making a human presence on the Moon and beyond an expectation, not a dream.

DEEP SPACE EXPLORATION SYSTEMS

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Exploration Systems Development	4086.8	4582.6	**4042.3**	4011.2	4071.7	3767.7	3634.8
Exploration Research & Development	958.0	1435.0	**4719.4**	6288.5	7533.4	7120.0	5327.4
Total Budget	**5044.8**	**6017.6**	**8761.7**	**10299.7**	**11605.1**	**10887.7**	**8962.2**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

DEEP SPACE EXPLORATION SYSTEMS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Exploration Systems Development	4086.8	4582.6	**4042.3**	4011.2	4071.7	3767.7	3634.8
Exploration Research & Development	958.0	1435.0	**4719.4**	6288.5	7533.4	7120.0	5327.4
Total Budget	**5044.8**	**6017.6**	**8761.7**	**10299.7**	**11605.1**	**10887.7**	**8962.2**
Change from FY 2020			**2744.1**				
Percentage change from FY 2020			**45.6%**				

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

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The FY 2021 budget request includes $8.762 billion for Deep Space Exploration Systems to pursue the Moon to Mars campaign, focused on returning humans to the Moon and enabling eventual missions to Mars and beyond. NASA will land the first woman and next man on the Moon by 2024 to explore more of the lunar surface than ever before, in collaboration with our commercial and international partners, and establish sustainable exploration. Then, we will use what we learn on the Moon to take the next giant leap – sending astronauts to Mars.

The Deep Space Exploration Systems account consists of two themes, Exploration Systems Development (ESD) and Exploration Research and Development (ERD), which provide for the development of systems and capabilities needed for human exploration of space. With new leadership onboard in the Human Exploration & Operations Mission Directorate, NASA is conducting a Program Status Assessment of the overall Moon to Mars Campaign, of which the Space Launch System (SLS), Orion, Gateway, and Exploration Ground Systems are key components. If the assessment results in any alterations to current plans, NASA will brief Congress immediately.

ESD's mission is to develop the launch vehicle, spacecraft, and ground support systems necessary to send crew beyond low-Earth orbit (LEO). ESD consists of three programs: Orion, SLS, and Exploration Ground Systems (EGS). The Orion spacecraft will carry humans beyond LEO, provide emergency abort capability, sustain the crew during space travel, and provide safe re-entry from deep space. The SLS will be the most powerful rocket ever built and the only rocket that can send crew in Orion to the Moon on a single mission. EGS develops and operates the systems and facilities needed to process and launch rockets and spacecraft during assembly, transport, and launch. This space transportation system is a key component of NASA's strategy for exploration in cislunar space, and it will have its first un-crewed test flight (Artemis I) and crewed test flight (Artemis II) in the near future; launch dates are currently under review.

ERD is comprised of five programs: Advanced Cislunar and Surface Capabilities (ACSC), the Human Landing System (HLS), Gateway, Advanced Exploration Systems (AES), and the Human Research Program (HRP). The overarching goal of ERD is to infuse technologies and research into the development of human exploration capabilities and missions that enable the return of humans to the

Moon by 2024 for long-term exploration and utilization, followed by human missions to Mars and other destinations. ERD programs pursue these goals using a combination of unique in-house activities and public-private partnerships.

In the FY 2021 President's Budget, there are several major initiatives:

ACSC funding focuses on utilizing innovative procurement approaches to develop strategies and systems for future missions to the lunar surface and beyond.

HLS funding focuses on establishing commercial partnerships to develop and deploy the integrated systems that will land humans on the Moon by 2024 and in future years. HLS will leverage the Science Mission Directorate's development of smaller landers for capabilities, such as navigation and precision landing. It will also leverage investments through the Space Technology Mission Directorate's lunar exploration activities.

Gateway funding focuses on developing a small orbital platform that will orbit the Moon and enable lunar landers and surface activities, to include a Power and Propulsion Element by 2022, followed by a Habitation and Logistics Outpost (HALO).

AES funding focuses on reducing operational risk, validating operational concepts, leveraging partner capabilities, and lowering lifecycle costs to help enable lunar and deep space missions.

In addition, HRP is dedicated to discovering the best methods and technologies to support safe, productive human space travel. From the challenges of managing the environmental risks posed by radiation and lunar dust, to providing appetizing food and optimal nutrition, HRP scientists and engineers work to predict, assess, and solve the problems that humans encounter in space. Planned missions will dramatically increase the scope of the challenges and demands that face NASA's astronauts. HRP is working to improve astronauts' ability to collect data, solve problems, respond to emergencies, and remain healthy during and after extended space travel.

For more information, go to: http://www.nasa.gov/directorates/heo/home/index.html

EXPLORATION SYSTEMS DEVELOPMENT

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Orion Program	1350.0	1406.7	**1400.5**	1322.3	1391.0	1239.9	1084.7
Crew Vehicle Development	1339.5	1396.2	**1390.0**	1311.8	1378.9	1229.9	1064.7
Orion Program Integration and Support	10.5	--	**10.5**	10.5	12.1	10.0	20.0
Space Launch System	2144.0	2585.9	**2257.1**	2238.3	2249.2	2091.8	2087.1
Launch Vehicle Development	2093.1	2525.8	**2200.2**	2177.0	2188.0	2035.8	2001.1
SLS Program Integration and Support	50.9	--	**56.9**	61.3	61.1	56.0	86.0
Exploration Ground Systems	592.8	590.0	**384.7**	450.6	431.6	436.0	463.0
Exploration Ground Systems Development	586.6	558.7	**377.0**	447.0	428.0	436.0	443.0
EGS Program Integration and Support	6.2	--	**7.7**	3.6	3.6	0.0	20.0
Construction & Envrmtl Compl Restoration	31.9	52.1	**22.3**	0.0	0.0	0.0	0.0
Exploration CoF	31.9	52.1	**22.3**	0.0	0.0	0.0	0.0
Total Budget	**4118.7**	**4634.7**	**4064.6**	**4011.2**	**4071.7**	**3767.7**	**3634.8**
Change from FY 2020			**-570.1**				
Percentage change from FY 2020			**-12.3%**				

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

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EXPLORATION SYSTEMS DEVELOPMENT

NASA's Pegasus Barge is shown here arriving at the Launch Complex 39 turn basin wharf at Kennedy Space Center (KSC) in Florida to make its first delivery to KSC in support of the Agency's Artemis missions. The upgraded 310-foot-long barge arrived September 27, 2019, ferrying the 212-foot-long Space Launch System (SLS) rocket core stage pathfinder. Weighing 228,000 pounds, the pathfinder is a full-scale mock-up of the rocket's core stage and will be used to validate ground support equipment and demonstrate it can be integrated with KSC facilities.

NASA's Exploration Systems Development (ESD) programs are working together to build the space transportation system made up of the Orion crew vehicle, the Space Launch System (SLS) rocket, and the Exploration Ground Systems (EGS). This system will enable the Agency's Artemis missions, extending human presence into the solar system by transporting crews to the Gateway or to the Moon's surface in the Human Landing System for long-term exploration and preparation for future missions to Mars. These program objectives support National Space Policy Directive-1 and Agency Strategic Goal 2, which seeks to extend human presence deeper into space and to the Moon for sustainable, long-term exploration and utilization.

NASA's Orion spacecraft is designed to support human exploration missions to deep space, with a crew of four, for periods of 21 days. Building upon more than 50 years of spaceflight research and development, Orion's versatile design will not only carry crew to space, but also provide emergency abort capability, sustain crew during space travel, and provide safe reentry at deep space return velocities. The Orion systems are designed to operate in a contingency mode to augment life support systems in other space transport systems.

The SLS rocket is a heavy-lift launch vehicle for a new era of exploration beyond Earth's orbit into deep space. SLS will launch astronauts in the Orion spacecraft on missions to cislunar space so they can return to the surface of the Moon and other destinations. The objective of the EGS is to enable Kennedy Space Center (KSC) to process and launch next-generation vehicles and spacecraft, like Orion and SLS, in support of the Artemis missions. To achieve this transformation, NASA is developing new ground systems while refurbishing and upgrading infrastructure and facilities to meet tomorrow's demands. This modernization effort keeps maximum flexibility to accommodate a multitude of Government, commercial, and other customers. Drawing on five decades of excellence in processing and launch, NASA is paving the way to the spaceport's future. KSC is now the multi-user spaceport that was envisioned post Shuttle retirement.

The Artemis program is the next step in human exploration of our solar system. It is a part of NASA's Moon to Mars exploration approach, in which we will pursue our next giant leap – sustained human exploration of the Moon to develop the skills, systems, and operational capabilities to enable a human mission to Mars. As NASA works towards a sustainable Moon to Mars campaign, it is essential that the Agency and its contractors reduce production and operations costs for ESD systems. Through reduction in costs, the Agency can focus on capabilities needed for future deep space systems and successful exploration missions.

ORION PROGRAM

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Crew Vehicle Development	1339.5	1396.2	**1390.0**	1311.8	1378.9	1229.9	1064.7
Orion Program Integration and Support	10.5	--	**10.5**	10.5	12.1	10.0	20.0
Total Budget	**1350.0**	**1406.7**	**1400.5**	**1322.3**	**1391.0**	**1239.9**	**1084.7**
Change from FY 2020			**-6.2**				
Percentage change from FY 2020			**-0.4%**				

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

The Orion spacecraft will play an integral role in the Artemis program. The Orion Program continues to take major steps toward transporting humans safely to deep space and back. Orion will serve as an exploration vehicle that will carry crew to space, sustain crew during space travel, provide emergency abort capability, and provide safe re-entry from deep space return velocities. This capsule-shaped vehicle has a familiar look, but it incorporates numerous technology advancements and innovations. The spacecraft will enable extended duration missions beyond Earth's orbit and to the Moon.

Orion design, development, and testing (including the flight tests) will have the spacecraft ready to carry crew on Artemis II; the mission's launch date is under review pending the completion of an independent assessment of the integrated mission schedule by Agency leadership. Given ongoing challenges, NASA is assessing options for improving program performance and the proposed FY 2021 President's Budget level is enough to support a launch on the earliest technically feasible date.

For more information, go to: http://www.nasa.gov/orion

Program Elements

ORION PROGRAM INTEGRATION AND SUPPORT

Orion Program Integration and Support activities manage the program interfaces between the Space Launch System (SLS) and the Exploration Ground System (EGS). This effort is critical to ensuring Orion’s performance meets technical and safety specifications, and it supports programmatic assessments key to achieving integrated technical, cost, and schedule management. In addition, the Orion integration effort is vital to managing interfaces with other Human Exploration and Operations Mission Directorate (HEOMD) activities, including strategic studies, feasibility studies, and small-scale research tasks that feed into future human exploration. Coordination and timely integration across the programs enable the Agency to avoid potential design overlaps, schedule disconnects, and cost issues.

ORION PROGRAM

CREW VEHICLE DEVELOPMENT

See the Crew Vehicle Development section.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

FY 2021 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	BTC	Total
Formulation	4510.4	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	4510.4
Development/Implementation	4296.5	1192.6	1039.4	**711.0**	285.0	162.0	0.0	0.0	0.0	7686.5
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2020 MPAR LCC Estimate	**8806.9**	**1192.6**	**1039.4**	**711.0**	**285.0**	**162.0**	**0.0**	**0.0**	**0.0**	**12196.9**
Total Budget	**8869.9**	**1339.5**	**1396.2**	**1390.0**	**1311.8**	**1378.9**	**1229.9**	**1064.7**	**0.0**	**17980.8**
Change from FY 2020				**-6.2**						
Percentage change from FY 2020				**-0.4%**						

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

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The difference between the total budget and the MPAR LCC estimate is the total budget includes content outside of Artemis II and excludes CoF; LCC only includes Artemis II content, including CoF.

The total budget prior line represents FY 2011 pre-formulation and FY 2012 - FY 2017 budgets, excluding CoF and additional expenditures from 2005-2011 under the Constellation program.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

In July 2019, NASA completed mating Crew Module with Service Module for Artemis I. The spacecraft is shown here being prepared for its uncrewed test flight atop the Space Launch System (SLS) rocket.

PROJECT PURPOSE

In support of the Agency's strategic goal to extend and sustain human activities across the solar system, Orion will be capable of transporting humans to and around the Moon, sustaining them longer than ever before, and returning them safely to Earth. Drawing from more than 50 years of human spaceflight research and development and stimulating new and innovative manufacturing and production capabilities, Orion's design will meet the evolving needs of our Nation's space program.

For more information, go to: http://www.nasa.gov/orion

EXPLANATION OF MAJOR CHANGES IN FY 2021

The Artemis I and II launch dates are under review pending completion of several assessments. NASA is conducting a Program Status Assessment of the overall Artemis effort, of which the Space Launch System (SLS) and Exploration Ground Systems (EGS) are key components. This assessment includes review of the schedule and technical approaches as well as systems engineering integration and program management. In parallel, NASA is performing an independent technical and programmatic assessment, including a joint cost and schedule confidence level analysis of the SLS and EGS programs. NASA Leadership will review the results of these assessments before considering potential updates to the Artemis I and II launch planning dates.

PROJECT PARAMETERS

Orion is the vehicle that will fly astronauts to and from the Moon. As such, the Orion program is a critical element of the Artemis mission that will land the first woman and the next man on the Moon in 2024. The Artemis program is intended to establish sustainable exploration of the Moon with our commercial and international partners by 2028 in preparation for eventual human missions to Mars. Orion will be able to carry a crew of four astronauts to cislunar space and beyond and provide habitation and life support for up to 21 days. The spacecraft's four elements are the Crew Module (CM), the Crew Module Adaptor (CMA), the European Service Module (ESM), and the Launch Abort System (LAS). The European Space Agency (ESA) is designing and developing the ESM, which provides in-space power, propulsion, and other life support systems. The CM, which is the pressure vessel, will be mounted to the CMA and ESM to become the Crew and Service Module (CSM). Atop the CSM will sit the LAS, which will activate within milliseconds to propel the CM to safety away from the launch vehicle in the event of an emergency during launch or climb to orbit. The abort system also provides a protective shell that shields the CM from dangerous atmospheric loads and heating during ascent. Once Orion is out of the atmosphere and safely on its way to orbit, the spacecraft will jettison the LAS. The vehicle will travel 280,000 miles from Earth and thousands of miles beyond the Moon. The first mission is Artemis I, an uncrewed flight test that will demonstrate key Orion spacecraft capabilities. The next mission, Artemis II, is intended as a crewed test flight, with a current mission profile of transporting up to four crew members on a free return trajectory. Starting with the Artemis III, a lunar landing mission in 2024, the Orion spacecraft will

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

rendezvous and dock with Gateway or the Human Landing System (HLS) spacecraft. From the Gateway Near-Rectilinear Halo Orbit, astronauts will have access to more areas of the lunar surface more frequently and with better communications capability than the Apollo missions. The crew and necessary equipment will transfer from the Orion spacecraft – potentially via Gateway – into the HLS, which will then undock, descend, and land on the lunar surface. At the conclusion of lunar surface operations, the HLS will lift off from the lunar surface and re-dock with the Gateway or the Orion spacecraft and return to Earth. Although the module has a familiar visual shape, its interior and exterior capabilities far exceed any geometrically similar predecessors. The state-of-the-art crew systems will provide a safe environment for astronauts to live and work for long durations far from Earth. Orion's advanced heat shield will protect the crew during a high-speed reentry into Earth's atmosphere – heating that will exceed that experienced by any human spacecraft in more than four decades.

ACHIEVEMENTS IN FY 2019

NASA completed the first Propulsion Qualification Module (PQM) Orbital Maneuvering System (OMS) Engine five-second firing and a successful 20-second firing of the PQM OMS Engine with active control of the pressurization system in October 2018. In August 2019, the stressful test case called "Abort to Orbit," was successfully completed at White Sands Test Facility near Las Cruces, New Mexico. This test was one of the prerequisites for ESA to deliver the ESM-1 to the U.S. for integration.

Airbus delivered the first ESM from its aerospace site in Bremen, Germany, on November 6, 2018, by Antonov cargo aircraft to NASA's Kennedy Space Center (KSC). Functional checkouts were completed to ensure all elements were working properly before integration.

The ESM-1 was mated with the CMA-1 to complete the Service Module (SM) assembly. The completed SM-1 was joined to the CM-1, resulting in the combined CSM-1 in June 2019. This work was performed at KSC and marked the first time all three major elements were integrated. In July, the world's largest heat shield structure for Artemis II arrived at KSC for assembly and integration onto the Orion crew module for the Artemis II mission. Measuring approximately 16 feet in diameter, the heat shield provides critical protection for the crew upon re-entry into Earth's atmosphere and during splashdown.

The Orion program completed the CM-2 primary structure in January 2019 and the proof testing on the crew module in February 2019.

ESM-2 integration has begun in the Bremen, Germany, clean room. Long-lead activities, such as welding of high-pressure valves and engine manufacturing, are underway. The ESM-2 will provide power, propulsion, and air to the Orion spacecraft.

The Ascent Abort-2 (AA-2) test, which demonstrates the ability of the LAS to safely separate the CM from the SLS during an ascent abort scenario, was successfully carried out at Cape Canaveral from Launch Complex 46 on July 2, 2019. The test is another milestone in the Agency's preparation for Artemis missions to the Moon that will lead to astronaut missions to Mars.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

WORK IN PROGRESS IN FY 2020

The Orion program completed the CMA-1 primary structure in October 2019 at the Operations and Checkout (O&C) Facility at KSC.

The Artemis I's CSM arrived at Glenn Research Center-Plum Brook Station (GRC-PBS) on November 26, 2019, for in-space environmental testing in preparation for Artemis I. While at GRC-PBS, the CSM will endure thermal vacuum, acoustics, and electromagnetic interference testing to confirm all components and systems work properly under in-space conditions, a crucial step towards launch readiness.

Once the testing at GRC-PBS is completed in spring of 2020, the mated CSM-1 will be returned to KSC for final assembly and installation of the Solar Array Wing and the Spacecraft Adaptor. The CSM will then be turned over to the EGS program for servicing and subsequent mating with the LAS in the LAS facility. After the mating, it will be stacked on the SLS rocket in the Vehicle Assembly Building.

The Integrated Test Lab (ITL) will conclude its verification and validation testing of the Artemis I software and will begin its testing of the Artemis II software in March 2020. The ITL simulates the flight environment to test the flight software functions, such as ascent abort, safe mode, fault detection, isolation and recovery, optical navigation, maneuver plan management, and propulsion failure detection for both Artemis I and II. These tests are essential for identifying software problems and validating proper functionality and performance of the spacecraft.

Lockheed Martin will complete the Artemis I Structure Test Article in Denver, CO, during summer 2020 and will prepare the CM test article for shipment to Langley Research Center (LaRC) for subsequent Water Impact Testing (WIT). The WIT is the last in the series of tests, and it will complete the test campaign on the full-scale replica of the Orion spacecraft. These tests are conducted to ensure the space bound-article is ready to withstand the pressure and loads it will endure during launch, flight, and landing.

In preparations for Artemis II, the first crewed mission, Orion will continue outfitting the CM Pressure Vessel at KSC's Operation and Checkout (O&C) building. Orion will also install the Environment Control and Life Support System (ECLSS) that enables the crew to live and work and the core avionics for the navigation and control. The heatshield that protects the vehicle and crew from extreme temperatures will also be installed. Orion will conduct a series of power-on, leak, functional, and proof pressure tests to ensure the health of the vehicle. These outfitting efforts will ensure the CM will be prepared for sustaining its crewmembers.

Continuing the manufacturing efforts for Artemis II, the CMA was moved into a clean room in mid-November 2019, for precision welding to install the ECLSS and propulsion tubing.

In the spring of 2020, the CMA-2 will undergo proof pressure and leak tests followed by subsystem installations, harness testing, and Developmental Flight Instrumentation testing. Once the tests are complete, it will dwell until it is mated with the ESM-2 and CM-2 in FY 2021.

Long-lead material purchases for Artemis III will arrive and Orion will start vehicle production. The Artemis III will be the second crewed Artemis mission, and it will be NASA's first mission to utilize the Rendezvous, Proximity Operations, Docking, and Undocking capability for integrated Orion/Gateway

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

and lunar surface activities. Artemis III CM pressure vessel weld operations will be initiated in late summer 2020 to support the 2024 launch date.

The program initiated long lead material purchases for Artemis III, IV, and V, enabling the program to meet an annual flight rate to support lunar exploration, while establishing a sustainable Production and Operations cadence. These missions represent the commitment of the U.S. to a core piece of NASA's infrastructure for exploration. Essential to building a sustainable exploration strategy will be finalizing development and reducing production and operation costs. Artemis III, IV, and V long lead (and selected lifetime) parts procurements will be in execution by the second quarter of FY 2020.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

The Artemis I CSM will mate to the SLS rocket in the Vehicle Assembly Building (VAB) at KSC, and it will launch from KSC's Launch Complex 39B. The mission will take the spacecraft beyond the Moon to demonstrate its performance capability during launch, transit to lunar orbit, return to Earth, re-entry, landing, and recovery.

After the Artemis I mission, the Orion program will conduct a post-flight analysis to assess spacecraft performance against flight test objectives. The program will recover certain core avionics components from the returned spacecraft for reuse in future flights. These core avionics will be removed, refurbished, and delivered to KSC for installation into the Artemis II CM. The non-core Artemis II avionics are planned to be delivered to KSC in winter 2021. Re-use of avionics components reduces assembly costs of subsequent Orion builds and is a key feature of the recently awarded Orion Production Operation Contract that is being used to deliver Orion spacecraft for the Artemis III through Artemis V missions.

Orion will complete delivery of Artemis II software Build 203 (fall 2020) and Build 204 (spring 2021). These software builds support Artemis II Initial Power-on and ITL testing. The Artemis II software integration testing and checkout campaign, ITL-03, will be completed in fall 2021, and ITL-04 test campaign will be completed in spring 2021. These test campaigns must be successfully completed to certify Artemis II for crewed flight.

ESA will continue manufacturing of the ESM-2 for delivery to KSC's O&C in fall 2020. Functional checkouts will be performed to ensure all elements are working properly before integration.

After the functional tests are completed, the ESM-2 will be mated to the CMA in fall 2020 to become SM-2. After mating, the SM-2 will undergo clean room operations for ECLSS welding, followed by proof pressure and leak tests in preparation for integrating with the CM-2 in summer 2021.

Orion will complete functional testing of the CM-2 and install the heatshield, back shell, forward bay cover, and avionics in spring 2021. It will then be mated to the SM-2 in summer 2021, followed by integrated testing and verification activities through the remainder of the fiscal year.

CM-3 pressure vessel weld will be completed and ready to ship to KSC for proof testing and final assembly operations by late summer 2021 to support a 2024 launch.

CM-4 pressure vessel weld operations will be initiated in summer 2021 to support a 2025 launch date.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Orion is working on the Draft Request for Proposal for OMS engines. The contract award is planned for fall 2021. Orion has enough OMS engines remaining from the shuttle program to fly on the ESM through Artemis V. The new Orion Main Engine will be first flown on Artemis VI.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2021 PB Request
System Design Review (SDR)		Aug 2007
Preliminary Design Review (PDR)		Aug 2009
Key Decision Point-A (KDP-A)	Feb 2012	Feb 2012
Resynchronization Review		Jul 2012
KDP-B	Q1 FY 2013	Jan 2013
Delta PDR	Q4 FY 2013	Aug 2014
EFT-1 Launch	Dec 2014	Dec 2014
KDP-C, Project Confirmation	FY 2015	Sep 2015
CDR	Oct 2015	Oct 2015
AA-2 Flight Test	FY 2020	FY 2019
Artemis I Launch Readiness	FY 2018	Under review
Artemis II Launch Readiness*	FY 2023	Under review

** The program is currently reviewing cost and schedule impacts based on the change to the Artemis 1 launch readiness date.*

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2015	6,768.4	70%	2020	7,686.6	+13.5%	Artemis II	Apr 2023	*TBD	*TBD

The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

** The Current Year Development Cost Estimate and Milestone data do not accurately reflect current planning and are based on prior planning. The Artemis I and II launch dates are under review pending completion of several assessments. NASA is conducting a Program Status Assessment of the overall Artemis effort, of which Orion, SLS and EGS are key components. This assessment includes review of the schedule and technical approaches as well as systems engineering integration and program management. In parallel, NASA is performing an independent technical and programmatic assessment, including a joint cost and schedule confidence level analysis of the SLS and EGS programs. NASA Leadership will review the results of these assessments before considering potential updates to the Artemis I and II launch planning dates.*

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**6,768.4**	**7,686.6**	**+918.2**
Mission Operations	281.6	280.7	-0.9
Program Management	671.5	844.2	+172.7
Safety and Mission Assurance	191.4	159.1	-32.3
Spacecraft and Payload	3,205.1	4,777.9	+1,572.8
Systems Engineering and Integration	539.3	717.0	+177.7
Test and Verification	460.6	663.7	+203.1
Other Direct Project Costs	1,418.9	244.1	-1,174.8

Program UFE was held in "Other" category in the base year estimate and realigned to other elements as the program matured.

** The Current Year Development Cost Estimate and Milestone data do not accurately reflect current planning and are based on prior planning. The Artemis I and II launch dates are under review pending completion of several assessments. NASA is conducting a Program Status Assessment of the overall Artemis effort, of which Orion, SLS and EGS are key components. This assessment includes review of the schedule and technical approaches as well as systems engineering integration and program management. In parallel, NASA is performing an independent technical and programmatic assessment, including a joint cost and schedule confidence level analysis of the SLS and EGS programs. NASA Leadership will review the results of these assessments before considering potential updates to the Artemis I and II launch planning dates.*

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Crew Module	The transportation capsule provides a safe habitat for the crew as well as storage for consumables and research instruments, and it serves as the docking port for crew transfers.	Provider: Johnson Space Center (JSC) Lead Center: JSC Performing Center(s): Ames Research Center (ARC), GRC, JSC, and LaRC Cost Share Partner(s): N/A	N/A
Service Module	The service module, the powerhouse that fuels and propels the Orion spacecraft, will support the Crew Module from launch through separation before reentry.	Provider: ESA Lead Center: GRC Performing Center(s): ARC, GRC, JSC, and LaRC Cost Share Partner(s): ESA	N/A
Launch Abort System	The LAS maneuvers the Crew Module to safety in the event of an emergency during launch or climb to orbit.	Provider: JSC Lead Center: LaRC Performing Center(s): JSC, LaRC, and Marshall Space Flight Center (MSFC) Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: the ESA-provided Multi-Purpose Crew Vehicle (MPCV) ESM-2 encounters development issues and is delayed in its delivery (as ESM-1 was), Then: Orion will impact the Artemis II handover date to EGS.	The ESA Prime contractor is aggressively managing its suppliers' component delivery schedule to minimize risk for ESM-2 delivery to KSC. Component delivery dates are being tracked to an October 1, 2020, on-dock date versus the actual on-dock date of November 22, 2020. The contractor is also working with its major subcontractor and suppliers to implement incentives to accelerate delivery of critical path components.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Acquisition Strategy

NASA is using a competitively awarded contract to Lockheed Martin Corporation for Orion's design development, test, and evaluation. The contract was awarded in 2006 and reaffirmed in 2011 as part of reformulating the Orion Crew Exploration Vehicle as the Orion program. Orion adjusted this contract to meet NASA and HEOMD requirements to include the current flight test plan and the Artemis II flight readiness date. The Orion Program released a Request for Proposal to Lockheed Martin for the Production and Operations effort in January 2018. The Orion Program's Production and Operations contract beginning with Artemis III was awarded as a sole-source contract with Lockheed Martin in September 2019. It is an indefinite-delivery-indefinite-quantity contract that includes a commitment to order a minimum of six and a maximum of twelve Orion spacecraft over the next ten years. The first six spacecraft (Artemis III through VIII) will be acquired by cost-plus-incentive-fee orders. NASA will negotiate firm-fixed-price orders for future missions to take advantage of the anticipated spacecraft production cost decreases. NASA signed an Implementing Arrangement with ESA to provide service modules for the Orion spacecraft for Artemis I and II. Incorporating the partnership with ESA also required a contract modification with Lockheed Martin to integrate the ESA-provided service module with the Lockheed Martin portion of the spacecraft. Lockheed Martin has already integrated the first ESM with Artemis I CM, and it is preparing for thermal-vacuum testing of the integrated spacecraft. NASA is coordinating with the Department of State regarding the ESA contribution and implementing arrangement for Artemis III and subsequent missions.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Orion Design and Development	Lockheed Martin	Littleton, CO
Orion Production and Operations	Lockheed Martin	Littleton, CO

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
System Readiness Review (SRR)	Standing Review Board (SRB)	Mar 2007	To evaluate the program's functional and performance requirements ensuring proper formulation and correlation with Agency and HEOMD's strategic objectives; assess the credibility of the program's estimated budget and schedule.	Program cleared to proceed to next phase.	N/A

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
System Design Review (SDR)	SRB	Aug 2007	To evaluate the proposed program requirements and architecture; allocation of requirements to initial projects; assess the adequacy of project pre-formulation efforts; determine if maturity of the program's definition and plans are sufficient to begin implementation.	Program cleared to proceed to next phase.	N/A
Preliminary Design Review (PDR)	SRB	Sep 2009	To evaluate completeness and consistency of the program's preliminary design, including its projects, is meeting all requirements with appropriate margins, acceptable risk, and within cost and schedule constraints; determine the program's readiness to proceed with the detailed design phase.	Program cleared to proceed to next phase.	N/A
Resynchronization Review	SRB	Jul 2012	The purpose of the review is to realign the program's preliminary design to the current Exploration system development requirements. NASA policies allow changes to a program's management agreement in response to internal and external events. An amendment to the decision memorandum is signed at the KDP-B review held before PDR if a significant divergence occurs.	Program cleared to proceed to next phase.	N/A
Delta PDR	SRB	Aug 2014	To update the program's preliminary design; ensures completeness and consistency; determine the program's readiness to proceed with the detailed design phase.	Program cleared to proceed to next phase.	N/A

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Critical Design Review (CDR)	SRB	Oct 2015	To evaluate the integrity of the program integrated design, including its projects and ground systems, its ability to meet mission requirements with appropriate margins and acceptable risk, planned within cost and schedule constraints; determine if the integrated design is appropriately mature to continue with the final design and fabrication phase for EM-1.	Program cleared to proceed to next phase.	N/A
ESM CDR	SRB	Oct 2016	To evaluate the integrity of the program integrated design, including its projects and ground systems, its ability to meet mission requirements with appropriate margins and acceptable risk, planned within cost and schedule constraints; determine if the integrated design is appropriately mature to continue with the final design and fabrication phase for EM-1.	Program cleared to proceed to next phase.	N/A
Critical Integration Review (CIR) / System Integration Review (SIR)	N/A	Nov 2016	To evaluate the readiness of the program, including its projects and supporting infrastructure, to begin system Assembly, Integration, and Testing (AI&T) with acceptable risk, and within cost and schedule constraints.	Program cleared to proceed to next phase.	N/A
Artemis II CDR	IA / Independent Review Team (IRT)	Dec 2018	To evaluate the integrity of the program integrated design, including its projects and ground systems, its ability to meet mission requirements with appropriate margins and acceptable risk, planned within cost and schedule constraints; determine if the integrated design is appropriately mature to continue with the final design and fabrication phase for EM-2.	Program cleared to proceed to next phase.	N/A

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
ESD Artemis I Independent Schedule Assessment	Schedule Assessors from Office of the Chief Financial Officer (OCFO)	Jun 2019	Programmatic assessment and analysis of Artemis I schedules across all ESD programs with an emphasis on program performance and risks.	NASA leadership briefed on Artemis I launch date options.	N/A
System Integration Review (SIR)	IA/IRT	Sept 2020	To assess risks and plans for starting integration of all hardware into the structure to build up the flight vehicle.	N/A	N/A

SPACE LAUNCH SYSTEM

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Launch Vehicle Development	2093.1	2525.8	**2200.2**	2177.0	2188.0	2035.8	2001.1
SLS Program Integration and Support	50.9	--	**56.9**	61.3	61.1	56.0	86.0
Total Budget	**2144.0**	**2585.9**	**2257.1**	**2238.3**	**2249.2**	**2091.8**	**2087.1**
Change from FY 2020			**-328.8**				
Percentage change from FY 2020			**-12.7%**				

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

The Agency's Space Launch System (SLS), shown here, is the first vehicle designed to meet the challenges of the journey to the Moon and to Mars, and is the first exploration class rocket since the Saturn V.

NASA continues the development of a heavy-lift launch vehicle to deliver crew and large volumes of cargo to deep space. The Space Launch System (SLS) program is leading the way by preparing to carry humans farther into deep space than ever before.

SLS will be a human-rated launch system intended to deliver Orion beyond low-Earth orbit (LEO). This launch system is an instrumental part of the Artemis program as NASA prepares for the fast-approaching Artemis missions. The Agency will continue to identify and implement affordability strategies to help SLS become a sustainable exploration capability.

For more information, go to: http://www.nasa.gov/exploration/systems/sls/index.html

SPACE LAUNCH SYSTEM

Program Elements

SLS PROGRAM INTEGRATION AND SUPPORT

SLS program integration and support activities manage the Orion and Exploration Ground Systems program interfaces. This effort is critical to ensuring SLS systems' performance meets technical and safety specifications and supports programmatic assessments key to achieving integrated technical, cost, and schedule management. In addition, the SLS integration effort is vital to managing interfaces with other Human Exploration and Operations Mission Directorate activities, including strategic studies, feasibility studies, and small-scale research tasks that feed into future human exploration. Coordination and timely integration across the programs enables the Agency to avoid potential design overlaps, schedule disconnects, and cost issues.

LAUNCH VEHICLE DEVELOPMENT

See Launch Vehicle Development section.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

FY 2021 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	BTC	Total
Formulation	2674.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	2674.0
Development/Implementation	7135.4	844.6	590.7	**179.4**	0.0	0.0	0.0	0.0	0.0	8750.1
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2020 MPAR LCC Estimate	**9809.4**	**844.6**	**590.7**	**179.4**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**11424.1**
Total Budget	**12115.0**	**2093.1**	**2525.8**	**2200.2**	**2177.0**	**2188.0**	**2035.8**	**2001.1**	**0.0**	**27336.2**
Change from FY 2020				**-325.6**						
Percentage change from FY 2020				**-12.9%**						

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

The difference between the total budget and the MPAR LCC estimate is the total budget includes content outside of Artemis I and excludes CoF; LCC only includes Artemis I content, including CoF.

The Artemis I and II launch dates are under review pending completion of several assessments. NASA is conducting a Program Status Assessment of the overall Artemis effort, of which SLS and EGS are key components. This assessment includes review of the schedule and technical approaches as well as systems engineering integration and program management. In parallel, NASA is performing an independent technical and programmatic assessment, including a joint cost and schedule confidence level analysis of the SLS and EGS programs. NASA Leadership will review the results of these assessments before considering potential updates to the Artemis I and II launch planning dates.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Engineers and technicians completed installation of all four RS-25 engines, shown above, that will provide the necessary thrust for the SLS rocket to reach space. This installation completes core stage assembly. The core stage is now at SSC preparing for Green Run testing.

PROJECT PURPOSE

In support of the Artemis mission, the Launch Vehicle Development project will enable deep space exploration with the Space Launch System (SLS) launch vehicle. For the first time since the Apollo program in 1972, American astronauts will explore space beyond low-Earth orbit (LEO) and return to the Moon, reinvigorating America's human exploration of the solar system.

EXPLANATION OF MAJOR CHANGES IN FY 2021

The FY 2021 President's Budget proposes funding to support the Nation's next lunar landing in 2024. Through its development, the SLS program has faced technical and performance challenges requiring multiple changes to its Launch Readiness Dates (LRD). This proposed budget addresses Artemis I Design, Development, Test, and Evaluation (DDT&E) schedule and performance challenges. The current LRD remains under review. The core stage for Artemis I is in preparation for Green Run testing at Stennis Space Center (SSC). Green Run is the term used for the hot fire testing of the flight core stage with all four engines as it is secured in the test stand at SSC. NASA is aware of continuing risk involving SLS end item completion and functional test and integration tasks, so Green Run testing length remains under review.

The Artemis I and II launch dates are under review pending completion of several assessments. NASA is conducting a Program Status Assessment of the overall Artemis effort, of which SLS and EGS are key components. This assessment includes review of the schedule and technical approaches as well as systems engineering integration and program management. In parallel, NASA is performing an independent technical and programmatic assessment, including a joint cost and schedule confidence level analysis of the SLS and EGS programs. NASA Leadership will review the results of these assessments before considering potential updates to the Artemis I and II launch planning dates. NASA anticipates updated launch planning dates no later than the third quarter of FY 2020.

NASA is focused on the successful completion of Artemis I and II and the preparation required for Artemis III in FY 2024. The first flights will feature the SLS Block 1 configuration, utilizing a human-rated Interim Cryogenic Propulsion Stage (ICPS). While the SLS Block 1B configuration with the Exploration Upper Stage (EUS) remains an important future capability, the significant performance and cost challenges faced by NASA's prime contract, Boeing, in finalizing the Block 1 core stage, requires that NASA and its contractors concentrate in the near term on the successful completion of the Block 1 SLS and reliably manufacturing flight systems. As a result, the President's Budget proposes deferring SLS Block 1B final design efforts. This approach is intended to ensure that NASA and its contractors

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

successfully deliver a Block 1 SLS, establish a regular flight cadence, and responsibly manage program resources.

PROJECT PARAMETERS

SLS will be an integral part of Artemis and will launch Orion to the Moon. Artemis III, which will launch in 2024, will return the first woman and next man to the surface of the moon. The primary components of the SLS include the Launch Vehicle Stage Adapter (LVSA), the Interim Cryogenic Propulsion Stage (ICPS), the core stage and avionics, two five-segment solid rocket boosters, and four RS-25 engines.

The SLS core stage towers over 200 feet tall, and atop sits the LVSA, which connects the ICPS and core stage. The LVSA provides structural support for launch and separation loads and protects propulsion system electrical components. Fitted directly below the LVSA is the core stage, serving as the backbone of the entire rocket. The core stage contains five primary subcomponents, including the forward skirt, liquid oxygen tank, intertank, liquid hydrogen tank, and engine section. The engine section is the attach point for the four RS-25 engines, which combined with the boosters will produce 8.8 million pounds of thrust. On each side of the core stage, the five-segment solid rocket boosters will stand 17 stories tall and will generate more thrust than 14 four-engine jumbo commercial airliners. The boosters connect via the intertank and engine section attach points and will provide initial thrust for the first two minutes of flight.

The Launch Vehicle Development project leverages hardware designed for heritage programs, including adapted and refurbished Space Shuttle main engines, five-segment Shuttle-derived solid rocket boosters, and an ICPS from a derivative of the Delta cryogenic second stage. The program benefits from NASA’s half-century of experience and knowledge of liquid oxygen and hydrogen heavy-lift vehicles, large solid rocket motors, and advances in technology and manufacturing practices, such as friction stir welding. The SLS rocket will blast a total thrust greater than that of the Saturn V.

SLS, through the launch of Artemis I, will demonstrate a critical capability that will serve as the mainstay for future human deep spaceflight missions. The launch vehicle development follows a block evolution framework where the core stage will serve as the common component of future configurations. The Block 1 configuration, which is the configuration for Artemis I, features a lift capability of 95 metric tons to LEO, with 8.8 million pounds of maximum thrust. Block 1 will use its Trans-Lunar Injection (TLI) performance to send 27 metric tons to cislunar space. The TLI, which is a propulsive maneuver used to set a spacecraft on a trajectory, will set Orion on a trajectory toward the Moon. This SLS configuration will demonstrate deep space technologies and hardware required for Earth-independent missions and maintain U.S. space exploration leadership.

ACHIEVEMENTS IN FY 2019

The Artemis I core stage is entering final integration because of many successful activities in FY 2019, and Artemis II components are under development. Artemis II flight components, including core stage-2, rocket booster segments, ICPS-2, and other elements, continue development.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

The full-scale core stage mock-up, also known as Pathfinder, completed multiple handling and maneuver exercises at SSC and KSC. Core stage maneuvers into and out of SSC's B-2 test stand provided training for heavy lifting and stacking operations ahead of Green Run testing. The SLS core stage pathfinder was also used for maneuvering exercises in High Bay 3 of the Vehicle Assembly Building (VAB) at KSC.

In the engines element area, over four years of RS-25 engine testing is complete. The fourth 500-second RS-25 hot fire test and full-power, full duration 650-second hot fire test were completed in February 2019. SLS completed acceptance testing of all 16 former Space Shuttle main engines, in addition to development and flightworthy testing for new controllers to be used on the first four missions. These test series demonstrated RS-25 engines can perform at higher power levels needed for SLS while achieving cost reductions with innovative and advanced manufacturing methods. The final four engines for Artemis I were delivered to Michoud Assembly Facility (MAF) in New Orleans, LA. Additionally, Artemis II engines are complete and will serve as contingency engines for Artemis I.

The software team completed the Green Run advance to shutdown regression testing, in addition to release 14 of the flight control application software. Additional testing was conducted in the Software Integration Test Facility, where qualification testing was conducted to complete avionics subsystem qualification.

Manufacturing and checkout of 10 motor segments that will power the initial two solid rocket boosters is complete. The boosters team finalized the fabrication of all 10 motor segments and fitted them with key flight instrumentation. The propellant-liner-insulation flight rationale (PLI) is complete, and the Artemis I PLI waiver is signed, resolving motor segment solid propellant and outer casing insulation concerns.

Artemis I core stage elements integration is nearing finalization with the completion of the "forward join," the mating of the forward skirt, liquid oxygen tank, and intertank. The team horizontally connected the liquid hydrogen tank to the intertank using 360 bolts. The boat-tail structure, a fairing-like covering to protect the bottom end of the core stage, joined to the engine section, marking the completion of the engine section integration.

WORK IN PROGRESS IN FY 2020

Artemis I core stage hot fire testing, also known as the Green Run test, is to be completed in FY 2020. Green Run testing will test fire the flight core stage with a full load of fuel and liquid oxygen in the B-2 test stand at SSC. The test will conduct modal testing, vehicle power-on checks, main propulsion system and engine leak function checks, and other systems verifications. This hot-fire test is critical to ensuring all core stage components are cleared and ready for vehicle certification and final integration at KSC. The LVSA assembly and check out for Artemis I will also complete at KSC. The Design Certification Review Board will certify the vehicle in preparation for the Artemis I Flight Readiness Review.

Upon completion of a successful Green Run test, the core stage will be delivered to KSC. With all Artemis I SLS hardware at KSC, SLS will hand off all launch vehicle components to Exploration Ground Systems (EGS). EGS will integrate the launch system with the Orion crew vehicle in KSC's Vehicle Assembly Building using a co-developed design center concept. The SLS team will continue to provide subject matter expertise as needed to support vehicle build-up and Integrated Test and Checkout. Artemis

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

I booster segments will ship to KSC by spring 2020 to take advantage of favorable warmer conditions from Utah, where the segments are stored. Once the booster segments arrive at KSC, booster stacking will begin. SLS will continue DDT&E work on the universal stage adaptor and payload attach fitting.

The SLS program will shift focus to Artemis II and III upon delivery of the first core stage to KSC. Manufacturing of Artemis II and beyond SLS components will continue with the fabrication of the intertank, liquid oxygen tank, and others. Additionally, long lead items for Artemis III, core stage IV and V, will begin the procurement process. Per appropriations direction, SLS will continue design and development of the Exploration Upper Stage (EUS) and work toward the EUS Critical Design Review (CDR) in FY 2021. However, the President's Budget recommends deferring these activities to support the successful completion of Block 1 and Artemis mission objectives.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

FY 2021 will be an exciting year for SLS, and the Agency, with the potential for an Artemis I launch. Prior to launch, the Artemis I Design Certification Review and Preliminary Flight Readiness Review will be completed. The integrated test flight will provide critical data regarding ground systems, the launch vehicle, spacecraft performance, and human deep space exploration operations.

SLS will also continue Artemis II core stage hardware manufacturing with the production of the Orion stage adaptor, production of the engine section boat tail join, the completion of ICPS-2, engine delivery to MAF, and others. The flight readiness analysis cycle for Artemis II will begin, and SLS will start core stage final assembly and integration for a March 2022 delivery to EGS at KSC.

While Artemis I and II are well on their way, Artemis III hardware builds will continue, including the Artemis III Orion stage adaptor, ICPS-3, and launch vehicle stage adaptor for the anticipated 2024 crewed launch. Artemis III will be the first Artemis lunar surface mission. SLS will also initiate contract actions for the Artemis IV launch vehicle stage adaptor and the stages production evolution contract.

Schedule Commitments/Key Milestones

Milestone	Confirmation Baseline Date	FY 2021 PB Request
KDP-A	Nov 2011	Nov 2011
Formulation Authorization	May 2012	May 2012
SRR/S	May 2012	May 2012
KDP-B Agency Project Management Council (APMC)	Jul 2012	Jul 2012
PDR Board	Jun 2013	Jun 2013
KDP-C APMC	Jan 2014	Jan 2014

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Milestone	Confirmation Baseline Date	FY 2021 PB Request
CDR Board	Jul 2015	Jul 2015
Design Certification Review	Sep 2017	Date under review
Artemis 1 Launch Readiness	Nov 2018	Date under review

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2015	7,021.4	70%	2020	8,750.2	+24.6%	Artemis I Launch Readiness	Nov 2018	TBD	TBD

Note: The confidence level estimates reported reflect an evolving process as NASA improves its confidence-related estimation techniques and actual expenditures reporting processes. NASA continues to review past reporting, and estimates do not necessarily accurately incorporate actual expenditures to date. Additionally, cost and confidence levels do not reflect the cost impacts of currently anticipated schedule delays. The estimates are expected to increase as NASA assesses the impacts of further delays and updates reporting on expenditures. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

The Artemis I and II launch dates are under review pending completion of several assessments. NASA is conducting a Program Status Assessment of the overall Artemis effort, of which SLS and EGS are key components. This assessment includes review of the schedule and technical approaches as well as systems engineering integration and program management. In parallel, NASA is performing an independent technical and programmatic assessment, including a joint cost and schedule confidence level analysis of the SLS and EGS programs. NASA Leadership will review the results of these assessments before considering potential updates to the Artemis I and II launch planning dates.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**7,021.4**	**8,750.2**	**+1,728.8**
Stages Element	3,138.6	4,957.4	+1,818.8
Liquid Engines Office*	1,198.3	485.4	-712.9
Booster Element	1,090.3	1,020.4	-69.9
Spacecraft Payload Integration and Evolution (SPIE)	447.1	558.0	+110.9
Other	1,147.1	1,728.9	+581.8

**The Agency Baseline Commitment previously included fixed and shared costs with the RS-25 production restart activity (in the Liquid Engines Office), which supports Artemis I and later missions. SLS removed those costs from the estimate and significantly lowered the Artemis I Liquid Engines Office and Current Year Development Cost Estimate.*

The Artemis I and II launch dates are under review pending completion of several assessments. NASA is conducting a Program Status Assessment of the overall Artemis effort, of which SLS and EGS are key components. This assessment includes review of the schedule and technical approaches as well as systems engineering integration and program management. In parallel, NASA is performing an independent technical and programmatic assessment, including a joint cost and schedule confidence level analysis of the SLS and EGS programs. NASA Leadership will review the results of these assessments before considering potential updates to the Artemis I and II launch planning dates.

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Booster	Responsible for development, testing, production, and support for the five-segment solid rocket motor to be used on initial capability flights.	Provider: Marshall Space Flight Center (MSFC) Lead Center: MSFC Performing Center(s): MSFC Cost Share Partner(s): N/A	N/A
Engines	Responsible for development and/or testing, production, and support for both core stage (RS-25) and upper stage liquid engines.	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC; SSC Cost Share Partner(s): N/A	N/A

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Stages	Responsible for development, testing, production, and support of hardware elements, including core and upper stages, liquid engine integration, and avionics integration.	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC/MAF; SSC Cost Share Partner(s): N/A	N/A
Spacecraft Payloads and Integration	Responsible for development, testing, production, and support of hardware elements for integrating the Orion and payloads onto SLS, including the ICPS, Orion stage adapter, LVSA, universal stage adaptor, and payload fairings.	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC, LaRC, GRC, and KSC Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement (Ranked in Sequential order)	Mitigation
If: Challenges associated with the completion of remaining first-time core stage manufacturing and testing activities persist, Then: Schedule impacts and further delays will be realized.	Program is incorporating improved manufacturing techniques, including optimized tooling and lapping activities prior to engine installs. White light scanning and access kit modeling to identify structural interferences will reduce taxing confined space entry and re-entry. Fully integrated functional testing will provide resolution of technical challenges resulting from qualification of components and subsystems. Enhanced planning processes and tracking metrics will mitigate schedule risks and unforeseen challenges for first-time development and manufacturing. Relocation of key program leadership on-site to MAF to support day-to-day activities will enable real-time decision-making, increasing opportunities to improve schedule performance.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Risk Statement (Ranked in Sequential order)	Mitigation
If: Green Run schedule risks - stage controller certification for wet dress and hot fire test, system-level problems, interactions of hardware, software, and avionics in an operational environment - materialize, Then: Delivery date to EGS at KSC will be impacted.	Contractor implemented two-phase approach to mitigate schedule risks associated with first-time stage controller development. Pathfinder vehicle operations training at SSC's B-2 test stand provided technicians with opportunities to practice Pegasus barge logistics, self-propelled modular transport operations, facility sizing verifications, heavy lift crane operations, and maneuvering. Planned pre-wet dress rehearsal commodities stress test to ensure cryogenics vendor's logistics preparations and B-2 test stand readiness. Contractor will conduct integrated console training for stage controller activities and additional on stand training with "pit crew" approach. Procure spares for vehicle, facility, and ground support equipment. Planned optimized access for instrumentation removal at B-2 test stand will reduce damage to thermal protection system and other core stage components.
If: Significant follow-on traveled work to EGS at KSC is required, Then: Final integration will experience additional delays.	Reduce post hot-fire engine refurbishments and thermal protection system repairs by reducing and eliminating inconsequential, low-risk tasks. Planned indoor engine refurbishment as traveled work to KSC will eliminate weather element exposure. VAB high-bay platforms allow for improved core stage component access versus SSC B-2 test stand access. Delivery to EGS as early as possible to allow for additional full hardware integration in support of launch readiness date.

Acquisition Strategy

MAJOR CONTRACTS/AWARDS

Procurement for SLS launch vehicle development meets the Agency's requirement to provide an evolvable vehicle within a schedule that supports various mission requirements. Procurements include use of existing assets to expedite development and further development of technologies and future competitions for advanced systems and key technology areas specific to SLS vehicle needs.

Element	Vendor	Location (of work performance)
Boosters	Northrop Grumman Innovation Systems (formerly Orbital ATK)	Magna, UT
Core Stage Engine	Aerojet Rocketdyne	Desoto Park, CA; SSC
ICPS	United Launch Alliance under contract to Boeing Aerospace	Huntsville, AL
Stages	Boeing Aerospace	New Orleans, LA

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Element	Vendor	Location (of work performance)
Upper Stage Engines	Aerojet Rocketdyne	West Palm Beach, FL

INDEPENDENT REVIEWS

NASA established an SRB to perform the independent reviews of the Launch Vehicle Development project as required by NASA Procedural Requirements (NPR) 7120.5.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
PDR	SRB	Aug 2013	To evaluate the completeness/ consistency of the planning, technical, cost, and schedule baselines developed during formulation; assess compliance of the preliminary design with applicable requirements; and determine if the project is sufficiently mature to begin Phase C.	The SRB evaluated the project and determined the project is sufficiently mature to begin Phase C and begin final design and fabrication.	N/A
CDR	SRB	Jul 2015	To evaluate the integrity of the project design and its ability to meet mission requirements with appropriate margins and acceptable risk within defined project constraints, including available resources. To determine if the design is appropriately mature to continue with the final design and fabrication phase.	The SRB evaluated the project and determined the project is sufficiently mature to progress to major manufacturing, assembly, and integration.	N/A
ESD Artemis I Independent Schedule Assessment	Schedule assessors from the OCFO	Jun 2019	Programmatic assessment and analysis of Artemis I schedules and schedule risk across all ESD programs with an emphasis on program performance and risks.	NASA leadership was briefed on Artemis I launch date options.	N/A
ESD Artemis I Re-baseline	Independent Review Team	Spring 2020	Programmatic assessment and analysis of Artemis I schedule and schedule risks of Artemis I launch date and JCL.	Upon completion of review, establish revised baseline and launch readiness date.	N/A

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
CDR	SLS Independent Review Team	Sept 2020	To certify the implemented design complies with applicable requirements and necessary verification activities are satisfactorily completed.	Certification of the SLS Block 1 design.	N/A

EXPLORATION GROUND SYSTEMS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**592.8**	**590.0**	**384.7**	**450.6**	**431.6**	**436.0**	**463.0**
Change from FY 2020			**-205.3**				
Percentage change from FY 2020			**-34.8%**				

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

This image shows the Space Launch System (SLS) 212-foot-long core stage pathfinder at the north end of the transfer aisle inside the Vehicle Assembly Building (VAB) at Kennedy Space Center (KSC). The Exploration Ground System (EGS) is using the core stage pathfinder to practice offloading, moving and stacking maneuvers, using important ground support equipment to train employees and certify all the equipment works properly.

The Exploration Ground System (EGS) program enables integration, processing, and launch of the Space Launch System (SLS) and Orion spacecraft. EGS is making all required facility and ground support equipment modifications at Kennedy Space Center (KSC) to enable assembly, test, launch, and recovery of the SLS and Orion flight elements in support of the Artemis missions. EGS is also modernizing communication and control systems to support these activities. Upon completion, the KSC launch site will provide a more flexible, affordable, and responsive national launch capability compared to prior approaches.

The EGS program, based at KSC, develops and operates the systems and facilities necessary to process, assemble, transport, and launch spacecraft and rockets. EGS' mission is to transform the Center to a spaceport that can handle future Artemis missions as well as varieties of spacecraft and rockets—both Government and commercial.

EGS is upgrading Launch Pad 39B, the crawler-transporters, the Vehicle Assembly Building (VAB), the Launch Control Center's Young-Crippen Firing Room 1, the mobile launcher, and other ground facilities.

For more information, go to: http://www.nasa.gov/exploration/systems/sls/index.html

EXPLORATION GROUND SYSTEMS

Program Elements

EGS PROGRAM INTEGRATION AND SUPPORT

EGS program integration and support activities manage the SLS and Orion program interfaces. This effort is critical to ensuring ground systems' performance meets technical and safety specifications and supports the programmatic assessments key to achieving integrated technical, cost, and schedule management. In addition, the EGS integration effort is vital to managing interfaces with other Human Exploration and Operations Mission Directorate (HEOMD) activities, including strategic studies, feasibility studies, and small-scale research tasks that feed into future human exploration. Coordination and timely integration across the three programs enable the Agency to avoid potential design overlaps, schedule disconnects, and cost issues.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

See the Exploration Ground Systems Development.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

FY 2021 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	BTC	Total
Formulation	974.7	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	974.7
Development/Implementation	1721.7	342.3	179.2	**85.8**	0.0	0.0	0.0	0.0	0.0	2329.0
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2020 MPAR LCC Estimate	**2696.4**	**342.3**	**179.2**	**85.8**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**3303.7**
Total Budget	**3014.7**	**586.6**	**558.7**	**377.0**	**447.0**	**428.0**	**436.0**	**443.0**	**0.0**	**6291.0**
Change from FY 2020				**-181.7**						
Percentage change from FY 2020				**-32.5%**						

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

The difference between the total budget and the MPAR LCC estimate is the total budget includes content outside of Artemis I and excludes CoF; LCC only includes Artemis I content, including CoF.

The Artemis I and II launch dates are under review pending completion of several assessments. NASA is conducting a Program Status Assessment of the overall Artemis effort, of which SLS and EGS are key components. This assessment includes review of the schedule and technical approaches as well as systems engineering integration and program management. In parallel, NASA is performing an independent technical and programmatic assessment, including a joint cost and schedule confidence level analysis of the SLS and EGS programs. NASA Leadership will review the results of these assessments before considering potential updates to the Artemis I and II launch planning dates.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

The 212-foot-long Space Launch System (SLS) rocket core stage pathfinder is moved into the low bay of the Vehicle Assembly Building at Kennedy Space Center (KSC) on October 1, 2019.

PROJECT PURPOSE

Exploration Ground Systems (EGS) is preparing to launch the Space Launch System (SLS) and Orion space transportation systems in support of Artemis missions. EGS is developing the necessary ground systems while refurbishing and upgrading infrastructure and facilities required for assembly, test, and launch of SLS and Orion, along with the landing and recovery activities of Orion. This includes the pad, known as Launch Complex-39B (LC-39B), the Vehicle Assembly Building (VAB), the mobile launcher (ML), and other smaller facilities to move from a Space Shuttle focus to one in support of Artemis missions. The modernization efforts maintain flexibility on LC-39B and in the VAB to accommodate other potential users and commercial partners. Additionally, following the Artemis I launch of SLS and Orion, the ML-1, VAB, and pad will undergo modifications to accommodate crewed flight. KSC has more than 50 years serving as our nation's gateway to exploring the universe. Taking the knowledge and assets of NASA's successful spacefaring past, the EGS Program is helping to build a successful and diverse future in spaceflight.

For more information, go to: http://go.nasa.gov/groundsystems

EXPLANATION OF MAJOR CHANGES IN FY 2021

The Artemis I and II launch dates are under review pending completion of several assessments. NASA is conducting a Program Status Assessment of the overall Artemis effort, of which SLS and EGS are key components. This assessment includes review of the schedule and technical approaches as well as systems engineering integration and program management. In parallel, NASA is performing an independent technical and programmatic assessment, including a joint cost and schedule confidence level analysis of the SLS and EGS programs. NASA Leadership will review the results of these assessments before considering potential updates to the Artemis I and II launch planning dates. NASA anticipates updated launch planning dates no later than the third quarter of FY 2020.

PROJECT PARAMETERS

Unlike previous work focusing on a single kind of launch vehicle, such as the Saturn V or Space Shuttle, engineers and managers in EGS are preparing infrastructure to support several different kinds of spacecraft and rockets that are in development, including the SLS rocket and Orion spacecraft for the Artemis program. EGS is focusing on the equipment, management and operations required to safely connect a spacecraft with a rocket, move the launch vehicle to the launch pad and successfully launch it into space. The work entails use of many of the facilities unique to KSC, such as the 52-story VAB and

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

LC-39B. EGS is modernizing and upgrading KSC's ground systems and facilities required to integrate SLS and Orion, move the integrated vehicle to the launch pad, and launch it successfully into space. For the Artemis missions, the EGS team is developing procedures and protocols to process the spacecraft, rocket stages, and launch abort system before assembly into one vehicle. Additional work required to launch astronauts into space includes modifying the ML-1 and crawler-transporters; preparing LC-39B at KSC; and modernizing computers, software, tracking systems, and other network communications.

ACHIEVEMENTS IN FY 2019

In October 2018, EGS completed the first high speed retraction test on the Orion Service Module Umbilical (OSMU) on the ML-1. The test verified umbilical arm alignment, rotation speed, and latch back systems. The OSMU will transfer power, data, and coolant for the electronics and purge air from the environmental controls to the Orion service module and Launch Abort System.

The program performed several water flow tests on the Ignition Overpressure Protection and Sound Suppression water deluge system on the ML-1 at LC-39B. The testing was part of a series of tests done to verify the system is ready for the new SLS rocket. Modifications were made to the pad after previous wet flow test, increasing the performance of the system. At peak flow, the water reached about 100 feet in the air above the pad surface. During the launch of Artemis I and subsequent missions, this water deluge system will release approximately 450,000 gallons of water across the ML-1 and Flame Deflector to reduce the extreme heat and energy generated by the rocket during ignition and liftoff.

EGS engineers conducted Underway Recovery Test-7 (URT-7) off the coast of San Diego, California, using a mock Orion Spacecraft capsule. With astronauts on hand to add their perspective, the team worked to perfect the capabilities that will be used for recovery of future missions to the Moon and beyond. URT-7 is one in a series of tests to verify and validate procedures and hardware used to recover the Orion spacecraft after it splashes down in the Pacific Ocean following deep space exploration missions. The team performed the first complete recovery at night, which lasted until the early hours of the morning. During recovery operations, future astronauts aboard Orion will have the choice to stay in the capsule while it is pulled into the well deck of a U.S. Navy ship or be pulled out immediately and put on the "front porch" until taken by small boat back to the ship. Orion will have an emergency abort capability, which will sustain the crew during space travel and provide safe re-entry from deep space return velocities.

The European Service Module (ESM) arrived at KSC in November 2018. The service module will undergo a host of tests and integration work ahead of Artemis I. Engineers will complete functional checkouts to ensure all elements are working properly before connecting to the Orion Crew Module (CM). Teams will weld together fluid lines to route gases and fuel and make electrical wiring connections.

In April 2019, the engine installer, one of the larger pieces of Ground Support Equipment (GSE) that will be used to prepare the SLS rocket for its launch, arrived at KSC. The new equipment will be ready for preflight processing in the event one of the four RS-25 engines on the core stage of the rocket needs to be

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

replaced. The engine installer has its own dedicated platform measuring 30 feet wide by 30 feet long by 15 feet tall.

In July, the System Acceptance Review and Operational Readiness Review (ORR) was successfully completed for the Rotation, Processing, and Surge Facility (RPSF). This life cycle review evaluated the RPSF's readiness to receive, process, integrate, and launch flight hardware for Artemis I and beyond. The RPSF will receive the Solid Rocket Booster segments for the SLS rocket. The pieces are inspected before two 200-ton cranes are positioned to lift the booster segments from a horizontal position to a vertical position. The RPSF will also receive the booster aft skirt from the Booster Fabrication Facility. During processing, the aft segment is attached to the aft skirt and aft exit cone. All the SLS solid rocket components processed in the RPSF will be transported to the transfer aisle in the VAB for final assembly on the ML-1.

The program performed the first terminal countdown demonstration for the inaugural flight of the SLS rocket and Orion spacecraft. The demonstration was intended to validate the launch team's capability to perform an Artemis I countdown and respond to problems put into the system for practice.

A drop test of the Tail Service Mast Umbilicals (TSMU) for the SLS launch vehicle was completed on the ML-1 in June 2019. The drop test was performed to ensure that the umbilicals will disconnect before launch of the SLS carrying Orion on its first uncrewed mission, Artemis I, from LC-39B.

The ML-1, carried atop the crawler-transporter 2, made the 10-hour trip to the pad from the VAB, where it had been for testing since last fall. At 380 feet tall, the ML-1 contains all the connection lines – known as umbilicals – and ground support equipment that will provide SLS and Orion with the necessary power, communications, fuel, and coolant for launch. The ML-1 went through a series of critical tests in the VAB, which included umbilical arm swing tests, environmental control system tests, hydraulic testing, nitrogen and helium testing, and electrical tests to verify commands from the Launch Control Center were properly communicating with the GSE and umbilicals.

One important test involved swinging three umbilical arms on the ML-1 simultaneously, which is the first time all three arms moved together, just as they would during launch. The three arms being tested were the core stage intertank umbilical, the core stage forward skirt umbilical, and the interim cryogenic propulsion stage (ICPS) umbilical. The umbilicals for the intertank and forward skirt will provide power and air to purge the lines for the SLS rocket. The umbilical for the ICPS will provide cryogenic propellants – or super-cooled liquid hydrogen and liquid oxygen – in addition to power and purge air to the ICPS. The ML-1 will roll back to the VAB for minor testing before SLS and Orion stacking.

Per FY 2019 appropriation, the program is building a second mobile launcher, known as Mobile Launcher-2 (ML-2). The design and build contract was awarded to Bechtel National, Inc., of Reston, Virginia. ML-2 is the ground structure that will be used to assemble, process, and launch the SLS Block 1B rocket and Orion spacecraft from LC-39B.

NASA's Pegasus barge arrived at KSC in September 2019 with a full-scale mock-up of the core stage called a "pathfinder". Weighing in at nearly 225,000 pounds, the core stage of the SLS is one of the

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

largest and heaviest pieces of hardware that will be processed for Artemis missions. The core stage pathfinder was used to practice offloading, moving, and stacking maneuvers, using important GSE to train employees and certify all the equipment works properly. The core stage pathfinder is the first opportunity for the entire KSC team to verify, validate, and execute the engineering and planning associated with handling of the SLS core stage flight hardware, setting the stage for an experienced workforce and efficient processing for the historic Artemis missions. The core stage pathfinder stayed at KSC for approximately one month to complete these activities.

EGS continued ground systems development efforts, including structural modifications for ML-1, installation of GSE and completion of the Environmental Control System. Additionally, EGS started construction activities for the new VAB platforms, ML-2, and LC-39B's new liquid hydrogen storage tank.

WORK IN PROGRESS IN FY 2020

The program conducted the final water flow test in a series of sound suppression tests at LC-39B in preparation for the first Artemis I launch, scheduled for October 2020. The brief test is one of the final checkouts between the launch pad and the ML-1. At launch, the SLS will produce nearly 9,000,000 pounds of thrust—and a lot of sound. The purpose of the sound suppression system is to dampen sound and vibrations to keep the rocket and the launch pad safe at lift-off. During the test and the launch of early Artemis missions, 450,000 gallons of water will be released onto the ML-1 and the flame deflector.

The core stage pathfinder was reloaded onto the Pegasus barge and returned to the Michoud Assembly Facility in New Orleans following the completion of testing inside the VAB and the ML-1.

ML-1 has returned to the VAB, after completing Multi Element Validation and Verification (MEVV) at the pad in December 2019.

EGS teams tested the flow of cryogenic fluids through the pad’s infrastructure – those systems that will send liquid hydrogen (LH2) and liquid oxygen (LOX) to the rocket at the time of launch. These tests are in preparation for the launch of SLS with the Orion spacecraft atop for the uncrewed Artemis I mission. The test verified the disposal methods for excess fluids, checked for leaks, confirmed that the LOX pumps could perform appropriately and validated that piping on ML-1 could handle the extremely cold temperatures of LOX and LH2. The next time these systems are used will be about two months before launch for the wet dress rehearsal, during which the SLS rocket deploys to the pad completely fueled and drained.

Much of the work in 2020 will be to complete a punch list of detail work inside the VAB. This includes cleaning the platforms and making minor repairs to any platform hardware that will be near flight hardware as the facility prepares for arrival of SLS components and stacking operations.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

EGS will complete software development efforts and MEVV of the ground systems in support of Artemis I. Spacecraft processing operations for Orion will take place at the Multi-Payload Processing Facility (MPPF), followed by SLS flight hardware assembly and SLS/Orion integration and testing at the VAB in support of the Artemis I mission.

The program will conduct URT-8 at U.S. Naval Base San Diego to ensure safe recovery of the Orion crew module post the Artemis I mission.

EGS software and ground facilities are nearing completion to support Artemis I.

In addition, EGS will continue ground systems development efforts in support of future mission requirements, including the first crewed flight on Artemis II. These preparations include modifications to LC-39, the VAB's Environmental Control System (ECS), and to ML-1 to support crewed missions. Upgrades to the Converter Compressor Facility will also occur. The program will continue construction activities of the Liquid Hydrogen Sphere at LC-39B.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

FY 2021 will be an exciting year as Artemis I is expected to launch. Prior to launch, the Artemis I Design Certification Review and Preliminary Flight Readiness Review will be completed. Once the vehicle is cleared for flight, the Artemis I mission will be set to become the first human spacecraft to the Moon in the 21st century. The integrated test flight will provide critical data regarding ground systems, the launch vehicle, spacecraft performance, and human deep space exploration operations.

EGS program will begin upgrades and modifications to the VAB and ML-1 in support of Artemis II, the first crewed mission, and Artemis III, the mission landing the first woman and next man on the moon.

The program will complete construction of LC-39's Liquid Hydrogen Sphere and begin verification and validation certification. The program will continue the Emergency Egress System and hardware pre-fabrication modifications and construction on ML-1 in support of Artemis II.

In preparation for Artemis I, the program will complete the Integrated Test and Check Out (ITCO), launch, and recovery of Artemis I.

EGS will continue fabrication of ECS in the VAB and begin upgrades at LC-39B to support Artemis II and Artemis III missions, continue upgrades at Compressor Converter Facility and begin modifications to support crew missions on ML-1. The program will also continue design of the liquid Nitrogen RL-10 Chilldown system at LC-39B.

Following the completion of Artemis I, the landing and recovery operations to recover the CM will be completed and the CM will be returned to KSC.

Although NASA began design and construction of the second mobile launcher platform, additional funding to complete the project is being deferred. NASA does not have plans to utilize the second mobile

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

launcher in the near-term, and a final Block 1B design has not been set. Moving forward with further construction and design prior to understanding requirements would lead to future cost, schedule, and safety challenges. NASA is deferring these activities until needed but allowing core design and construction of the platform to continue while awaiting a decision on the upper stage configuration for future missions.

Schedule Commitments/Key Milestones

Milestone	Confirmation Baseline Date	FY 2021 PB Request
Key Decision Point-A (KDP-A)	Feb 2012	Feb 2012
Formulation Authorization	Apr 2012	Apr 2012
Systems Requirement Review (SRR) / System Design Review (SDR)	Aug 2012	Aug 2012
KDP-B Agency Project Management Council (APMC)	Nov 2012	Nov 2012
Preliminary Design Review (PDR) Board	Mar 2014	Mar 2014
KDP-C APMC	May 2014	May 2014
Critical Design Review (CDR) Board	Dec 2015	Dec 2015
System Integration Review (SIR)	Apr 2018	Jun 2018
ORR / Flight Readiness Review (FRR)	Aug 2018	Under Review
Artemis I Launch Readiness	Sept 2018	Under Review

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2015	1,843.5	80%	2020	2,329.0	26.3%	Artemis I Readiness	Nov 2018	*TBD	TBD

The estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and actual expenditures reporting processes. NASA continues to review past reporting and estimates do not necessarily accurately incorporate actual expenditures to date. Additionally, cost and confidence levels don't reflect the cost impacts of currently anticipated schedule delays. The estimates are expected to increase as NASA assesses the impacts of further delays and updates reporting on expenditures.

The Artemis I and II launch dates are under review pending completion of several assessments. NASA is conducting a Program Status Assessment of the overall Artemis effort, of which SLS and EGS are key components. This assessment includes review of the schedule and technical approaches as well as systems engineering integration and program management. In parallel, NASA is performing an independent technical and programmatic assessment, including a joint cost and schedule confidence level analysis of the SLS and EGS programs. NASA Leadership will review the results of these assessments before considering potential updates to the Artemis I and II launch planning dates.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL	**1,843.5**	**2,329.0**	**+485.5**
Mobile Launcher	213.1	491.4	+278.3
LC-39B Pad	77.5	47.3	-30.2
VAB	92.7	40.4	-52.3
Command, Control, and Communications	198.0	458.7	+260.7
Offline Processing and Infrastructure	110.2	81.3	-28.9
Other	1,152.0	1,210.0	+58.0

**Other includes Crawler Transporter, Launch Equipment Test Facility, Integrated Operations, Program Management, Logistics, Safety and Mission Assurance (S&MA), and Systems Engineering and Integration (SE&I).*

The Agency Baseline Commitment for LC-39B, VAB, and Offline Processing and Infrastructure previously integrated Operations cost which support Artemis I and later missions. EGS realigned those costs from each element and moved those costs to the Other element; significantly lowering those elements' Current Year Development Cost Estimate. In addition, the program removed $27 million in costs for the VAB Utility Annex from the VAB element estimate. Those costs were covered by Center Management and Operations as that work was determined to benefit all programs at KSC.

The Artemis I and II launch dates are under review pending completion of several assessments. NASA is conducting a Program Status Assessment of the overall Artemis effort, of which SLS and EGS are key components. This assessment includes review of the schedule and technical approaches as well as systems engineering integration and program management. In parallel, NASA is performing an independent technical and programmatic assessment, including a joint cost and schedule confidence level analysis of the SLS and EGS programs. NASA Leadership will review the results of these assessments before considering potential updates to the Artemis I and II launch planning dates.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Project Management & Commitments

EGS balances customer requirements among SLS, Orion, and other Government and commercial users. EGS is developing ground systems infrastructure necessary to assemble, test, launch, and recover Orion elements.

Element	Description	Provider Details	Change from Baseline
Ground Systems Implementation (GSI)	GSI is responsible for the design, development, build, hardware/software integration, verification and validation (V&V), test, and transition to operations for Program facility systems and Ground Support Equipment (GSE).	Provider: KSC Lead Center: KSC Performing Center(s): Ames Research Center Cost Share Partner(s): N/A	N/A
Operations and Test Management (O&TM)	O&TM is responsible for conducting overall planning and execution of both flight hardware and ground systems processing activities.	Provider: KSC Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Command, Control, Communication (C3)	C3 is responsible for development, operation, and sustainment of End-to-End Command and Control and Communications services.	Provider: KSC Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Program Management Team (PMT)	PMT includes project management, safety and mission assurance, logistics, systems engineering, utilities and facility operations, and maintenance.	Provider: KSC Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: There is insufficient time to perform all Verification and Validation (V&V) activities, Then: There is a possibility of a schedule delay to the EGS Operations Readiness Date.	Adding notification milestones to program schedule to track a nd manage progress throughout V&V.
If: The ML-1 GSE installation design is running in parallel with ground subsystem GSE and vehicle designs, Then: There is a possibility that unplanned revisions to the GSE Installation Design will be required and installation construction contract cost and schedules may be significantly impacted. This risk has a significant impact to the ML-1 operational readiness date to support launch.	Acceleration Schedule is under review by ML-1 team and contractors.
If: The current LH2 Tail Service Mast Umbilical quick disconnect leakage experienced at the Launch Equipment Test Facility (LETF) during testing continues, Then: There is the possibility that the component level leakage specification will continue to be exceeded during V&V testing, resulting in the inability to sustain LH2 flow and complete Wet Dress Rehearsal.	Boeing / SLS to deliver prototype 8" LH2 Fill/Drain disconnect interface seal to resolve hydrogen leakage observed during LETF testing. Perform an Offline Integrated Core Stage Engine Section LH2 Umbilical Ground/Flight Plate test to retest the LH2 disconnects under cryogenic conditions. Perform successful ambient temperature helium leak checks of the LH2 Umbilical disconnect ground-to-flight interfaces.

Acquisition Strategy

To retain flexibility and maximize affordability, EGS serves as its own prime contractor for development activities. EGS executes SLS and Orion ground infrastructure and processing requirements by leveraging center and programmatic contracts. For more routine work, EGS also uses pre-qualified indefinite-delivery-indefinite-quantity contractors while exercising full and open competition for larger or more specialized projects, such as facility systems construction contracts, and associated GSE fabrication firm-fixed-price contracts. A fixed-price contracting approach is the first choice whenever possible, as it provides maximum incentive for contractors to control costs because the contractors are subject to any losses incurred. In addition, a fixed-price contract imposes minimal administrative burden on the contracting parties.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

EGS development activities will encompass projects of varying content and size. EGS does not have a prime contract; it uses the Center's institutional contracts to execute the development, engineering, construction, and programmatic activities. If the project size or scope falls outside existing Center capabilities, then a competitively bid firm-fixed-price contract will be used.

Element	Vendor	Location (of work performance)
ML-1 Structural and Facility Support Modification Contract	J.P. Donovan Construction, Inc.	KSC
VAB Platform Construction	Hensel Phelps Construction, Inc.	KSC
ML-2 Design Build	Bechtel National, Inc.	KSC

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
All	Standing Review Board (SRB)	Nov 2012	To provide independent assessment of program technical plan, cost estimates, schedules, and risks at KDP-B.	Program cleared to proceed to next phase.	N/A
PDR	SRB	Mar 2014	To evaluate completeness and consistency of program preliminary design; to determine readiness to proceed with detailed design phase.	Program cleared to proceed to next phase.	N/A
CDR	SRB	Mar 2016	To demonstrate that program design is mature; support full-scale fabrication, assembly, integration, and test; and meet overall performance requirements within cost and schedule constraints.	Program cleared to proceed to next phase.	N/A
SIR	KSC Independent Review Team (IRT)	Jun 2018	To evaluate the readiness of the program, including its projects and supporting infrastructure, to begin system Assembly, Integration, and Test with acceptable risk and within cost and schedule constraints.	Program cleared to proceed to next phase.	N/A

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
ESD Artemis I Independent Schedule Assessment	Schedule assessors from Office of the Chief Financial Officer (OCFO)	Jun 2019	Programmatic assessment and analysis of Artemis I schedules across all ESD programs with an emphasis on program performance and risks.	OCFO staff briefed NASA leadership on Artemis I launch date options	N/A
ESD Artemis I Re-baseline	Independent Review Team	Spring 2020	Programmatic assessment and analysis of Artemis I schedule and schedule risks of Artemis I launch date and JCL.	Upon completion of review, establish revised baseline and launch readiness date.	N/A

EXPLORATION RESEARCH & DEVELOPMENT

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Advanced Exploration Systems	348.9	--	**258.2**	226.9	146.7	130.1	130.1
Advanced Cislunar and Surface Capabilities	132.1	--	**212.1**	821.4	1664.5	1502.1	1152.6
Gateway	332.0	--	**739.3**	712.1	481.8	376.5	476.4
Human Landing System	0.0	--	**3369.8**	4388.1	5100.4	4971.3	3428.3
Human Research Program	145.0	--	**140.0**	140.0	140.0	140.0	140.0
Total Budget	**958.0**	**1435.0**	**4719.4**	**6288.5**	**7533.4**	**7120.0**	**5327.4**
Change from FY 2020			**3284.4**				
Percentage change from FY 2020			**228.9%**				

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Artist rendition of the Human Landing System that will return astronauts to the Moon in 2024.

The Exploration Research and Development (ERD) theme comprises five areas: the Human Landing System (HLS), Advanced Cislunar Surface Capabilities (ACSC), Gateway, Advanced Exploration Systems (AES), and the Human Research Program (HRP). The overarching goal of ERD is to infuse technologies and research into the development of human exploration capabilities and missions using a combination of unique in-house activities, public-private partnerships, and international partnerships. ERD is both developing and testing prototype systems as well as planning and developing flight missions to lunar orbit and the Moon to develop systems and operation capabilities that enable an eventual mission to Mars. ERD's work will form the basis for future human spaceflight missions throughout the Moon to Mars campaign. These program objectives support the National Space Policy Directive (SPD)-1 and SPD-2, as well as the Agency's Strategic Goal 2, which seeks to extend human presence deeper into space and to the Moon for sustainable, long-term exploration and utilization.

The goal of the HLS program is to establish U.S. preeminence on the Moon by returning American astronauts to the lunar service, beginning with the first woman and the next man in 2024. HLS will utilize partnerships with industry to achieve this goal. NASA will select multiple industry partners and collaborate with them to control long-term costs and schedule and maximize crew safety.

The focus of ACSC is to develop lunar surface systems and lunar strategies and technologies that enable future Mars efforts.

EXPLORATION RESEARCH & DEVELOPMENT

As a key part of the return to the Moon and a foundation for Mars, ERD will lead development of the Gateway, a small way station that will orbit the Moon and will serve as an orbital platform for human and robotic missions to the lunar surface. The Gateway will support sustainable human lunar surface exploration missions.

AES invests in development and demonstration of exploration capabilities to reduce risks, lower life cycle costs, and validate operational concepts for future human missions. Ground habitation prototypes were developed through public-private partnerships to evaluate human factors for different habitat configurations. A primary focus will be to continue to mature and test capabilities in support of habitation life support systems that will be applied to life on the Moon and Mars.

The goal of HRP is to provide human health and performance countermeasures, knowledge, technologies, and tools to enable safe, reliable, and productive human space exploration. As an applied research and development technology program, HRP uses research findings to develop procedures to lessen the effects of the space environment on the health and performance of humans working in that setting. With the goal of traveling to Mars and beyond, the program is using ground research facilities, the International Space Station, and analog environments to develop procedures and to advance research areas that are unique to Mars.

ERD activities utilize a variety of agreements and contracts that enable NASA, private industry, academia, and international partners to share in the risks and rewards of Government investments. These shared risks include incentivizing technical performance and building future commercial markets with financial interest in developing capabilities. These programs are also utilizing the unique skills of the NASA workforce to perform risk reduction, develop life support systems, and build the missions that will take humanity back to the Moon and beyond.

The technology capabilities and processes pioneered by ERD will enable the first intrepid crews of the new space age to travel safely to and from the surface of the Moon, mature sustainability on the Moon, and land on the surface of Mars. These missions will enable new scientific discoveries and promote new technologies, research, and systems needed to sustain living in deep space for the benefit of all humankind.

EXPLANATION OF MAJOR CHANGES IN FY 2021

The HLS program was established and is no longer a component of ACSC.

ADVANCED EXPLORATION SYSTEMS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**348.9**	**--**	**258.2**	**226.9**	**146.7**	**130.1**	**130.1**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

The Spacecraft Atmosphere Monitor (SAM), shown here, was launched to the International Space Station (ISS) and has begun operating successfully.

The Advanced Exploration Systems (AES) activities develop high-priority technologies and capabilities and infuse them into prototype systems that will form the basis for future human spaceflight missions. These activities use a combination of unique in-house activities and public-private partnerships.

To enable NASA's Artemis initiative, AES is investing in development and demonstration of exploration capabilities to reduce risk, lower life cycle cost, and validate operational concepts for future human missions through habitation capabilities, systems, and other technologies. The Agency identifies and addresses potential risks by performing early validation and ground/flight testing of new capabilities prior to integration into planned operational systems. This approach minimizes cost growth and improves affordability of future space exploration. AES is focusing on advancing the technologies that will foster a sustainable presence on the Moon and enable a lasting and productive presence utilizing reusable systems. These technologies will provide access for a diverse body of contributing partners and sustainability for repeatable trips to multiple destinations across the lunar surface.

To test the technologies, capabilities, and systems required for deep space missions, AES is employing a stepping-stone approach by testing on the ground, in low-Earth orbit (LEO), and in cislunar space. The goal is to make exploration missions more capable, safer, and more affordable.

AES will continue to work on identifying and addressing knowledge gaps and delivering fundamental capabilities to provide astronauts a place to live and work with integrated life support systems, radiation protection, food, fire safety, avionics and software, logistics management, and systems to manage waste.

AES provides the critical technologies to enable Artemis missions, including capabilities that enable sustained surface missions. The technology capabilities and processes pioneered by AES will enable the crews of the new space age to cross countless frontiers, stay safe and healthy, make scientific discoveries, and sustain new homes away from Earth for the benefit of all humankind.

ADVANCED EXPLORATION SYSTEMS

EXPLANATION OF MAJOR CHANGES IN FY 2021

AES transferred content and budget for three activities that have matured enough to move to the next phase of implementation. The Disruption Tolerant Network was transferred to Space Communications and Navigation (SCaN), the Cube Satellite Launch Initiative is now managed by the Launch Services Program (LSP), and the Synchronized Position Hold, Engage, Reorient, Experimental Satellites (SPHERES) activity is being executed by the International Space Station (ISS) program.

ACHIEVEMENTS IN FY 2019

In FY 2019, AES continued a crucial set of activities to gain a fundamental understanding of novel habitation structures, integrated advanced life support systems, environmental monitoring, logistics reduction, fire safety, crew health and radiation protection, and avionics and software for increased autonomy. AES continued work on additional technologies in the areas of synthetic biology applications, in-space manufacturing, robotic precursor missions, and vehicle systems, including modular power systems, advanced propulsion technologies, and lander technologies. Together, these technologies will close critical capability gaps necessary for deep space missions, including the Artemis architecture, and future human crewed missions to Mars.

AES completed assembly of Spacecraft Fire Safety (Saffire) IV and nearly completed assembly of Saffire V. The Saffire payloads help us understand how large-scale fires spread in microgravity and help us improve fire detection, suppression, and clean-up techniques. NASA will use the knowledge obtained from these experiments in detailed analysis and optimization for future fire protection systems.

AES continued to integrate advanced autonomy software, sensors, and feedback controls with advanced life support hardware to demonstrate improved overall efficiency and increased autonomy. The NASA Platform for Autonomous Systems was developed as a prototype hierarchical distributed autonomous operation capability for the Next Space Technologies for Exploration Partnerships (NextSTEP)-2 Northrup Grumman Habitat. It includes a software capability required for beyond LEO operations that does not rely on mission control from the ground.

AES continued the NextSTEP with commercial industry to prototype habitats, life support systems, and other habitation technologies and conduct integrated ground and ISS-based testing to reduce risk for deep space missions.

AES began ISS flight demonstrations of life support and environmental monitoring subsystems when the Spacecraft Atmosphere Monitor (SAM) launched on SpaceX 18. The SAM is installed on ISS and is continuously monitoring concentrations of major constituents of the atmosphere such as oxygen and nitrogen. SAM is just one example of reliable, energy efficient, and low-mass spacecraft systems that provide environmental control and life support systems that are critical to enabling long duration human missions beyond LEO.

Space radiation environments must be measured to determine astronaut exposures. In FY 2019, the Hybrid Electronic Radiation Assessor was deployed on ISS to refine radiation data analysis and serve as an opportunity to evaluate the hardware prior to the Artemis I flight.

AES support for the Orion Ascent Abort-2 (AA-2) flight test article was completed. The AA-2 flight test successfully demonstrated the ability of the Launch Abort System to safely separate the Orion Crew

Module from the Space Launch System (SLS) during an ascent abort scenario. The avionics and core flight software developed by AES was used on the test flight and is now mature enough to be utilized on other systems for future capabilities.

Through ISS flight demonstrations and improvements to the current ISS life support, environmental monitoring, fire safety, and crew health systems, AES habitation capabilities are progressing. There was also continued progress in the reliability and performance of the ISS oxygen generation assembly, the ISS urine processor assembly, the ISS water processor assembly, the temperature and humidity control condensing heat exchangers, and the technologies used for carbon dioxide removal. The first of three candidate carbon dioxide removal devices was flown to ISS in 2019. Ground development of smaller, more efficient exercise devices and a crop production capability is also continuing development for upcoming ISS flight demonstrations.

WORK IN PROGRESS IN FY 2020

As NASA works to extend human space exploration beyond LEO, AES will continue to develop reliable life support systems, deep space habitats, and overall capabilities to reduce logistics requirements to support sustainable human spaceflight missions that eliminate the dependencies on frequent resupply from Earth.

The NextSTEP habitation prototype industry partners provided NASA the functional habitat ground prototype units in FY 2019 for ground testing in FY 2020. The ground prototypes are allowing NASA and the NextSTEP habitation partners to evaluate configurations and habitability attributes of the habitat, assess how the various systems interact together and with other capabilities such as propulsion modules and airlocks, and provide platforms to test and ensure standards and common interfaces to enable interoperability.

Through a consistent test and verification approach, NASA will incorporate and test subsystems, facilities, and crew training approaches and receive feedback on human factors. The intended outcome of these activities is a complete set of long-duration deep space architecture designs (including standards, common interfaces, and testing approaches) from the awarded contractors as well as development and test of full-size ground prototypes.

AES will launch and operate Saffire IV in early FY 2020 while also continuing the development of Saffire V and VI flight experiments to demonstrate combustion products monitoring and post fire cleanup.

AES, in support of Gateway development, will continue to advance work on a graphical user interface requirement for day-to-day operations and system interaction. Avionics and software are the foundation that enables the command, control, communications, and computing capabilities needed to operate a spacecraft and subsystems in LEO and beyond.

AES is completing development of four small CubeSats for launch on Artemis I in 2021: BioSentinel, Near Earth Asteroid (NEA) Scout, Lunar IceCube, and LunIR. Lunar IceCube and LunIR are NextSTEP partnerships in which costs are shared with industry and universities. All four projects are nearing completion with final spacecraft integration planned to occur this year. These CubeSats will not only help answer strategic knowledge gaps associated with the Moon, asteroids, and effects of space radiation on biological systems, but also will develop capabilities for deep space CubeSats enabling future missions for academia and industry. BioSentinel will study the effects of the deep space radiation environment on DNA, NEA Scout CubeSat will visit a candidate asteroid for future human exploration using a solar sail, Lunar IceCube will prospect for water in its various forms by scanning the lunar surface, and the LunIR satellite will capture and downlink infrared images of the lunar surface.

AES will continue ISS flight demonstrations of life support and environmental monitoring subsystems, including SAM, the Universal Waste Management System (UWMS), the Brine Processor Assembly- an advanced water separator, the ISS urine and water processors, and one of three planned advanced carbon dioxide removal systems. In addition, a UWMS will be delivered to Orion for the Artemis II mission. Development and production work continues in all other life support, logistics reduction, environmental monitoring, and crew health improvements toward ISS flight demonstrations in 2021 and beyond. Additionally, AES will embark on a ground-based test campaign of life support technologies intended to complement ISS-based testing and gather further reliability and performance data to ensure these systems are ready for use in missions beyond LEO.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

By FY 2021, the AES portfolio will be more aligned to the support of landing humans on the Moon and establishing a sustainable, long-term presence there. AES will be focused primarily on technology development that could be infused into flight or surface elements for the Gateway, Advanced Cislunar and Surface Capabilities (ACSC), and the Human Landing System (HLS) programs.

AES habitation work will continue to deliver the fundamental capabilities and systems to provide astronauts a place to live and work in space. In addition to continuing ISS flight demonstrations begun prior to FY 2021, AES, in partnership with ISS, plans to complete flight hardware and demonstrate prototype systems and sub-systems on ISS, including improved carbon dioxide removal technologies and additional improvements to the ISS urine and water processors. Work on all other advanced habitation systems will also continue, with ISS flight demonstrations by 2025. AES will continue building upon the current commercial engagement contracts to advance commercial habitation, avionics, flight software, life support, in-space refueling capabilities, and other commercial space industries.

Program Elements

HABITATION

Habitation capabilities and systems deliver the fundamental capability to provide integrated life support systems, environmental monitoring, crew health, radiation protection, fire safety, and systems to manage food, waste, clothing, and tools that enable astronauts to carry out NASA’s mission in space and on other worlds. AES focuses on developing key habitation systems to enable the crews to live and work safely in space, with an initial focus on lunar missions.

Activities include the expandable habitat Bigelow Expandable Activity Module (BEAM), NextSTEP deep space habitation prototype development efforts, life support systems, logistics reduction, food and crew health systems, and radiation measurements and protection. Experiments to improve spacecraft fire safety are also underway to better understand how fire spreads and how to recover from fire events in microgravity. These investments will progressively move from habitation subsystems to integrated systems and then be infused into deep space exploration elements and system designs.

AES oversees the Agency's habitation strategy and serves as the central management authority for NextSTEP. In this capacity, AES is the primary interface between the external NextSTEP partners and internal stakeholders, including Exploration Technology, ISS, Orion, SLS, the Human Research Program, and the SCaN program.

Through the NextSTEP effort, NASA and industry identify commercial capability development for LEO that intersects with the Agency's long-duration, deep space habitation requirements, along with any potential options to leverage commercial LEO advancements and promote commercial activity in LEO. The multiple phases of NextSTEP are informing NASA's acquisition strategy for its deep space, long-duration habitation capability.

ROBOTIC PRECURSOR ACTIVITIES

Robotic Precursor Activities acquire strategic knowledge about potential destinations for human exploration. These efforts include the Artemis I CubeSats that will perform activities such as prospecting for lunar ice, studying the effects of space radiation, and demonstrating other instruments, research, and analysis.

STRATEGIC OPERATIONS, INTEGRATION, AND STUDIES

Studies and analysis are conducted in AES to translate strategy into developmental (technology and capability) priorities and operational efficiencies, such as the NASA Agency Video, Audio, and Imagery Library.

Program Schedule

Date	Significant Event
Dec 2019	Downselected exercise device for flight on ISS
Feb 2020	Begin ISS flight demonstration of water capture device
Mar 2020	Begin UWMS demonstration on ISS
Aug 2020	Upgrade ISS urine processor distillation assembly
Aug 2020	Begin Brine Processor Assembly (BPA) demonstration on ISS
Aug 2020	Upgrade ISS water processor assembly catalytic reactor

Program Management & Commitments

Human Exploration and Operations Mission Directorate (HEOMD) executes AES activities, and the Directorate's Associate Administrator delegated management authority, responsibility, and accountability to the AES Division at NASA Headquarters. AES Division establishes overall direction and scope, budget, and resource allocation for activities implemented by the NASA centers.

Program Element	Provider
Habitation Capabilities	Provider: NASA Centers Lead Center: Headquarters (HQ) Performing Center(s): Johnson Space Center (JSC), Marshall Space Flight Center (MSFC), Ames Research Center (ARC), Glenn Research Center (GRC), Langley Research Center (LaRC), Kennedy Space Center (KSC), and Jet Propulsion Laboratory (JPL) Cost Share Partner(s): Bigelow Aerospace, Boeing, Lockheed Martin, Orbital ATK, Sierra Nevada, and NanoRacks (NextSTEP), Dynetics, UTAS, Paragon
Habitation Systems	Provider: NASA Centers Lead Center: HQ Performing Center(s): JSC, MSFC, ARC, GRC, Goddard Space Flight Center (GSFC), and JPL Cost Share Partner(s): N/A
Strategic Operations	Provider: NASA Centers Lead Center: HQ Performing Center(s): ARC Cost Share Partner(s): N/A
Robotic Precursors	Provider: NASA Centers Lead Center: HQ Performing Center(s): MSFC, JPL, ARC Cost Share Partner(s): N/A

ADVANCED EXPLORATION SYSTEMS

Acquisition Strategy

Each year, AES evaluates how the portfolio aligns with human exploration priorities and technology gaps and either terminates or realigns activities that do not demonstrate adequate progress. AES also adds new activities to the portfolio as appropriate. AES will continue to utilize this process to identify and evaluate risk reduction activities needed in support of Gateway, HLS, and ACSC. AES strives to maximize specialized skills within the civil service workforce, but it may also utilize a small amount of contractor effort in areas where NASA can cost effectively leverage external skills and knowledge. AES will also use the Small Business Innovation Research program to engage small businesses for risk reduction and technology maturation. AES continues the use of competitively selected external awards and public-private partnerships. Upgrades to existing ISS life support systems will use existing contracts.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Habitation Systems: Universal Waste Management System	Collins Aerospace Systems	JSC
Habitation Systems: Inflatable Module	Bigelow Aerospace	North Las Vegas, NV; JSC
Habitation Systems: Brine Water Processor	Paragon	Tucson, AZ; MSFC
Habitation Systems: Thermal Amine CO2 Scrubber	Collins Aerospace	Windsor Locks, CT
Habitation Systems: Oxygen Generation Assembly	Collins Aerospace	Windsor Locks, CT
Habitation Systems: Water Processor Assembly	Collins Aerospace	Windsor Locks, CT
NextSTEP Broad Agency Announcement Awards	Boeing, Bigelow Aerospace, Lockheed Martin, Orbital ATK, Dynetics	JSC; MSFC; KSC

ADVANCED EXPLORATION SYSTEMS

INDEPENDENT REVIEWS

AES undergoes quarterly Directorate Program Management Council reviews, and periodically, representatives from the Office of Chief Engineer, the Office of Safety and Mission Assurance, and the Office of Chief Financial Officer will assess AES performance during Agency-level Baseline Performance Reviews (BPR). In addition, AES provides briefing reports to, and seeks feedback on planning and development activities from, the NASA Advisory Council Human Exploration and Operation Committee and the Technology Committee.

ADVANCED CISLUNAR AND SURFACE CAPABILITIES

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**132.1**	**--**	**212.1**	**821.4**	**1664.5**	**1502.1**	**1152.6**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Through the Advanced Cislunar and Surface Capabilities Program, NASA will begin formulation of an architecture that will lead to humans landing on the surface of the Moon and Mars. An artist's rendition of landing activities is presented here.

The Advanced Cislunar and Surface Capabilities (ACSC) program is formulating the systems that NASA will use to explore the surface of the Moon, which will provide experiences and capabilities that support future Mars missions. These include surface mobility and foundational habitation systems. ACSC will utilize initial studies and pre-formulation activities for future surface systems and the elements required for lunar sustainability. As these critical lunar-related technologies and systems mature, they will be the building blocks for the capability to extend stays on the Moon.

In the near term, ACSC is conducting risk reduction studies to develop strategies and identify lunar surface technologies to contribute to both lunar sustainability and future missions to Mars. ACSC risk reduction is focused on extending the duration of lunar missions and investigating potential solutions for surface logistics through systems development and payload delivery services. ACSC is also investigating and testing refueling options and lunar robotics with a goal of achieving a continuous lunar presence.

EXPLANATION OF MAJOR CHANGES IN FY 2021

All content and budget specifically related to the 2024 return to the lunar surface, as well as subsequent lunar landing missions that directly result from the Next Space Technologies for Exploration Partnerships (NextSTEP) Broad Agency Announcement (BAA) Appendix H, is now managed by the HLS program.

All Exploration Extra-Vehicular Activity (xEVA) suit related content, including risk reduction activities, is now managed by the Gateway program.

Lunar surface logistics services will be funded in ACSC.

ADVANCED CISLUNAR AND SURFACE CAPABILITIES

ACSC contains funding for lunar surface elements studies, risk reduction activities, and initial development. Surface elements include a lunar terrain vehicle, mobile habitation, and foundational habitation systems that will enable extended surface missions as required for a sustainable lunar presence.

ACHIEVEMENTS IN FY 2019

NASA released and awarded Appendix E: Human Landing System Studies, Risk Reduction, Development, and Demonstration under the NextSTEP Phase 2 BAA. Through these awards, NASA solicited lander risk reduction activities and concepts which lead towards sending humans to the surface of the Moon and bringing them home safely as part of a sustainable campaign of exploration.

In the lead up to the Appendix E awards, a second Human Landing System design analysis cycle was conducted to introduce early concepts for eventual missions to the lunar surface. This analysis fed directly into the requirements documents for the NextSTEP Phase 2 BAA Appendix H for the HLS program.

Lunar Cargo Transportation and Landing by Soft Touchdown (Lunar CATALYST) partnerships concluded and the results are being evaluated. These efforts are directly applicable to future lander technologies. The CATALYST partnerships stimulated development of robotic lunar landers that can be integrated with U.S. Commercial Launch Vehicles (CLVs) to deliver payloads to the lunar surface, a capability that will inform the design of the Artemis missions in 2024 and beyond.

WORK IN PROGRESS IN FY 2020

The Moon and Mars Architecture (M&MA) activity will initiate studies that provide context for how near-term lunar activities can be "Mars forward." M&MA will identify potential lunar surface systems, operations, and technology that will help NASA gain experience on and around the Moon that may evolve into the systems, operations, and technology necessary for eventual Mars missions. Studies will incorporate a lunar terrain vehicle Request for Information (RFI) to be released in order to evaluate potential industry partnerships.

Through a partnership with the Korea Aerospace Research Institute (KARI), ACSC will deliver the ShadowCam flight instrument for launch on the Korea Pathfinder Lunar Orbiter (KPLO) in March 2020. NASA will provide Deep Space Network lunar navigation and trajectory assistance in return for accommodating ShadowCam, which will image the shadowed regions at the Moon's poles to detect the presence of ice and potentially help to identify future sites for human lunar landings and surface operations.

The Tank Health Monitoring activity will construct a tank testing enclosure, control room, and test-to-failure pad at Kennedy Space Center. In collaboration with the HLS program, ACSC will continue experiments to extend the life of lightweight composite fuel tanks and develop sensors for measuring the mass of fuel available to Artemis missions in microgravity.

ACSC is funding the first two Gateway Logistics Services (GLS) missions. The project is managed by Gateway.

ADVANCED CISLUNAR AND SURFACE CAPABILITIES

Solar Systems Trek is a software application that is combining images and other science data to simulate exploration of the solar system including the Moon, Mars, and small-bodies (e.g., asteroids) to inform future missions.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

Studies conducted through the M&MA activity will continue to further develop strategies to take NASA beyond the initial Artemis missions. This will include a focus on lunar/Mars mission analog technologies and systems leading to Mars risk reduction activities on and around the Moon. Candidates for development could include a lunar terrain vehicle, a mobile lunar surface habitat, a foundation habitat, and surface power. By 2025, NASA expects multiple hardware developments for lunar surface assets to be underway.

ACSC will demonstrate the Cryogenic Fluids In-Situ Liquefaction for Landers (CryoFILL), which is a prototype tank integrated with a vacuum jacket and a cryo-cooler that will liquefy and store cryogenic propellants produced by In-Situ Resource Utilization (ISRU). This is a key technology for the Mars ascent vehicle that will produce propellants from the Mars atmosphere.

Program Elements

MOON & MARS ARCHITECTURE

M&MA activities are focused on developing the future exploration architecture to take humans from the initial lunar landing to a Mars landing. This architecture will identify needed capabilities and technologies, as well as define operational concepts that will guide the development of flight systems.

Concepts and potential partnerships for crewed lunar surface systems such as habitats, rovers, and a robotic precursor to support human exploration will be formulated through these studies.

SURFACE LOGISTICS

Through the GLS Request for Proposal, ACSC will use commercial partnerships to examine potential solutions for surface logistics through systems development and delivery.

ACSC CORE

These activities are focused on non-landing capabilities tied to lunar exploration. They include lunar mapping to inform selection of future HLS landing zones on the surface of the Moon, CryoFILL, tank structural health monitoring, and an international partnership with KARI.

ADVANCED CISLUNAR AND SURFACE CAPABILITIES

Program Schedule

The specific schedule for ACSC is still in the formulation phase and needs to be informed primarily by commercial responses to planned industry engagements. During FY 2021, NASA will make significant progress on establishing milestones, program implementation assignments, and acquisition strategy beyond the initial engagements.

Date	Significant Event
Feb 2020	Complete NextSTEP BAA HLS Appendix E for initial risk reduction capabilities
Mar 2020	Deliver ShadowCam instrument to KARI
Mar 2020	CryoFILL Complete prototype test article build-up
Sep 2020	CryoFILL sync-review Subscale Lander Tank Liquefaction ConOps Demo
Jun - Sep 2020	Mass Propellant Gauging/Tank Health Monitoring Development. Ground testing on flight type tanks including cryogenics and Test to Failure

Program Management & Commitments

The Human Exploration and Operations Mission Directorate (HEOMD) manages the ACSC activities.

Program Element	Provider
ACSC Core	Provider: NASA Centers Lead Center: NASA Headquarters (HQ) Performing Center(s): Marshall Space Flight Center (MSFC), Langley Research Center (LaRC), Glenn Research Center (GRC), Goddard Space Flight Center (GSFC), Johnson Space Center (JSC), Jet Propulsion Laboratory (JPL), Kennedy Space Center (KSC), Ames Research Center (ARC), Armstrong Flight Research Center (AFRC) Cost Share Partner(s): N/A
Moon & Mars Architecture	Provider: NASA Centers Lead Center: HQ Performing Center(s): MSFC, LaRC, GRC, GSFC, JSC, KSC, ARC Cost Share Partner(s): N/A
Surface Logistics	Provider: TBD Lead Center: KSC Performing Center(s): JSC, JPL, KSC, ARC Cost Share Partner(s): TBD

ADVANCED CISLUNAR AND SURFACE CAPABILITIES

Acquisition Strategy

Acquisition plans for all functions/elements of ACSC will be varied and depend upon specific activities as this effort is comprised of risk reduction activities, studies, and pre-formulation work.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

None.

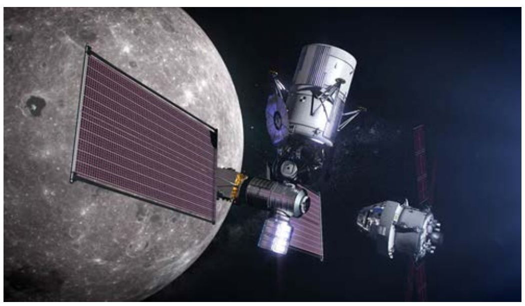
GATEWAY

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	332.0	--	739.3	712.1	481.8	376.5	476.4

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.



Shown here is an artist's rendition of the Gateway Phase 1, which will enable initial Artemis missions.

The Gateway will be an outpost orbiting the Moon that provides support for a sustainable, long-term human return to the lunar surface. The functionality will provide minimum systems to support human lunar landings and serve as a command center and aggregation point for future lunar missions. This approach enables a flexible human exploration architecture and will allow future collaboration with private sector companies and international partners. Depending on mission needs, the Gateway can potentially evolve to support future missions. The Gateway architecture is focused on two functional elements for sustaining lunar operations on the Moon. Those elements are the Power and Propulsion Element (PPE) and the Habitation and Logistics Outpost (HALO). The Gateway program also funds the Exploration Extravehicular Activity (xEVA) lunar surface efforts and a logistics capability for cargo delivery. Human lunar landers will dock with the Gateway and provide communications and support for lunar surface missions. In addition, NASA is working with international partners on potential future contributions for habitation and docking capability. The Gateway will enable science utilization, exploration technology demonstrations, and potential commercial utilization.

The PPE is the initial element of the Gateway. NASA selected Maxar Technologies for the development, launch, and in-space demonstration of the PPE. Maxar is currently targeting launch of the element on a commercial rocket by late 2022. The flight demonstration will last up to one year, during which time the spacecraft will be fully owned and operated by Maxar. Maxar will vet the capabilities of the PPE spacecraft, perform commercialization activities, and ultimately transfer the PPE into the Gateway Near-Rectilinear Halo Orbit (NRHO) in cislunar space. Following a successful demonstration, NASA will have the option to acquire the spacecraft for use as the first element of the Gateway. Working in partnership with the Space Technology Mission Directorate, PPE will demonstrate advanced high-power Solar Electric Propulsion (SEP) bus systems that will support future NASA and commercial applications. The PPE will generate and store a minimum of 50 kilowatts, transfer power to the Gateway elements, and provide attitude control. Additionally, the PPE will provide accommodations for science and technology demonstration payloads.

GATEWAY

Negotiations are ongoing with Northrop Grumman to develop and deliver HALO. It will use a pressurized module with the same 10-foot diameter as the Cygnus cargo compartment, allowing the spacecraft to fit inside the payload fairing envelope of existing commercial rockets. HALO will dock with the PPE by 2023. HALO will provide habitable and stowage volume and Environmental Control and Life Support Systems (ECLSS). HALO will also provide thermal control, allow power to pass through to other Gateway elements, provide communications with visiting vehicles and the lunar surface, and support external robotics and payloads.

Gateway Logistics Services (GLS) are required for future human lunar landing missions. NASA is seeking capabilities from American companies to deliver logistics to the Gateway in support of lunar surface operations.

A critical component for a return to the lunar surface is the xEVA System, which includes the Exploration Extravehicular Mobility Unit (xEMU) spacesuit development, suit-to-vehicle interface equipment, system servicing equipment, and specialized tools for conducting extravehicular activities (EVA) on the lunar surface. The xEMU is designed to provide astronauts with enhanced mobility to accomplish their exploration tasks on the lunar surface.

In addition to supporting human missions to the lunar surface and bringing crewmembers back safely to Earth, NASA will utilize the Gateway and lunar surface operations to conduct technology trials and scientific experiments to prepare for future crewed missions to Mars.

On the Gateway, the U.S. and its partners will test new technologies and systems as infrastructure is built on the surface of the Moon for lunar exploration and in preparation for future missions to Mars. NASA will also study the effects of the deep space environment, learning how living organisms react to the radiation and microgravity of a deep space environment over long periods.

EXPLANATION OF MAJOR CHANGES IN FY 2021

Updates to the Gateway implementation strategy are now focused on making the orbiting outpost a smaller configuration than previously planned to support missions as soon as 2024. The PPE budget has been adjusted to align with the award to Maxar, and the Utilization Module is being re-designed as the smaller habitation element (HALO). In previous years, xEVA development was funded jointly by the International Space Station (ISS) Program and the Advanced Exploration Systems (AES) Division. With the maturation of xEVA to a project managed by Gateway Program, the xEVA budget has been aligned to Gateway.

ACHIEVEMENTS IN FY 2019

Gateway began defining system requirements, developing design and interoperability standards, establishing program and system-level control boards, developing strategy and execution mechanisms to acquire Gateway modules, and developing an integrated ground test plan for prototype habitats.

At the conclusion of the NextSTEP Phase 2 study contracts, industry partners provided the functional habitat ground prototype units to NASA for testing. Ground testing began in 2019 and will complete in 2020. It will further enable Gateway habitation design through a demonstrated, consistent test and verification approach, allowing NASA to incorporate and test subsystems, facilities, crew training approaches, and human factors. The intended outcome of these activities is a complete set of long-duration deep space architecture designs (including standards, common interfaces, and testing approaches) from the awarded contractors, as well as development and testing of full-size ground prototypes.

NASA also used the NextSTEP Broad Agency Announcements (BAAs) to select Maxar Technologies to build the first element of the Gateway, PPE, which is set to launch in late 2022. Maxar successfully completed the PPE strategic requirements review (SRR) in September 2019.

A Request for Proposal (RFP) for HALO was issued to Northrop Grumman to provide a minimum capability necessary to support a lunar mission with significant reliance on the Orion life support and crew systems.

An RFP for Gateway Logistics was released in August 2019 to help NASA understand service options to transport cargo, equipment, and other goods, like food, to and from the orbiting outpost.

xEVA completed preliminary design review (PDR) for the xEMU suit demonstration at ISS.

WORK IN PROGRESS IN FY 2020

Gateway will conduct a Phase 1-focused Systems Definition Review (SDR) and implement the Gateway Digital Architecture to support SDR. Gateway will monitor development of transponder and baseband processor for S-Band communication systems for PPE and minimal habitation capability in coordination with Orion. A Modular Power Flight Hardware contract will be initiated. Design, Development, Test, and Evaluation (DDT&E) of the Vehicle Systems Manager (VSM), one of the Gateway/Lander backbone systems, will begin.

The PPE will complete Safety Reviews, PDR, and Baseline Completion Review.

NASA will award a contract to Northrop Grumman for development and delivery of the HALO SRR/SDR, and PDR will be completed.

Gateway will evaluate Gateway Logistics proposals received in October 2019 for firm fixed-price contract award.

Within the xEVA system, the hi-fidelity Engineering Development Unit (EDU) of the xEMU is scheduled to be completed. Once tested, the xEMU will proceed to a critical design review (CDR) and assembly, integration, and tests of the unit will occur. The Spacesuit Evaporation Rejection Flight Experiment will be conducted on the ISS to validate the design of the xEMU thermal loop.

A Request for Information (RFI) issued in early 2020 sought industry input on transitioning the xEVA production line to private industry for 2025 and beyond. A subsequent Request for Proposals (RFP) is planned to be issued.

GATEWAY

KEY ACHIEVEMENTS PLANNED FOR FY 2021

Gateway will conduct a PDR.

NASA will continue working with Maxar Technologies on PPE to enable successful delivery of the development schedule. The expected PPE milestones will include requirements, design reviews, and component procurements. PPE will work with NASA internal partners to codify deliverables and ensure NASA's confirmation baseline is established.

Gateway planning will continue to identify technological advancements in commercial habitation, avionics, flight software, life support, in-space refueling capabilities, and other commercial space industries that may be incorporated into the Gateway modules.

The HALO will complete CDR.

PDR for the first Logistics Module will be conducted.

Program Projects

PROGRAM INTEGRATION AND MANAGEMENT

The Program Integration and Management Element is responsible for overall Gateway program management and management of cross-element and cross-program interfaces. The program office is responsible for the overall systems engineering and integration of the Gateway, programmatic guidance, oversight and insight, and assessments (e.g., technical, cost, schedule, acquisition, and legislative) of Gateway development health.

POWER AND PROPULSION ELEMENT (PPE)

The first element of the Gateway is the PPE project. The PPE is a robotic spacecraft that will provide electrical power and propulsion, orbital station keeping, orbital translation, and communication for the Gateway. It is being developed partially through a public-private partnership so that the capability is directly applicable to a wide range of NASA, commercial, robotic, and human spaceflight missions. PPE will leverage U.S. commercially available space system development and launch capabilities and align with anticipated industry needs. It will provide transportation for the Gateway between cislunar orbits as well as perform needed orbital maintenance. It will provide altitude control for the Gateway in multiple configurations, accommodations for external research payloads, communication to and from Earth, space-to-space communication, and space-to-lunar communication. PPE will incorporate the NASA Docking System (NDS) for docking and refueling capabilities. At the end of the Gateway's operational life, PPE will move the integrated Gateway stack to a disposal orbit.

PPE works with U.S. industry while leveraging Exploration Technology investments in Advanced Electric Propulsion Systems (AEPS). PPE will demonstrate an advanced 50 kilowatt-class SEP system. PPE has a targeted launch readiness no earlier than December 2022.

GATEWAY

HABITATION AND LOGISTICS OUTPOST (HALO)

The Gateway HALO project provides a livable section and short-duration life support functions for the crew in cislunar space. The docking ports allow for attachment to the PPE, other elements, and visiting vehicles. The HALO also provides attach points for external robotics, external payloads, or rendezvous sensors; thermal radiators that provide heat rejection and micro-meteoroid protection; and additional habitat systems that provide accommodations for crew exercise, science/utilization, and stowage. Some functions may be outfitted via future logistics flights. HALO will be based on Northrup Grumman's Cygnus spacecraft, which is used for ISS cargo missions. HALO will have an extra section, or bay, compared to the current three-bay Cygnus used on cargo missions. The stretched version will provide more volume and ensure adequate clearance for its docking ports. It will have two axial and two radial docking ports, power distribution systems, and command and control systems. HALO is scheduled for a late 2023 launch on a commercial rocket. HALO will then dock autonomously with the PPE.

LOGISTICS SERVICES

The functional reality of human habitation anywhere is that it involves the consumption of resources and the generation of waste. The Logistics Services project handles transportation of cargo to and from the Gateway. The orbit of the Gateway is optimized to enable Orion access and commercial logistics delivery for on-going resupply of the Gateway.

NASA is currently assessing specific configurations and strategy for pressurized and unpressurized logistics delivery, refueling, commercial launch vehicles (CLV), and the Orion pressurized logistics. All potential concepts deliver cargo to the Gateway to support the Artemis program.

Logistics flights are being considered for cargo delivery to the Gateway to support potential lunar surface operations in 2024 and 2025, if needed. A logistics flight will also deliver the Canadian robotics arm.

The Logistics spacecraft will have their own power, propulsion, and navigation systems to rendezvous autonomously with the Gateway in cislunar orbit and dock at a radial port. The Logistics spacecraft could provide consumable resupply, outfitting equipment, and cargo delivery and disposal, including utilization and spares.

EXPLORATION EXTRAVEHICULAR ACTIVITY (XEVA)

To support crewed exploration of the surface, NASA is developing the xEVA System. The xEVA System encompasses the complete suite of hardware required to conduct spacewalks on the lunar surface and the associated vehicle interfaces for servicing, recharge, and consumables exchange. The largest element of the xEVA System is the xEMU, NASA's next generation spacesuit. It is designed to protect the crew during dynamic phases of flight, enables surface and microgravity EVA from an airlock, and requires minimal in-flight maintenance.

The xEMU is optimized for lunar surface missions and addresses the most challenging requirements for mobility, environmental protection, and spacewalk durations. The xEMU will tolerate the lunar thermal and dust environment and will incorporate features to minimize dust migration into the habitable environment. As the Artemis missions progress, and pre-deployed assets and infrastructure become available, the intent is to incorporate additional features for the sustained capability xEMU, which will support more complex EVA tasks, increased traverse capability, extended service life, and increased crew autonomy during EVAs. The xEMU will be an in-house build for the 2024 expedition with testing of components and full suit demonstrations on ISS through 2023.

Program Schedule

The Gateway elements and final configuration are still in the formulation phase. During FY 2020, NASA will make significant progress on establishing milestones, program implementation assignments, and further acquisition strategy decisions.

Date	Significant Event
Q1 FY 2020	Gateway System Definition Review (SDR)
Q4 FY 2020	PPE Key Decision Point-C (KDP-C)
Q1-2 FY 2021	Gateway Preliminary Design Review (PDR)
Dec 2022	PPE Launch Readiness Date (LRD)

Program Management & Commitments

The Human Exploration and Operations Mission Directorate (HEOMD) Associate Administrator (AA) assigned authority for the Gateway Program to Johnson Space Center (JSC). The Program Manager reports directly to the HEOMD AA in coordination with the Director of Human Lunar Exploration Programs. The Gateway program will make an Agency Baseline Commitment (ABC) for each project after it has reached a PDR-level of maturity. PPE will make an ABC in conjunction with the Gateway KDP-0, and HALO, Logistics, and xEVA will make ABCs in conjunction with Gateway KDP-1.

Program Element	Provider
Power and Propulsion Element	Provider: Maxar Technologies Lead Center: Glenn Research Center (GRC) Performing Center(s): GRC and JSC Cost Share Partner(s): Maxar Technologies
HALO	Provider: Northrup Grumman Lead Center: JSC Performing Center(s): JSC and Marshall Space Flight Center (MSFC) Cost Share Partner(s): N/A
Logistics	Provider: TBD Lead Center: Kennedy Space Center (KSC) Performing Center(s): KSC Cost Share Partner(s): N/A

Program Element	Provider
xEVA	Provider: JSC Lead Center: JSC Performing Center(s): JSC Cost Share Partner(s): N/A

Acquisition Strategy

The acquisition of the Gateway will incorporate a hybrid mix of contracted development, international and domestic partnerships, in-house expertise, and other innovative initiatives that have not yet been identified. All approaches that improve NASA's acquisition agility and responsiveness to an evolutionary mission will be considered. NASA's mandate to return American astronauts to the lunar surface by 2024 necessitates that all acquisition options must be considered. The comprehensive attribute that binds the Gateway acquisition strategy is adherence to NASA's strategic principles for sustainable exploration.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
PPE (May 2019)	Maxar Technologies	GRC
HALO (Mar 2020)	Northrup Grumman	JSC
Gateway Logistic Services (Q2 FY 2020)	TBD	KSC

INDEPENDENT REVIEWS

*Independent review of PPE will be in conjunction with the Baseline Completion Review.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
PPE Authorization Review	Independent Review Team (IRT) Goddard Space Flight Center (GSFC) chaired; NASA members	Jul 2017	Independent review to support HEOMD Directorate Program Management Council (DPMC) decision to proceed with PPE	Passed	PPE Baseline Completion Review
Gateway Formulation Synchronization Review (FSR)	Independent Review Team	Feb 2019	Equivalent to an SRR, the FSR evaluated the program's functional and performance requirements, ensuring proper formulation and correlation with Agency and HEOMD strategic objectives	Program cleared to proceed to next phase	Gateway SDR
Gateway Program Systems Design Review (SDR)	Standing Review Board (SRB)	2020	To evaluate the completeness/ consistency of the planning, technical, cost, and schedule baselines developed during formulation; assess compliance of the preliminary design with applicable requirements; and determine if the project is sufficiently mature for Gateway Program KDP-0	TBD	Gateway PDR
Gateway Program Preliminary Design Review (PDR)	SRB	2021	To evaluate the completeness/ consistency of the planning, technical, cost, and schedule baselines developed during formulation; assess compliance of the preliminary design with applicable requirements; and determine if the project is sufficiently mature for Gateway Program KDP-1	TBD	TBD

HUMAN LANDING SYSTEM

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**0.0**	**--**	**3369.8**	**4388.1**	**5100.4**	**4971.3**	**3428.3**

Shown here is an artist's rendition of the Human Landing System (HLS), which NASA will use to return humans to the lunar surface.

The Human Landing System (HLS) program is an integral part of achieving NASA's Artemis goal of enabling discovery, economic growth, and American global leadership by landing the first woman and next man on the Moon's South Pole in 2024 as part of a sustained exploration program.

Utilizing partnerships and competition to ensure affordability, the program relies on commercial partners to develop and jointly deploy the integrated landing system that will transport humans to and from the Moon. HLS is developing a series of lunar missions that build in capability beginning with the initial return of humans to the surface. Starting with Artemis III, HLS will support subsequent crewed missions to the lunar surface. HLS capabilities (including potential re-use of HLS hardware) will enable a sustainable long-term presence on the lunar surface in preparation for a human mission to Mars.

The HLS program is working in parallel with Space Technology Mission Directorate (STMD) exploration technology, Science Mission Directorate (SMD) scientific lunar exploration, and launch capabilities from commercial providers. The STMD Tipping Point program includes six awards that are related to lunar landers. HLS will work with STMD to ensure that the technologies developed are relevant and have high-potential to on-ramp to the lunar missions. These technologies, being developed by STMD, will be available for HLS providers to incorporate into their designs. Agency partnerships through Artemis will continue with SMD's Lunar Discovery and Exploration Program (LDEP). The partnership with SMD includes conducting scientific reconnaissance to help inform the science the astronauts will conduct on the lunar surface, coordinating and identifying NASA payloads to fly on commercial lunar transportation services missions, and identifying long-term exploration needs.

EXPLANATION OF MAJOR CHANGES IN FY 2021

The HLS program was created to manage and integrate NASA content, supporting industry development of an integrated lunar landing system.

HLS has accelerated development of a human lunar landing architecture that will include human missions to the lunar surface. The human return to the lunar surface will now occur in 2024. The program will focus on working with industry to create an affordable and sustainable capability.

HUMAN LANDING SYSTEM

ACHIEVEMENTS IN FY 2019

NASA published a formal request for proposals for the Next Space Technologies for Exploration Partnerships (NextSTEP-2) Broad Agency Announcement (BAA) Appendix E: Human Landing System Studies, Risk Reduction, Development, and Demonstration to seek proposals from industry in support of design analysis, technology maturation, system development and integration, and spaceflight demonstrations for a human lunar landing system. NASA selected and funded 11 companies to conduct studies and produce prototypes of human landers for its Artemis lunar exploration program. The selected companies' studies and prototypes will provide schedule risk reduction for a potential descent, transfer, and/or refueling element for a prospective HLS by initiating landing system-related work prior to a potential HLS award. NASA was charged with accelerating plans to return to the Moon and to land humans on the surface again by 2024.

To best accelerate NASA's return to the Moon, the HLS Program released the NextSTEP BAA Appendix H: Human Landing System - Integrated Lander to seek proposals from industry in support of design analysis, technology maturation, system development and integration, and space flight demonstrations for a human lunar landing system. The initial integrated lunar transportation system will deliver humans to the lunar surface and develop and demonstrate a more sustainable HLS for subsequent missions. NASA released the final call to industry in September 2019 following the issue of two drafts.

WORK IN PROGRESS IN FY 2020

HLS will select multiple industry partners for development and demonstration of an integrated landing system for lunar missions.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

Industry partners will design lander systems, and HLS will hold design reviews with those partners in FY 2021. The schedules for those reviews will be negotiated with the industry partners during the base period in FY 2020.

Program Elements

HLS PROGRAM MANAGEMENT

Human Landing System Program Management is responsible for executing programmatic roles assigned to Marshall Space Flight Center (MSFC) by the Human Exploration Operations Mission Directorate (HEOMD). HLS is responsible for the insight and oversight activities in collaboration with commercial partners associated with human landing system hardware development, integration, and flight demonstration, leading to services for NASA. HLS performs risk reduction activities and identifies and prioritizes upgrades to the human landing systems so it can support sustainable future exploration missions. HLS will include a lander ground operations office at Kennedy Space Center (KSC), a crew compartment office, and a lander flight operations office at Johnson Space Center (JSC). HLS will also prioritize and coordinate collaboration resources across multiple NASA Centers and manage major integrated system test activities (as applicable).

Program Schedule

Date	Significant Event
Feb 2020	Select and award multiple industry partners
Late 2020 / Early 2021	Continuation Review to select two industry partners
2024	First lunar surface mission
2025	Second lunar surface mission

Program Management & Commitments

MSFC manages the HLS program.

Program Element	Provider
HLS Program Management	Lead Center: MSFC Performing Center(s): Ames Research Center (ARC), Glenn Research Center (GRC), Langley Research Center (LaRC), Goddard Space Flight Center (GSFC), Stennis Space Center (SSC), JSC, KSC Cost Share Partner(s): TBD
Partner(s)	Provider: TBD Lead Center: MSFC Performing Center(s): TBD Cost Share Partner(s): TBD

Acquisition Strategy

The HLS program will utilize the NextSTEP BAA contract vehicle. Through this approach, NASA will award multiple firm-fixed-price, milestone-based proposals to enable rapid development of a crewed flight demonstrations of the human landing system. NASA has structured the solicitation to award contracts with the following contract line item numbers (CLINs):

- Base CLIN - contract award through nine months - only long-lead items supporting the first mission and various design activities are allowed during this base period.
- Option A CLIN - flight and landing demonstrations of human landing systems.
- Option B CLIN - follow-on flight demonstration with a focus on sustainability.

Human Landing System

Initial proposals include a firm-fixed-price contract for the Base period and Option A period. The Option B period will be priced at a later date.

Major Contracts/Awards

N/A

Independent Reviews

N/A

Historical Performance

N/A

HUMAN RESEARCH PROGRAM

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	145.0	--	140.0	140.0	140.0	140.0	140.0

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.


In this photo from Expedition 56, NASA astronaut Serena Auñón-Chancellor examines her eye with a Funduscope.

Sending astronauts into space involves a multitude of complicated systems, but perhaps the most complex is the human system – human health, human factors (how crews interact with their environment, including the spacecraft, habitat, and systems during missions), and the crew interactions. While NASA has more than 50 years of crew experience in low-Earth orbit (LEO), researchers are continuing to unravel the mysteries of how the human body responds to the harsh environment of space. The Human Research Program (HRP) is responsible for understanding and mitigating the highest risks to astronaut health and performance to ensure crews remain healthy and productive during long-duration missions beyond LEO.

As NASA prepares to conduct crewed missions via the Artemis program to cislunar space, the lunar surface, and eventually to Mars, HRP is developing the scientific and technological capabilities to support these exploration missions. In support of the risk reduction strategy for human space exploration contained in the human research roadmap, HRP is coordinating with the National Academies, the National Council on Radiation Protection and Measurements (NCRP), and other domestic and international partners, to deliver products and strategies to protect crew health and performance during and after exploration spaceflight missions. Current research on the International Space Station (ISS) in low earth orbit and in ground-based analog laboratories, are expanding our capabilities to enhance crew performance and protect the health and safety of astronauts. Investigations regarding space radiation protection, deep space habitat systems, behavioral health, innovative medical technologies, advanced food and pharmaceutical systems, space suit requirements, and validated countermeasures are evolving to ensure crew health. HRP also collaborates with NASA's Office of Chief Health and Medical Officer (OCHMO) and the Crew Health and Safety (CHS) and Spaceflight Crew Operations (SFCO) offices to research these issues and answer other questions to ensure crew health, safety, and mission success. SFCO and CHS are responsible for astronaut training, readiness, and health, while HRP funds research development of human health and performance countermeasures, knowledge, and technologies that enable safe, reliable, and productive human space exploration.

For more information, go to: https://humanresearchroadmap.nasa.gov

HUMAN RESEARCH PROGRAM

Space poses significant health risks for crewmembers, including the possibility of developing long-term health effects manifesting later in life from space radiation exposure, health and performance decrements that develop during the mission, and decrements in capabilities immediately upon return to Earth. HRP is working with Advanced Exploration Systems (AES), CHS, and Orion teams on both in-mission and post-mission countermeasures, medical treatment capabilities to maximize crew health and performance, and rehabilitation protocols to minimize residual impacts on the crew, to minimize exposures, and to provide radiation protection. The collaborative efforts involve defining permissible exposure limits, requirements for real-time medical response, optimized mission architectures, biomedical monitoring, potential drug or nutritional countermeasures, as well as incorporating post-mission health surveillance to ensure that crewmembers can safely live and work in space without exceeding acceptable health risks.

In collaboration with other federal agencies, such as the Department of Defense (DoD), the Department of Energy (DOE), the National Science Foundation (NSF), the Department of Health and Human Services (HHS), and the National Institutes of Health (NIH), HRP supports human research to increase understanding of the effects of spaceflight on human physiological systems, behavioral responses to isolation and confinement, and space radiation health effects. This knowledge is critical to NASA's plans for long-duration human space missions beyond LEO. In addition, as is the case with many space-based medical investigations, this research may lead to significant advancements in treating patients on Earth.

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

ACHIEVEMENTS IN FY 2019

HRP researchers conducted 15 ISS biomedical research investigations across ISS Expeditions 57/58 and 59/60, completed five flight investigations, and initiated six new flight research investigations with the start of pre-flight baseline data collection or in-flight data collection. ISS studies to mitigate the risk of long-duration spaceflight included the following: 1) standardized behavioral measures; 2) exploration food technology assessments; 3) core measurements on human spaceflight risks from astronauts before, during, and after long-duration missions; 4) human factors assessments on operational tasks and team effectiveness; 5) exploration fresh-food production system; and 6) assessment of dynamic vertebral strength and injury risk following long-duration spaceflight.

ISS research publications for both the One-Year Mission and Twins Study were released in *Aerospace Medicine and Human Performance and Science*, respectively. These publications documented the health impacts of long-duration spaceflight from physiological to genomic levels. Some highlights of initial spaceflight-specific changes include decreased body mass, altered ocular structure, changes in DNA associated with age and metabolism, gastrointestinal microbiota alterations, and cognitive changes post-flight.

HRP implemented the ISS Spaceflight Standard Measures project that collects a set of core measurements from astronauts important for understanding many of the human spaceflight risks before, during, and after long-duration ISS missions. The project is designed to acquire a consistent set of validated, measured parameters that document the spaceflight normal response as well as variations in the astronaut population in response to diverse duration exposures to spaceflight. The results will function as a data repository for investigators to develop hypotheses, provide supporting experimental data, or be used in astronaut and Earth-based epidemiology assessments.

HRP continued working with the Translational Research Institute for Space Health (TRISH) to solicit research and educate the next generation of space life scientists. TRISH focuses on rapidly translating fundamental research concepts into practice, thereby generating tangible health outcomes—in this case, for astronauts. During 2019, TRISH had 56 active projects in its Science and Technology pipeline and released two research announcements: 1) Biomedical Research Advances for Space Health; and 2) the industry solicitation of proposals from small U.S.-based companies for technologies that would be essential for self-reliant healthcare in deep space.

In the area of behavioral health and performance and the effects of isolation, HRP relies on ground analogs to support risk mitigation. In FY 2019, HRP completed three 45-day isolation study campaigns using the Human Exploration Research Analog (HERA) facility located at Johnson Space Center (JSC). Each HERA campaign uses crews of four supported by a mission control team and includes a portfolio of research and operational tests to be conducted during the simulated exploration mission. Additionally, HRP completed long-duration isolation and confinement studies at the Nezemnyy Eksperimental'nyy Kompleks (NEK) facility in Moscow, Russia, in collaboration with the Russian Institute for Biomedical Problems. In the Scientific International Research in Unique Terrestrial Station (SIRIUS) 19 mission, crew members conducted experiments on behalf of nearly 80 different researchers from around the world, including seven studies funded by HRP. HRP also undertook joint NASA/NSF Antarctic analog studies to support behavioral health and performance research. During the 2019 Antarctic winter-over campaign, HRP completed two research studies focused on crew composition and teamwork using U.S. Antarctic program volunteers at the McMurdo and Amundsen-Scott South Pole Stations.

HRP conducted joint NASA/German Aerospace Center (DLR) analog studies to support human health countermeasures, exploration medical, and behavioral health and performance research at the DLR Institute of Aerospace Medicine :envihab facility in Cologne, Germany. The first campaign of the Artificial Gravity Bed Rest with the European Space Agency (AGBRESA) study was completed in FY 2019 following post bed rest Baseline Data Collection. The study involved a total of 12 test subjects, each of whom spent 60 days in strict 6-degree head down tilt bed rest, examining the effects of centrifugation as a potential countermeasure to some of the physiological effects of space flight.

In support of future human exploration missions, HRP research resulted in recommended updates to physiological medical standards to better protect muscle and aerobic capacity and better methods to maintain team function and performance. And finally, HRP continued space radiation research in support of human exploration at the NASA Space Radiation Laboratory using the galactic cosmic ray simulator for a more realistic simulation of the actual radiation environment found in space.

WORK IN PROGRESS IN FY 2020

HRP will continue to work on the highest human health and performance risk areas associated with human space exploration missions. To support this work, HRP will release NASA research solicitations to the national biomedical research community to better address the exploration spaceflight health, performance, and space radiation risks. HRP will also implement a research plan that fully utilizes the ISS biomedical research capabilities to test mitigation approaches and validate countermeasures; collaborate with CHS on ISS studies related to visual impairment, carbon dioxide analysis, exercise systems, and cognitive function measures; and leverage resources and expertise through collaborative research with other NASA programs, international partners, and other U.S. agencies (e.g., DoD, DOE, NSF, HHS, NIH).

HRP will implement an ISS research plan that fully utilizes the ISS biomedical research capabilities to test mitigation approaches and validate countermeasures including the following: 1) additional One-Year Missions; 2) ISS as an exploration analog to assess impacts of crew isolation; 3) the advanced food technology study to assess long term stowage quality in space; 4) testing and validation of the Advanced Twin Lifting and Aerobic System (ATLAS) deep space exercise device as part of the exploration system maturation project.

In support of exploration medical capability, HRP will continue to develop the medical data architecture, which is a prototype system to comprehensively manage and process medically-relevant information to support exploration medical operations. HRP is also collaborating with the Canadian Space Agency to integrate its novel Astroskin biosensor, a wearable vest that collects biometric information such as heart and breathing rates, into the prototype medical system.

HRP and ESA will implement a second AGBRESA study to assess the use of artificial gravity as a human physiology countermeasure using the DLR :envihab facility. During the new campaign, the subjects will be assigned to one of three groups: 1) will experience centrifugation for 30 continuous minutes each day; 2) will experience centrifugation in six bouts of five minutes each, with a five-minute rest between bouts; and 3) will serve as a control and will not experience centrifugation. Investigators will compare subjects with head down bedrest alone to subjects experiencing head down bedrest with continuous or intermittent artificial gravity on aspects such as ocular and carbon dioxide measures, cerebral autoregulation, cognition, neuroimaging, structural and functional Magnetic Resonance Imaging (MRI), and functional balance and vestibular tests.

In understanding the behavioral health challenges associated with isolation and confinement, HRP will continue implementing a collaborative NASA/NSF human health and performance study on the effects of remote location, extreme isolation, and confinement during winter-over missions in Antarctica using the NSF polar station. HRP will also undertake a mission on long-duration isolation and confinement studies in collaboration with Russia, including the SIRIUS-20 eight-month mission, and it will continue the 45-day HERA studies at JSC.

In support of Gateway development and future missions, HRP will continue work with NASA’s Deep Space Exploration Habitation development to define and evaluate exploration habitats, support Gateway Crew Health and Performance System requirements definition, deliver habitat standards and evaluation tools, and deliver food system requirements and nutritional recommendations for the exploration Gateway food system. Additionally, HRP continues to work on defining test objectives for the Gateway missions, providing final recommendations on food mass reduction for Orion missions and defining lunar surface research opportunities.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

HRP will implement an ISS flight research plan critical to mitigating crew health and performance risks for Artemis missions that includes the following: ISS Standard Measures Project to capture a core set of physiological and performance measures from crew members to accurately characterize the adaptive responses to long-duration spaceflight and monitor the effectiveness of countermeasures; a microbial risk assessment study to ensure crew safety and allow increased dependence on bioregenerative food systems; and a study on detecting individual performance susceptibilities to sleep loss and circadian desynchronization to optimize individualized countermeasures during spaceflight. HRP also plans to implement an ISS one-year mission to assess temporal effects in health and performance risks beyond six-month missions and validate exploration countermeasures that will be used on future planetary missions.

HRP will leverage resources through multiple research partnerships including advanced food and nutrition studies with DOD, behavioral studies during winter over campaign at NSF polar facilities, isolation and confinement studies with Russia and ESA, bed rest studies at the DLR :envihab facility, and develop joint flight research and data sharing with international partners.

Finally, in support of Artemis missions, HRP will develop space habitat standards and evaluation tools for use in designing and evaluating spacecraft volume and layout to optimize crew performance and develop research and technical flight objectives for Gateway and lunar surface missions.

Program Elements

EXPLORATION MEDICAL CAPABILITY

As NASA makes plans to extend human exploration beyond LEO, identifying and testing next generation medical care and crew health maintenance technologies is vital. Health care options evolve based on experience, anticipated needs, and input from flight surgeons and crew offices. Crews will not be able to rely on real-time conversations with Earth-based medical experts in the future due to communication lag-time associated with the distance between Earth and deep space. Therefore, crew and relevant systems must be able to facilitate autonomous medical care operations. Teams in this area draft requirements for medical equipment and clinical care, develop remote medical technologies, and assess medical requirements unique to long-duration space missions.

HUMAN HEALTH COUNTERMEASURES

Countermeasures are the procedures, medications, devices, and other strategies that offset the impacts of spaceflight stressors (e.g., low gravity, closed environment) and help keep astronauts healthy and productive during space travel and after their return to Earth. Researchers provide biomedical expertise; they are responsible for understanding the normal physiologic effects of spaceflight and developing countermeasures to those with harmful effects on human health and performance. These experts define health and medical standards, validate human health prescriptions and exercise system requirements, develop injury and sickness prevention standards, integrate and validate physiological countermeasures, and establish criteria for NASA fitness for duty, as well as crew selection and performance standards.

HUMAN RESEARCH PROGRAM

HUMAN FACTORS AND BEHAVIORAL PERFORMANCE

Just as the space environment poses physical risks to crewmembers, the unique stresses and challenges of spaceflight, as well as the vehicle design, can affect cognitive and mental performance. Considering external factors is essential when designing a spacecraft, habitat, or spacesuit. Human factors experts develop new equipment, procedures, and technologies designed to make the space environment more livable. Behavioral health researchers assess the impact of space travel on human behavioral health and develop interventions and countermeasures to ensure optimal health and performance. Experts in this area make extensive use of analogs, which are experimental environments created to simulate certain aspects of space travel. By duplicating space conditions, such as altered day and night cycles, heavy workloads, social isolation, and close living quarters, scientists gain insight into the impact of these circumstances on human behavior and performance. They then work to develop countermeasures, equipment, and other interventions to minimize these risks.

SPACE RADIATION

As NASA expands human presence through the solar system, it is critical that crews can safely live and work in a space radiation environment without exceeding exposure limits. Space radiation researchers develop the knowledge base necessary to determine the biological effects of space radiation. This information can then be used for standards for health and habitability and the requirements for radiation protection. They also develop tools to assess and predict risks due to space radiation exposure and strategies to mitigate exposure effects. The deep space radiation environment is far different from that on Earth or in LEO. NASA and the DOE have partnered on a facility at Brookhaven National Laboratory in New York to simulate the deep space radiation environment, which researchers use to help understand its biological effects.

RESEARCH OPERATIONS AND INTEGRATION

The ISS provides a unique testbed for HRP activities. The medical projects team plans, integrates, and implements approved biomedical flight experiments on the ISS, as well as research studies that use ground-based spaceflight analog facilities to accomplish program objectives. These experiments and studies pertain to pre- and post-flight activities, and the program objectives include coordinating flight or ground resources with our international partners, maintaining ISS biomedical research racks and flight hardware, and developing crew training for both flight and ground investigations. Teams also operate a Telescience Support Center, which provides real-time support and data services to all HRP flight experiments. Strong interfaces with external implementing organizations, such as the ISS payloads office, analog coordination offices, and international partners, are critical to maintaining a robust research program. This group is also responsible for operating the HERA analog facility and for arranging access to other analog facilities required by HRP researchers, including NSF Antarctic facilities, other national isolation analogs, and international partner facilities in Germany and Russia.

Program Schedule

Date	Significant Event
Jan 2020	Conduct 2020 HRP Investigators' Workshop
May 2020	2019 Human Exploration Research Opportunity (HERO) NASA Research Announcement Selections
Aug 2020	Release 2020 Human Exploration Research Opportunity (HERO) NASA Research Announcement
Sep 2020	Deliver Evaluation Tools for Spaceflight Habitats
Sep 2020	Deliver Validation of Bedrest as an Analog for Spaceflight Associated Neuro-ocular Syndrome (SANS)
Sep 2020	Deliver Gateway Crew Health and Performance (CHP) Con Ops (Level 4) - Recommendation
Oct 2020	Deliver Version 2020 Multi-model Ensemble Risk Assessment (MERA) Anchor Model

Program Management & Commitments

The program office is located at JSC with support from Ames Research Center (ARC), Glenn Research Center (GRC), Langley Research Center (LaRC), and Kennedy Space Center (KSC).

The Human Exploration and Operations Mission Directorate (HEOMD) Associate Administrator delegated the authority, responsibility, and accountability of HRP management to the Space Life and Physical Sciences Research and Applications (SLPSRA) Division at NASA Headquarters. Working closely with the Office of the Chief Scientist and the OCHMO, the SLPSRA Division establishes the overall direction, scope, budget, and resource allocation for the program, which the NASA centers then implement.

Program Element	Provider
Exploration Medical Capability	Provider: JSC Lead Center: JSC Performing Center(s): GRC, ARC, and LaRC Cost Share Partner(s): N/A
Human Health Countermeasures	Provider: JSC Lead Center: JSC Performing Center(s): ARC and GRC Cost Share Partner(s): N/A
Human Factors and Behavioral Performance	Provider: JSC Lead Center: JSC Performing Center(s): ARC, GRC, and KSC Cost Share Partner(s): N/A

HUMAN RESEARCH PROGRAM

Program Element	Provider
Space Radiation	Provider: JSC Lead Center: JSC Performing Center(s): LaRC Cost Share Partner(s): N/A
Research Operations and Integration	Provider: JSC Lead Center: JSC Performing Center(s): ARC and KSC Cost Share Partner(s): N/A

Acquisition Strategy

Based upon National Academies' recommendations, external peer reviews, and Agency human exploration plans, NASA HRP awards contracts and grants to further efforts in mitigating risks to crew health and performance by providing essential biomedical research and technologies for human space exploration. HRP uses a peer review process that engages leading members of the research community to competitively assess the merits of submitted proposals to assure a high-quality research program.

HRP plans to release the HERO umbrella NASA Research Announcement (NRA) that will request research proposals across all its research elements throughout the year. This NRA provides opportunities for universities, other Government agencies, and industry researchers from across the nation to develop high NASA priority ground and spaceflight experiments which directly contribute to NASA's exploration mission.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Program Management	Translational Research Institute for Space Health	Baylor College of Medicine

HUMAN RESEARCH PROGRAM

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	National Academies	Dec 2017	Review of NASA research on human health risks	Informed program research prioritization	Dec 2020
Quality	Peer Review Panel	Jan 2019	Peer review of NRA	Selected grantees	Jan 2020
Quality	National Council on Radiation Protection and Measurements (NCRP)	Feb 2019	Review of space radiation health risks	Established research priorities for space radiation research	TBD
Quality	Independent Program Assessment	Jun 2019	Review of program management policies and practices	Verify adherence to NASA program management policies	Jun 2022

EXPLORATION TECHNOLOGY

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Early Stage Innovation and Partnerships	101.7	--	**169.2**	179.2	196.2	196.2	196.2
Technology Maturation	201.2	--	**469.1**	551.5	654.1	748.4	835.8
Technology Demonstration	416.8	--	**537.2**	556.0	513.4	464.8	525.1
SBIR and STTR	207.2	--	**402.8**	478.7	542.6	544.8	481.1
Total Budget	**926.9**	**1100.0**	**1578.3**	**1765.4**	**1906.2**	**1954.2**	**2038.2**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Pursuant to P.L. 115-10 Title VII Sec 702(e), this budget is formulated in such a manner to avoid duplication of projects, programs, or missions conducted by other projects, programs, or missions conducted by another office or directorate of the Administration.

EXPLORATION TECHNOLOGY

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Early Stage Innovation and Partnerships	101.7	--	**169.2**	179.2	196.2	196.2	196.2
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Total Budget	**926.9**	**1100.0**	**1578.3**	**1765.4**	**1906.2**	**1954.2**	**2038.2**
Change from FY 2020			**478.3**				
Percentage change from FY 2020			**43.5%**				

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Pursuant to P.L. 115-10 Title VII Sec 702(e), this budget is formulated in such a manner to avoid duplication of projects, programs, or missions conducted by other projects, programs, or missions conducted by another office or directorate of the Administration.

To enable In-Situ Resources Utilization, the Polar Resources Ice Mining Experiment project will deliver water-enriched lunar regolith for identification and quantification of water during an experiment on an early Commercial Lunar Payload Services (CLPS) lander. The Regolith and Ice Drill for Exploring New Terrain are shown above.

The Space Technology Mission Directorate (STMD) serves as a catalyst for the new technology required to “lead the return of humans to the Moon for long-term exploration and utilization” (Space Policy Directive-1). The Exploration Technology account funds this critical technology research and development to support the 2024 lunar landing and the long-term success of the Artemis Moon to Mars campaign. Through STMD, NASA is enabling technology research and development needs for human space exploration with a near-term prioritization of sustainable lunar exploration and an eye toward Mars in the long-term, while spurring critical technologies that enable future science exploration goals and commercial endeavors. STMD accomplishes this mission by funding critical technology along the entire Technology Readiness Level spectrum and keeping NASA’s space technology pipeline growing with emerging, innovative technologies that meet NASA exploration needs and support commercial expansion of space. In direct alignment to Artemis and NASA mission needs, STMD investment decisions are driven by the following Technology Thrusts and desired outcomes:

- **Go:** Rapid, safe, and efficient space transportation, emphasizing reusable in-space transportation between Earth and the Moon, Mars, and beyond.
- **Land:** Expanded access to diverse surface destinations, routinely landing crew and cargo on the Moon and eventually Mars; and safely and efficiently returning large payloads to Earth; delivering robotic payloads to new, challenging destinations.
- **Live:** Sustainably living and working farther from Earth, routinely conducting crewed operations beyond low-Earth orbit (LEO); working toward a sustainable human presence on the Moon and eventually Mars; technologies to survive and operate through the lunar night; including production of propellant and consumables from local resources.
- **Explore:** Transforming missions and enabling discoveries to reach challenging sites and resources on the Moon, Mars, and beyond; rapid, low-cost missions to the Moon, Mars and beyond.

Within the Exploration Technology account, NASA conducts Lunar Surface Innovation Initiative activities through a combination of in-house activities, competitive programs, and public-private partnerships. This initiative brings together the full range of stakeholders, including entrepreneurs, academia, small businesses, industry and the NASA workforce to catalyze technology development. NASA advances technology readiness of key systems and components to facilitate a sustainable lunar surface presence, with the long-term goal of sending human to Mars. The lunar surface technologies planned for demonstrations over the next five years will lead to more affordable missions that are less dependent on support from Earth. These demonstrations include:

- In-Situ Resource Utilization with an emphasis on collecting, processing, storing, and using material found or manufactured on other astronomical objects;
- Sustainable Surface Power, enabling continuous power throughout the lunar day and night;
- Surface Excavation/Construction to enable affordable, autonomous manufacturing and construction;
- Lunar Dust Mitigation enhancements to mitigate lunar dust hazards; and
- Extreme Environments capabilities to operate through the full range of lunar surface and subsurface conditions.

Beyond the lunar surface, Exploration Technology is funding an array of efforts to accelerate NASA's broader Moon to Mars campaign. For example, the Agency will continue to enable complex spacecraft operations, such as autonomous landing and hazard avoidance, advanced cryogenic fluid management capabilities to enable long term storage of cryogens both in space and on the surface, rapid and efficient transit propulsion, high performance spaceflight computing, and advanced materials and in-space manufacturing and assembly technologies. In addition, Exploration Technology will make strategic Mars surface technology investments critical for future Mars human missions, leveraging the lunar surface technology development.

EXPLORATION TECHNOLOGY

Exploration Technology investments continue to target technologies that benefit both human and robotic exploration, actively engaging with internal NASA stakeholders, industry, academia, and other Federal Government agencies to help define investment content. Through a combination of unique in-house activities, procurements, research announcements, and public-private partnerships, STMD investments develop and test technologies that drive space exploration. Public-private partnerships enable NASA to develop mutually beneficial capabilities with private sector industry and allow for leveraging of private investments. The shared gains include incentivizing technical performance and spurring future commercial markets while developing new capabilities.

U.S. technological leadership remains vital to our national security, economic prosperity, and global competitiveness. The Nation's continued economic leadership is, in part, due to the technological investments made in earlier years and through the work of the engineers, scientists, and policy makers who had the wisdom and foresight to make long-term investments our country required to emerge as a global technological leader. That commitment accelerated the economy with the creation of new industries, products, and services that yielded lasting benefits. A technology-driven NASA will continue to help fuel the Nation’s economic engine for decades to come.

EXPLANATION OF MAJOR CHANGES IN FY 2021

Space Technology Mission Directorate is the name of the organization. Exploration Technology is the budget account funding Space Technology Mission Directorate programmatic content. This budget request includes a new Space Nuclear Technologies portfolio, which integrates NASA's power and propulsion technology research and development efforts.

ACHIEVEMENTS IN FY 2019

NASA delivered several technologies to orbit for flight demonstrations, including:

- **Go:** The Deep Space Atomic Clock launched in late June 2019 aboard the SpaceX Falcon Heavy as a rideshare with the U.S. Air Force's STP-2 mission. This mission is demonstrating a small, low-mass atomic clock based on mercury-ion trap technology, providing unprecedented stability needed for next-generation deep space navigation and radio science. The atomic clock on this mission offers the promise of 50 times greater accuracy than today’s best space navigation clocks. The Deep Space Atomic Clock was successfully activated in August and is in the process of conducting a year-long navigation demonstration that will provide a technology to improve accuracy of navigation and allow for gravity science measurements. In the coming months, the team will measure how well the clock keeps time down to the nanosecond. The results will contribute to the further improvement of technology that will help astronauts safely navigate themselves to other worlds.

- **Go:** NASA's Green Propellant Infusion Mission launched in late June 2019 aboard the SpaceX Falcon Heavy as a rideshare with the U.S. Air Force's STP-2 mission. The mission is demonstrating a propulsion system using a significantly less toxic propellant than hydrazine while providing 40 percent higher performance by volume. With a successful launch and on-orbit check-out of the Green Propellant Infusion Mission, the project will continue testing the “green” fuel and propulsion system by performing three lowering burns that place the spacecraft in a different orbit. Once proven in orbit, this technology could lower the cost of fueling spacecraft before launch and provide efficient propulsion solutions for small and large satellites. Upon completion of the demonstration, the propulsion system will be available as a commercial off-the-shelf product.

- **Go:** The CubeSat Handling of Multisystem Precision Time Transfer mission launched via Rocket Lab in December 2018 to demonstrate a precision timing satellite equipped with atomic clocks synchronized with a ground clock through laser pulse.

- **Go/Land:** Flight Opportunities flew 43 technology development payloads across four suborbital launch vehicle flights, one vertical takeoff/lander flight, six high-altitude balloon flights, and one parabolic campaign.

- **Live:** Launched bionutrients flight demonstration hardware to the International Space Station (ISS) to begin a five-year investigation of the long-term stability of a nutrient production system in space.

- **Explore:** Astrobee completed ground testing and delivered three flight units to the ISS in April. Astrobee will replace the Synchronized Position Hold, Engage, Reorient, Experimental Satellites, which was NASA’s first generation free-flying robot aboard the ISS. The intent is for robots like Astrobee to one day take on research, housekeeping, and monitoring duties without requiring astronaut supervision. In early October 2019, as part of its on-orbit commissioning, Astrobee completed its first autonomous flight, successfully undocking itself, following the flight plan delivered from the ground control team, and returning itself to the docking station. Astrobee is continuing its commissioning activities in FY 2020.

NASA completed major deliverables for the following Exploration Technology funded activities:

- **Land/Live:** All four Mars 2020 technology instruments- Terrain Relative Navigation, Mars Oxygen In-Situ Resources Utilization Experiment, Mars Environmental Dynamics Analyzer, and Mars Entry, Descent and Landing Instrumentation-2- completed hardware build and testing and were delivered between fall 2018 and spring 2019 to Mars 2020 mission integration to support a July 2020 launch schedule.

- **Go:** Aerojet Rocketdyne completed the build of engineering test unit components for Solar Electric Propulsion (SEP) and began initial functional and acceptance testing that will support the final design.

- **Go:** Continued testing nuclear thermal propulsion fuel forms for low and moderate temperature thermo-chemical stability, evaluated fuel element design, and complete feasibility assessment. In addition, NASA initiated studies in collaboration with several Government agencies and industry partners to develop candidate nuclear thermal propulsion flight demonstration concepts. The final engine requirements document was submitted in June 2019, and the System Feasibility Analysis was completed in September 2019. Such investments will help inform potential future nuclear propulsion efforts.

- **Land:** Through a Space Technology Research Grant, Jordan French from the University of Utah developed a new method of high-resolution, 3D imaging of biaxially stressed specimens during load testing. Insight into materials behavior when under load is of great interest to NASA. His device has already been used to test Mars entry and descent parachute material and revealed significant fiber straightening under load, resulting in increased confidence in Mars entry and descent design parameters. His methods will significantly advance the state-of-the-art by elucidating the progressive damage mechanisms associated with the failure of a variety of materials under biaxial loading conditions. This research has the potential to lead to improved materials for future NASA missions as well as numerous terrestrial applications.

- **Land:** Masten Space Systems successfully demonstrated the use of a commercial version of the Mars 2020 Terrain Relative Navigation system.

- **Live:** After 30 hours of autonomous 3D printing over four days of head-to-head competition, NASA and partner Bradley University of Peoria, IL, awarded $700,000 to two teams in the final round of the 3D-Printed Habitat Challenge. The top prize of $500,000 was awarded to New York-based AI SpaceFactory. The second-place prize of $200,000 was awarded to Pennsylvania State University, University Park, PA.

WORK IN PROGRESS IN FY 2020

- **Explore:** In the first year of the Lunar Surface Innovation Initiative, NASA kicked off the Polar Resources Ice Mining Experiment project by down-selecting a drill targeted for lunar surface demonstration. This project will complete Critical Design Review by mid-2020. In addition, NASA will perform swarm autonomous operations of three Autonomous Pop-Up Flat Folding Explorer Robot (PUFFER) robots navigating and exploring as a team on extreme terrain. Further, NASA will develop mission concepts to enlist these versatile robotic platforms for supporting Exploration and Science for reconnaissance of In-Situ Resource Utilization resources.

- **Go:** In FY 2020, Aerojet Rocketdyne will complete SEP integration and test of the engineering test units to ensure the final design meets performance requirements.

- **Go:** Development hot-fire testing of two 150-pound-force (lbf) thrusters and two 10-lbf thrusters designed for low temperature operation in space is scheduled to be completed in 2020. The Thruster Advancement for Low-temperature operation in space (TALOS) thrusters are being developed to prove low-cost, lightweight materials for propulsion systems.

- **Land:** Flight Opportunities will see the infusion of key technologies tested on suborbital demonstration flights into NASA and commercial missions, including the terrain relative navigation system for the NASA Mars 2020 lander and the hazard detection and avoidance system for the Astrobotic Peregrine lunar lander. In collaboration with eight commercial partners, NASA continues to develop and demonstrate landing technologies such as Navigation Doppler and Hazard Detection Light Detection and Ranging (LIDAR), and provide access to testing facilities and associated computational capabilities.

- **Land:** After completing inflation and vibration testing of a six-meter engineering design unit in fall 2019, NASA, in partnership with United Launch Alliance, will fabricate a flight-ready, inflatable aerodynamic decelerator technology for a 2022 flight test in the Earth's atmosphere to determine the feasibility of this technology in supporting high-mass entry descent and landing.

- **Explore:** NASA is conducting the second phase of the Space Robotics competition, which seeks to advance robotic software and autonomous capabilities for space exploration missions on the surface of extraterrestrial objects, such as distant planets or moons. This challenge will require competitors to develop software that allows a virtual team of robotic systems (i.e., virtual robotic team) to operate autonomously to successfully achieve these tasks.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

- **Explore:** NASA will deliver, integrate, and perform final system testing of the Laser Communications Relay Demonstration spacecraft in preparation for launch (no earlier than January 2021), and it will deliver the Deep Space Optical Communications to the Psyche spacecraft leading up to a launch in 2022.

- **Live:** Polar Resources Ice Mining Experiment project will complete The Regolith and Ice Drill for Exploring New Terrain (TRIDENT) drill for demonstration on a Commercial Lunar Payload Services lander.

- **Go:** Small Spacecraft will deliver spacecraft for three precursor CubeSat demonstrations between FY 2020 and FY 2021, including Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment and Lunar Flashlight.

- **Live:** NASA is proceeding with a lunar surface power system development as the first foundational project of its new Space Nuclear Technologies portfolio. In addition, we will complete autonomously operated prototype Regenerative Fuel Cell technology for a long duration ground test demonstration. This technology will provide sustained and reliable electrical power for surface and near-surface missions where photovoltaic, battery or nuclear options are not feasible and will provide the capability to survive the Lunar night (14 days).

- **Land/Explore:** Mars Entry Descent and Landing Instrumentation 2 (MEDLI-2) experiment will occur in February 2021 during the Mars 2020 Mission entry into the Martian atmosphere. Post-landing and transmission of data, the MEDLI -2 researchers will begin comparisons between analytical models and experimental data. Through these experiments, NASA will reduce landing ellipse uncertainties to improve landing accuracies and improve thermal protection system designs for future robotic and manned Mars missions. The Mars Oxygen In-Situ Resources Utilization Experiment and Mars Environmental Dynamics Analyzer will begin conducting experiments after the mission completes its surface operations transition period.

- **Live:** Prizes and Challenges will launch competitions to address lunar power requirements as well as lunar excavation, manufacturing, construction to support in-situ resource utilization application. Additionally, NASA will host a competition to support nutrition needs of astronauts on the lunar surface, an essential aspect of sustainable human presence on the Moon.

- **Go:** The Rapid Analysis and Manufacturing Propulsion Technology (RAMPT) project is maturing novel design and manufacturing technologies to increase scale, significantly reduce cost, and improve performance for regeneratively cooled thrust-chamber assemblies, specifically the combustion chamber and nozzle for Government and industry programs. This project will conduct a hot fire test of a large-scale composite overwrapped Thrust Chamber Assembly (TCA) with a directed energy depositioned (additive manufactured) nozzle. This development will address the longest lead, highest cost, and heaviest component in the rocket propulsion engine system.

NASA will continue to partner with researchers across academia and industry and explore transformative technologies and approaches. Upcoming Early Stage Innovation portfolio activities will investigate areas such as breakthrough propulsion, challenges in deep space human habitation, space-optimized energy systems, radiation protection, and advanced materials. These areas are part of a comprehensive approach to efficiently support innovative discovery, progress toward important goals, and the development of transformative new capabilities.

Programs

EARLY STAGE INNOVATION AND PARTNERSHIPS

This program funds early stage research and development sourced from academia, industry, entrepreneurs, and from the NASA workforce to generate pioneering approaches to the Agency's difficult and far reaching exploration challenges. NASA sustains these Early Stage investments at seven to eight percent of the overall Exploration Technology budget. This account supports several Agency integration functions, including technology transfer and technology commercialization activities, extending the benefits of NASA's technology investments so they have a direct, measurable, and tangible impact. It also supports the Agency's Prizes and Challenges activities (including Centennial Challenges). By leveraging industry for technology development that could aid NASA's missions, this approach ensures that NASA technologies energize the commercial space sector and provide the greatest benefit to the U.S.

TECHNOLOGY MATURATION

Within Technology Maturation, NASA focuses on advancing disruptive space technologies from a proof of concept to demonstration, maturing transformational technologies across the critical gap that resides between early stage concepts and flight demonstration. Technologies are prioritized for alignment with NASA's Exploration Campaign objectives, including sustainable surface technologies through the Lunar Surface Innovation Initiative. In addition, Technology Maturation includes strategic Mars surface technology investments that are critical for future human missions to Mars.

TECHNOLOGY DEMONSTRATION

The Technology Demonstration portfolio supports ground-based testing to determine feasibility and technology flight demonstrations in relevant environments to effectively transition technologies for NASA missions and for use by other Government agencies and industry. Ground and flight demonstrations are prioritized to enhance and enable the Moon to Mars exploration campaign. This account includes development of Small Spacecraft technologies and demonstration missions, including the Space Nuclear Technologies portfolio, and facilitates access to relevant flight demonstration environments through the Flight Opportunities suborbital flight demonstration platforms.

SMALL BUSINESS INNOVATION RESEARCH (SBIR) AND SMALL BUSINESS TECHNOLOGY TRANSFER (STTR)

Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) continues to support early-stage research and mid-Technology Readiness Level (TRL) development, performed by small businesses through competitively awarded contracts. These programs produce innovations for both Government and commercial applications. SBIR and STTR provide the high-technology small business sector with opportunities to develop space technology for NASA and commercialize those NASA-funded technologies that have the potential to address national needs in the aerospace industry and other sectors. Annual solicitations maintain commitment to an integrated Agency-wide SBIR/STTR program that supports both commercial interests and NASA missions with added emphasis on the Moon to Mars exploration campaign.

EARLY STAGE INNOVATION AND PARTNERSHIPS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Agency Technology and Innovation	8.8	--	**9.4**	9.4	9.4	9.4	9.4
Early Stage Innovation	66.5	--	**123.4**	133.4	150.4	150.4	150.4
Partnerships and Technology Transfer	26.4	--	**36.4**	36.4	36.4	36.4	36.4
Total Budget	**101.7**	**--**	**169.2**	**179.2**	**196.2**	**196.2**	**196.2**

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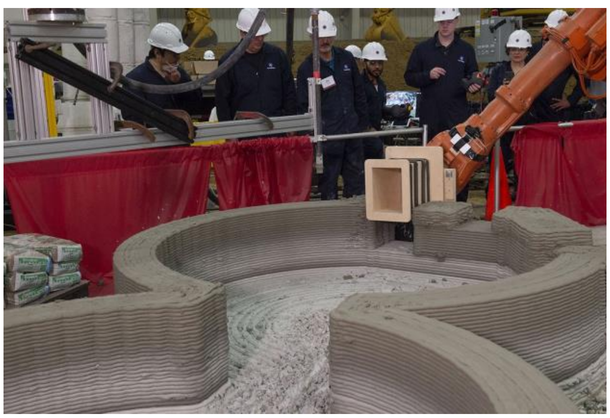
The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.



After 30 hours of 3D printing over four days of head-to-head competition, NASA and partner Bradley University of Peoria, Illinois, awarded $700,000 to two teams in the final round of the 3D-Printed Habitat Challenge, pictured above. The top prize of $500,000 was awarded to New York-based AI SpaceFactory. The second-place prize of $200,000 was awarded to Pennsylvania State University of University Park.

Early Stage Innovations and Partnerships spur collaboration with innovators across the Nation to capitalize on the ideas, talent, and experience of a diverse set of contributors to achieve NASA's Artemis Moon to Mars exploration campaign objectives.

Early Stage Innovation supports concept studies, applied research, and early technology development to spur innovation and transform future capabilities. Emphasis will be placed on identifying emerging concepts and technologies that support long range Lunar and Mars surface requirements. By leveraging the technical capabilities of the experts across the nation from academia, industry, entrepreneurs, and its own Centers, the Agency gains new ideas and alternative approaches to solving NASA’s difficult and far reaching exploration challenges.

Within Partnerships and Technology Transfers, NASA funds prize competitions and challenges as well as citizen science and other open innovation tools as appropriate to support NASA’s R&D objectives and to enhance the Agency’s connections with the American and global public. Such programs include the Centennial Challenges, the NASA Tournament Lab, NASA Solve, and iTech, each of which leverages high public interest to support NASA's Exploration objectives. NASA responds to Administration priorities and legislative requirements to promote technology transfer, including commercialization of technologies that emerge from NASA’s research and development activities to support commercial expansion in space.

EARLY STAGE INNOVATION AND PARTNERSHIPS

Agency Technology and Innovation funds the operations of the Office of the Chief Technologist (OCT), which manages Agency technology strategy and promotes innovative culture and partnerships within and outside of NASA.

EXPLANATION OF MAJOR CHANGES IN FY 2021

No Major Changes

ACHIEVEMENTS IN FY 2019

Agency Technology and Innovation:

- The Office of the Chief Technologist redefined the Agency's space technology taxonomy and Strategic Technology Integration Framework, which are now being used to inform the next NASA Strategic Technology Investment Plan and future technology roadmaps. The Office also coordinated inputs to the Strategic Technology Integration Framework from the Mission Directorates. The Office continues to foster NASA's culture of innovation across the Agency, hosting workshops and facilitating innovation seedling challenges (e.g., NASA@Work challenge on Surviving the Lunar Night, which engages the NASA workforce to crowdsource new technical solutions). With the Office of the Chief Information Officer, the Office co-chaired a study on NASA's digital transformation efforts, the results of which are being used to develop the Agency's digital transformation roadmaps.

Early Stage Innovation:

- In addition to issuing the annual solicitations for NASA Innovative Advanced Concepts (NIAC), Space Technology Research Grants, and the Center Innovation Fund, NASA selected two research institutes led by Purdue University and the University of California, Davis, focused on deep space habitat autonomous operations to lay the technological groundwork that enhances and enables deep space exploration.

- The Center for Utilization of Biological Engineering in Space (CUBES), led by the University of California, Berkeley, successfully demonstrated production methods for a recombinant protein using lettuce plants which can be grown in-situ on a potential Mars mission. The team successfully grew parathyroid hormone , a bone regenerative therapeutic that may prove essential in maintaining bone health during prolonged periods of reduced gravity. The technique is applicable to manufacturing other high value compounds, including medicines which have inadequate shelf life to support multi-year interplanetary missions.

- The Institute for Ultra-Strong Composites by Computational Design (US-COMP), led by Michigan Technological University, found that carbon nanotube composites (CNT) that exhibit higher strength contain assemblies of highly aligned and densified CNT bundles comprised of collapsed, flattened CNTs; these results were later confirmed by modeling. The team is now producing and testing composite materials based on work with industry partners, and early results show significant progress toward US-COMP's goal of developing carbon fiber composite materials with performance-to-weight ratios of at least 2-3 times better than current state-of-the-art.

EARLY STAGE INNOVATION AND PARTNERSHIPS

Partnerships & Technology Transfer:

- Centennial Challenges concluded the third phase of its 3D-Printed Habitat Challenge in May 2019 at a Caterpillar facility in Peoria, IL. The teams demonstrated technologies necessary to additively manufacture an off-world habitat. AI Space Factory of New York took the first-place prize of $500,000, and a team from Penn State took $200,000 for finishing in second place. The challenge awarded $2.06 million over the three phases of competition.

- The NASA Tournament Lab shepherded the development and implementation of the NASA Earth and Space Air Prize. The Robert Wood Johnson Foundation partnered with NASA on this challenge to advance the development of high-accuracy, low-maintenance aerosol sensor technologies useful in human space flight as well as on Earth. The Foundation provided $150,000 in prize funding for the top three applicants to prototype their proposed solutions as well as $200,000 in funding for administration of the prize. NASA awarded the $100,000 grand prize to Applied Particle Technology, LLC from St. Louis, MO.

- To standardize and streamline routine processes, simplify and improve customer interactions, and increase security, Technology Transfer initiated an effort to reorganize key functions at a centralized NASA field office rather than spread across the Agency. As part of this effort, NASA selected three Centers to provide integrated functions for all Centers in support of contract and grant closeout (Glenn Research Center), Software Usage Agreements (Stennis Space Center), and commercial assessments of intellectual property (Marshall Space Flight Center).

- NASA's Technology Transfer System (NTTS) is an enterprise software tool developed in-house over the last decade to manage the workflow of capturing, maintaining, and transferring new technologies and software. NASA and the Air Force Research Laboratory (AFRL) entered into a reimbursable agreement to provide the U.S. Air Force with a customized NTTS platform and data system.

WORK IN PROGRESS IN FY 2020

Agency Technology and Innovation:

- The Office of the Chief Technologist is demonstrating the effectiveness of the Strategic Technology Integration Framework, working with directorates to incorporate mission data into models for analysis, and will execute collaborative innovation experiments at each NASA Center and across the Agency. The Office of the Chief Technologist, in partnership with the Office of the Chief Information Officer, is continuing with the development of roadmaps and implementation of digital transformation focused activities (e.g., early win projects such as Digital Transformation for Model Based Mission Assurance in support of the Gateway program).

Early Stage Innovation:

- NASA Innovative Advanced Concepts awarded its first Phase III studies to complement its portfolio of Phase I and Phase II concepts. Phase III studies will be designed to strategically transition the most promising NIAC concepts to other NASA programs, other Government agencies, or commercial partners. William Whittaker of Carnegie Melon University was selected to continue work on Robotic Technologies Enabling the Exploration of Lunar Pits, and Joel

EARLY STAGE INNOVATION AND PARTNERSHIPS

Sercel of TransAstra Corporation will continue developing his Mini Bee Prototype to Demonstrate the Apis Mission Architecture and Optical Mining Technology.

- Space Technology Research Grants will add a Lunar Surface Innovation Initiative Research Opportunity to create an avenue for university researchers to contribute directly to NASA's Lunar Surface Innovation Initiative Objectives.

- Seven new Early Career Initiative awards were initiated during fall 2019, with NASA Centers partnering with industry and/or academia to rapidly develop technologies supporting Artemis. In addition, a Kennedy Space Center recycling technology designed to turn trash into water and gases like hydrogen, carbon monoxide, carbon dioxide, and methane was demonstrated on a Blue Origin New Shepard flight. These projects provide NASA's early career employees with direct, hands-on leadership experience, including applying innovative project management techniques with public-private partnerships.

Partnerships & Technology Transfer:

- Centennial Challenges is formulating and developing three new challenges focused on human lunar exploration needs, including excavation, manufacturing, and construction; power; and astronaut nutrition.

- NASA Technology Transfer will continue to consolidate key areas, which will enable the team to leverage Agency-level campaigns to increase web traffic, expand awareness, and develop new leads and licenses with the specific goal of promoting different areas of intellectual property available for licensing.

- NASA Technology Transfer, partnering with FedTech, will bring teams of entrepreneurs together to conduct commercial assessments of select NASA technologies, leading to the creation of new companies using NASA technologies. Additionally, the NASA Entrepreneurial Workforce Initiative introduces NASA innovators to entrepreneurial-focused thinking to maximize the commercial potential of their inventions.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

Agency Technology and Innovation:

- The Office of the Chief Technologist will continue to serve as the innovation champion at the Agency and will oversee innovation experiments to foster a culture of innovation at NASA. The Office will develop a report to Agency leadership on the state of the Agency's innovation culture, measuring the progress made since the 2018 National Academies Workshop on NASA's Innovation Ecosystem. OCT will evaluate and modify the Agency's Innovation Portal in support of Agency priority missions.

- The Strategic Technology Integration Framework will be incorporated into Agency reporting on the state of NASA's technology portfolio of investments and inform Agency leadership on potential technology gaps.

EARLY STAGE INNOVATION AND PARTNERSHIPS

Early Stage Innovation:

- NASA will continue to partner with researchers across academia and industry and explore transformative technologies and approaches. Upcoming Early Stage Innovation activities will investigate areas such as breakthrough propulsion, challenges in deep space human habitation, space-optimized energy systems, radiation protection, and advanced materials. These areas are part of a comprehensive approach to efficiently support innovative discovery, progress toward important goals, and the development of transformative new capabilities.

Partnerships & Technology Transfer:

- In collaboration with a variety of university, private industry, and public partners, Centennial Challenges will be running three new challenges focused on human lunar exploration needs. The Space Robotics Phase 2 "competition round," the second level of the challenge following the qualification round, will take place in FY 2021, and winners will be announced in October 2021.

- Technology Transfer will continue to streamline and automate internal processes to increase ability to conduct outreach to industry. With an increase in small business awards and partnerships with the commercial space industry in support of the Artemis campaign, it is essential that the NASA technology process for submitting New Technology Reports (NTRs) is streamlined and user-friendly. Technology Transfer will track, protect, and transfer technologies developed throughout the Artemis program.

Program Elements

AGENCY TECHNOLOGY AND INNOVATION

Agency Technology and Innovation funds the operations of the Office of the Chief Technologist and Agency activities for promoting innovative culture and partnerships within and outside of NASA, including with industry and commercial partners.

The NASA Chief Technologist serves as the Agency's principal advisor and advocate on matters concerning Agency-wide technology policy to internal and external stakeholders. The office also communicates and helps strategically integrate technology efforts within the Agency. The office conducts an annual review and assessment of technology investments across NASA, including the mission-focused investments made by the Agency's mission directorates, performing strategic technology integration. The organization also assesses and communicates the societal and economic impact of technology investments at NASA and outside the Agency.

The Office of the Chief Technologist hosts several technical interchange meetings in support of NASA's participation in the interagency Science and Technology (S&T) Partnership Forum activity, an ongoing activity that brings leaders in Government aerospace, defense, and national security communities together to better coordinate Federal investments and activities based on mutual critical needs and future plans. Technical interchange meetings this year have included topics such as Trusted Autonomy of Space Systems and Cybersecurity. These exchanges are working to leverage synergies and influence portfolios through partnerships that reduce duplication of effort and investment across Government while advancing the technology readiness levels of technology applications that will benefit Agency missions.

The Office of the Chief Technologist is also implementing a new Technology Strategic Integration Framework to more efficiently identify and connect technology investments to needs across the Agency. This initiative will help NASA achieve its aeronautics, science, and human exploration missions, including Artemis and future deep space exploration. These efforts will better inform future versions of NASA's Strategic Technology Investment Plan.

The Office of the Chief Technologist is working closely with stakeholders to develop strategies to expand NASA’s innovation ecosystem and develop an innovation framework. Recent innovation experiments include working with mission personnel to develop challenges to promote multi-center "co-opetition," providing the benefits of both collaboration and competition. Specific workforce innovation challenges have included Surviving the Lunar Night, Improving Rocket Engine Testing, and More Efficient Budgeting and Analytics. Lessons learned from innovation experiments will be communicated using the Agency-wide innovation portal, a Web-based platform which is in test phase.

For more information, go to: http://www.nasa.gov/oct

EARLY STAGE INNOVATION

It is not always clear which efforts will result in breakthroughs, effective improvements, or exciting new approaches. The technology innovation process is nonlinear and takes time. Therefore, a balance of early stage, mid-Technology Readiness Level (TRL), and technology demonstration investment is critical for an effective technology development portfolio.

NASA's Early Stage Innovation activities employ various approaches to engage subject matter experts at universities, companies, independent labs, NASA Centers, and other Government agencies. Through a steady cadence of competitive solicitations, NASA continuously develops new and innovative high-risk/high-payoff technologies. Early Stage studies cultivate new ideas and alternative approaches and leverage the technical capabilities of the experts across the nation that can fuel economic growth. Technologies are often developed with support and coordination among NASA and various external partners and primarily focus on innovative ways to further humankind’s exploration from conception to testing to spaceflight. NASA awards early stage efforts through Space Technology Research Grants, NASA Innovative Advanced Concepts, the Center Innovation Fund, and the Early Career Initiative, which are described further below:

Space Technology Research Grants

Space Technology Research Grants (STRG) conducts a series of annual and biennial competitive solicitations targeting high-priority technology areas that challenge the entire spectrum of academic researchers, from graduate students to early career and senior faculty members. STRG emphasizes technology areas that can make space activities more effective, affordable, and sustainable. In the process, close collaborations between U.S. universities and NASA are established and nurtured. The NASA Space Technology Graduate Research Opportunities solicitation, formerly called the NASA Space Technology Research Fellowships solicitation, seeks to sponsor graduate researchers who show significant potential to contribute to NASA’s goal of creating innovative new space technologies for our Nation’s exploration, science, and economic future. The topics featured in the Early Career Faculty, Early Stage Innovations, and Space Technology Research Institutes solicitations are of high priority to NASA and the aerospace community in areas where it is anticipated that academia is ideally suited to provide significant innovations. FY 2021 topics will target technologies that enable sustainable exploration of the Moon and Mars including a new Lunar Surface Innovation Initiative Research Opportunity.

Since its inception in FY 2011, Space Technology Research Grants have funded exciting space technology research through 696 grants at 111 universities across 43 states and one U.S. Territory. In FY 2019, NASA made 14 Early Stage Innovations awards, nine Early Career Faculty awards and 65 NASA Space Technology Graduate Research Opportunities awards; there are currently more than 300 active awards, including two new Space Technology Research Institute grants described below:

- The Resilient ExtraTerrestrial Habitats Institute (RETHi) is led by Purdue University with support from the University of Connecticut, Harvard University, the University of Texas, San Antonio, and industry partners Collins Aerospace and ILC Dover. RETHi aims to develop and demonstrate transformative smart autonomous technologies that will adapt, absorb, and rapidly recover from expected and unexpected disruptions to deep space habitat systems without fundamental changes in function or sacrifices in safety.

- The Habitats Optimized for Missions of Exploration (HOME) institute is led by the University of California, Davis with support from the University of Colorado, Boulder, Carnegie Mellon University, Georgia Institute of Technology, Howard University, University of Southern California, and Texas A&M with industry partners Sierra Nevada Corporation, Blue Origin, and Collins Aerospace. HOME will integrate engineering, research, and expertise in systems automation, machine learning, artificial intelligence, predictive analytics, robotics, and crewed spacecraft design to develop new paradigms for the design of deep space habitats.

NASA Innovative Advanced Concepts

NASA Innovative Advanced Concepts (NIAC) executes annual solicitations seeking exciting, unexplored, technically credible new concepts that could one day “change the possible” in space and aeronautics. These efforts improve the Nation’s leadership in key research areas, enable far-term capabilities, and spawn disruptive innovations that make space exploration more effective, affordable, and sustainable. Phase I and continuation Phase II solicitations are open to NASA Centers, other Government agencies, universities, industry, and individual entrepreneurs. NASA implemented Phase III studies to complement its portfolio of Phase I and Phase II concepts for the first time in FY 2019. Phase III studies are designed to continue maturation of Phase II transformative ideas allowing NASA to strategically transition the most promising NIAC concepts to other NASA programs, other Government agencies, or commercial partners. In 2019, NIAC made 12 Phase I, six Phase II, and the first two phase III awards across industry, academia, and NASA Centers, while completing 16 Phase I and seven Phase II studies. NIAC has been a regular source of transformative aerospace concepts, including Professor Chris Walker's pioneering lightweight, low power, steerable antenna systems, which provide big data at significantly lower cost. Dr. Walker developed his technology into a new business, Freefall Aerospace, adding to local economic development, and was awarded the 2019 Governor’s Award as ‘Innovator of the Year, Startup Company.’ His work has further developed into two NASA missions that will launch in the next two years: Galactic/Extragalactic Ultra Long Duration Balloon (ULDB) Spectroscopic Terahertz Observatory (GUSTO), which will launch from McMurdo Base in Antarctica, and a mission on LandSat 9 with a 6u CubeSat using this antenna system. This mission was initially funded by NIAC.

EARLY STAGE INNOVATION AND PARTNERSHIPS

Center Innovation Fund

The Center Innovation Fund (CIF) provides annual seed funding to each NASA Center and NASA's Jet Propulsion Laboratory to stimulate aerospace creativity and grassroots innovation to transform future missions and advance the Nation’s capabilities. CIF activities are competitively selected to explore alternative approaches or develop enhanced capabilities that will feed into NASA's Exploration objectives. Partnerships with academia, private industry, individual innovators, as well as among NASA Centers and Government agencies, are highly encouraged. An integrated review of all Center Innovation Fund candidates is conducted to ensure a strategic and coordinated portfolio. These investments have led to multiple successful NASA and commercial applications. For example, the California Institute of Technology and Ecliptic Enterprises are working to transition a CIF-funded 100GB Radiation Tolerant Solid State Drive (RT-SSD) as part of the Ecliptic Enterprises product portfolio. In addition, CIF projects have led to some well-known applications, such as the Woven Thermal Protection System (Woven TPS) used on Orion.

Early Career Initiative

As an element of the Center Innovation Fund, the Early Career Initiative (ECI) provides the opportunity to develop early career civil servants by allowing them to propose and work on technology projects with industry partners, engage in hands-on technology development opportunities, and learn different approaches to project management. To maximize the effectiveness of the early career projects, each team is mentored by local Center expert(s) as well as NASA's principal technologists. In FY 2020, NASA is targeting technology demonstrations that support lunar surface operations, providing NASA civil servant innovators the opportunity to have their technologies demonstrated on the lunar surface.

PARTNERSHIPS AND TECHNOLOGY TRANSFER

Partnerships and Technology Transfer provides Agency-level management and oversight of NASA-developed and NASA-owned intellectual property and manages transfer of these technologies to external entities. Activities include active collection and assessment of all NASA inventions, strategic management and marketing of intellectual property, negotiation and management of licenses, software release, development of technology transfer-focused partnerships, and the tracking and reporting of metrics related to these activities (e.g. numbers of new inventions, patents, licenses, cooperative research and development agreements, and software use agreements).

NASA's Technology Transfer System (NTTS) platform provides Technology Transfer personnel with tools to facilitate the entire technology transfer process, and it enables NASA to track activities in fine-grained, quantifiable detail.

The new NASA Software Catalog was released in early November 2019. The digital and print catalog serves as a complete inventory of software tools NASA has created during the course of mission work. The catalog also serves as an avenue for industry, academia, other Government agencies, and the public to download and use these software programs.

For more information, go to: https://software.nasa.gov/

EARLY STAGE INNOVATION AND PARTNERSHIPS

Prizes and Challenges (Includes Centennial Challenges)

NASA has recognized the value of incentivizing new technology advancement and problem solving through "open innovation" approaches, including the use of prize competitions and challenges open to the public. Government and non-Government organizations have demonstrated the value of prize competitions for their ability to tap into new sources of talent they have not typically reached. Prize competitions also reduce risk to the buyer because payments only occur after receipt of satisfactory solutions.

NASA utilizes the NASA Tournament Lab to enlist crowdsourcing to tackle challenges faced in its space and aeronautics research and development programs. The NASA Tournament Lab, which is managed by the Center of Excellence for Collaborative Innovation (CoECI), offers a wide variety of open innovation platforms that engage the crowdsourcing community in challenges to create the most innovative, efficient, and optimized solutions. When surveyed, NASA users of these tools have found them useful for meeting their needs in 94 percent of cases. CoECI supports the use of these platforms by other Federal agencies on a reimbursable basis. The NASA Tournament Lab also supports NASA@Work, an internal crowdsourcing and challenge platform designed to improve the ability of NASA employees to connect with others within the Agency to solve technical and non-technical problems.

Centennial Challenges offers incentive prizes to generate revolutionary solutions to support the Moon to Mars exploration campaign and, where appropriate, partners with other organizations to maximize return on investment. NASA is formulating additional challenges to address lunar excavation, manufacturing, and construction as well as lunar power needs. NASA is also developing a competition to support nutrition needs of astronauts on the lunar surface. In FY 2021, NASA plans to formulate new competitions to focus on advancing long-lead technologies for human exploration of the surface of Mars. These competitions will focus on topics such as long-duration environmental control and life support system needs, reduction of logistics mass, construction of high-fidelity outfitted structures on planetary surfaces, and use of in situ atmospheric elements to produce resources needed by astronauts. As such, this FY 2021 budget request includes $8 million in new prize authority (no-year funding) to support these challenges. In addition, active Centennial Challenges in progress include the following:

- Cube Quest Challenge - NASA's first in-space challenge, Cube Quest Challenge aims to advance communication and propulsion technologies for small spacecraft. The next phase of the challenge will start once the CubeSats reach lunar or deep space orbits. Teams will compete for a share of more than $4 million to be awarded to the CubeSats that communicate for the longest period of time with Earth and/or travel the farthest from Earth.

- Vascular Tissue Challenge - The purpose of the challenge is to produce viable thick-tissue assays that can be used to advance research both on Earth and in space environments. Awards will be made to the first three teams to achieve the goals by the end of FY 2020. 19 teams have registered for the competition.

- CO_2 Conversion Challenge - The purpose of this $1 million competition is to convert carbon dioxide (CO_2) into sugars such as glucose as a step to creating mission-critical resources. Such technologies will allow us to manufacture products using local, indigenous resources on Mars and Earth by using waste and atmospheric carbon dioxide as a resource. Phase 1 of the challenge awarded $250,000 to five teams for their system concepts; phase 2 seeks to award up to $750,000 to the top three teams that demonstrate operational systems in FY 2020.

EARLY STAGE INNOVATION AND PARTNERSHIPS

- Space Robotics Challenge - NASA is conducting the second phase of this competition, which seeks to advance robotic software and autonomous capabilities for space exploration missions on the surface of extraterrestrial objects, such as distant planets or moons. The $1 million competition will consist of two rounds to narrow the field of competitors and will culminate with awards made in early FY 2022.

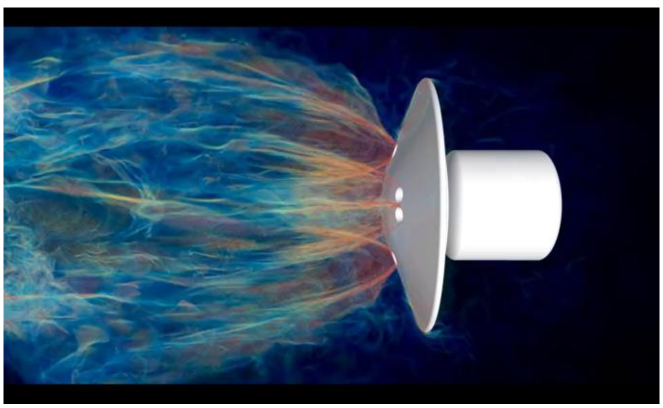
TECHNOLOGY MATURATION

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Technology Maturation Project Table	201.2	--	**469.1**	551.5	654.1	748.4	835.8
Total Budget	**201.2**	**--**	**469.1**	**551.5**	**654.1**	**748.4**	**835.8**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.



Led by Langley Research Center (LaRC), a team of scientists and engineers used Summit, the world's fastest supercomputer, at the US Department of Energy's (DOE) Oak Ridge National Laboratory (ORNL), to simulate retropropulsion for landing humans on Mars. The simulation is depicted above.

NASA is advancing disruptive space technologies from proof of concept to demonstration, maturing transformational and foundational technologies that primarily reside between early stage research and flight demonstration. Development of new technologies and capabilities lays the groundwork that enhances and enables lunar and Mars surface activities and space exploration beyond low-Earth orbit (LEO) in support of Artemis.

A substantial portion of the Technology Maturation funds are dedicated to the Lunar Surface Innovation Initiative, targeting critical technologies needed for surface activities over the next five years, including:

- In-Situ Resource Utilization with an emphasis on collecting, processing, storing, and using material found or manufactured on other astronomical objects;
- Sustainable Surface Power, enabling continuous power throughout lunar day and night;
- Surface Excavation/Construction to enable affordable, autonomous manufacturing and construction;
- Lunar Dust Mitigation enhancements to mitigate lunar dust hazards; and
- Extreme Environments and Extreme Access capabilities to operate through the full range of lunar surface and subsurface conditions.

The Technology Maturation portfolio develops and demonstrates technologies needed to enable exploration. The portfolio emphasizes technologies that address technical challenges faced by human explorers and is aligned with the Technology Thrusts.

TECHNOLOGY MATURATION

These investments will also support the Science Mission Directorate on exploration-related technology and research that also have relevance to achieving science goals. Public-private partnerships are an important mechanism used by NASA for Technology Maturation projects - as such, agreements enable NASA and private sector industry to share in the risk and benefit of Government investments. These shared risks and benefits include incentivizing technical performance, building future commercial markets, and sharing financial interest in the development of capabilities. NASA will execute a technology portfolio that enables human exploration and brings new knowledge and opportunities to Earth, enabled by the high-priority technology focus areas described in further detail below.

EXPLANATION OF MAJOR CHANGES IN FY 2021

Nuclear propulsion and power work transitions to the Space Nuclear Technologies portfolio described within Technology Demonstrations.

ACHIEVEMENTS IN FY 2019

Go

- The Thruster for the Advancement of Low-temperature Operation in Space activity completed the electrical discharge machining for the workhorse engine injector and completed the hot-fire testing of the workhorse engine. These thrusters will be infused into the Astrobotic (Pittsburgh, PA) Peregrine lander.

Live

- Completed thermal vacuum testing of two drills that will deliver water-enriched, lunar regolith for identification and quantification of water using a mass spectrometer, called the Mass Spectrometer observing lunar operations. These tests support the Polar Ice Mining Experiment , which will be sent to the lunar surface for demonstration on an early Commercial Lunar Payload Services (CLPS) company in calendar year 2022. Based on the outcome of early testing, The Regolith and Ice Drill for Exploring New Terrain drill from Honeybee Robotics was selected.

- In addition to Astrobee delivering three flight units, NASA delivered bionutrients flight demo hardware to the International Space Station (ISS) in April 2019 for a five-year investigation of the long-term stability of a nutrient production system in space.

Land

- In entry, descent, and landing systems, the Entry Systems Modeling project, in coordination with the Mars Entry Descent and Landing Instrumentation 2 (MEDLI-2) project, completed material property testing of the Phenolic Impregnated Carbon Ablator (PICA)-N and delivered MEDLI-2 flight hardware to Mars 2020. In addition, NASA completed ground demonstrations of the navigation Doppler LIDAR exceeding velocity requirements, completed the descent landing computer prototype, and began assembly of advanced hazard detection LIDAR. NASA partnered with Masten Space Systems and completed a flight demonstration of Terrain Relative Navigation technology.

TECHNOLOGY MATURATION

Explore

- In the area of In Space Manufacturing, NASA delivered and successfully checked out refabricator technology to the ISS. The unit is now ready to proceed with further printing and bonding operations. This machine can print plastic parts and recycle them back into reusable raw materials to make more and/or different parts. In addition, the Agency partnered with three U.S. companies - Interlog Corporation of Anaheim, CA, Techshot, Inc. of Greeneville, IN, and Tethers Unlimited, Inc. of Bothell, WA - to initiate development of a prototype, on-demand fabrication capability.

- To substantially improve computing capacity of spaceflight computers, NASA initiated the Advanced Memory project in partnership with the Air Force Research Laboratory to target volatile and non-volatile memory devices to support processor and digital devices.

WORK IN PROGRESS IN FY 2020

Go

- NASA will complete the design and combustion testing of the Thruster for the Advancement of Low-temperature Operation in Space (TALOS), leading to qualification testing in FY 2020. The qualification test will validate the thruster's performance in a relevant environment. This technology will then be shared with Frontier, through a public-private partnership, to develop a complete set of flight thrusters to be integrated onto the Astrobotic's Peregrine Lander.

- Busek conducted life testing of a 600-Watt Hall Thruster. The BHT-600 Hall effect thruster exceeded the baseline goal of 5,000 hours of operation in early FY 2020 and is now targeting 10,000 hours of operation by March 2020. This technology could be infused into sub-kilowatt power level electric propulsion systems to enable more affordable missions with smaller spacecraft.

Land

- NASA's Safe and Precise Landing Integrated Capabilities project will deliver units of the Navigation Doppler LIDAR, Descent Landing Computer, Terrain Relative Navigation, and Hazard Detection LIDAR to Blue Origin and Astrobotic to support their future sub-orbital flight and potential closed loop demonstrations in FY 2020 and FY 2021. These components are vital to an integrated suite of descent and landing technologies for a future lunar demonstration that emphasizes partnerships between NASA and industry.

Live

- NASA initiated an agreement with an existing Department of Defense University Affiliated Research Center (UARC), the Johns Hopkins University Applied Physics Laboratory, to provide an initial feasibility assessment on the structure, scope, and roles of a UARC to serve as a system integrator for the Lunar Surface Innovation Initiative (LSII). This consortium could expedite technology development and integration of lunar surface activities in support of a sustainable lunar surface presence

TECHNOLOGY MATURATION

- Completion of the preliminary design and critical design reviews of the 100-W class autonomous engineering model for the fuel cell, targeting an integrated demonstration in FY 2023 to validate for use on the lunar surface.

- Extreme Environmental Space Power will deliver a transformational solar array prototype that is much more efficient than current technology, enabling reliable operations that require power, even during periods of low sunlight intensity and low temperature. The prototype will demonstrate at least a 37 percent greater efficiency at the beginning of life and at least a 28 percent greater efficiency at the end of life than the current state-of-the-art. The industry awardee, Applied Physics Laboratory, will supply two of these transformational array strings for the Double Asteroid Redirection Test (DART) mission.

Explore

- Successfully manufactured a 16-meter composite boom for a deployment and will have a demonstration test on a zero-g aircraft flight to test deployment in an environment with significantly reduced gravitational forces. These deployable space structures will improve the packing efficiency of small volume spacecraft (e.g., CubeSats) and Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapters (ESPA) class satellites.

- Jet Propulsion Laboratory will complete a field test of multiple autonomous Pop-Up Flat Folding Exploration Robots (PUFFERs). PUFFER could potentially serve as initial scouting of robots on the lunar surface.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

Land

- Blue Origin will complete Hardware In the Loop simulations that will integrate Navigation Doppler LIDAR and Descent Landing Computer sensor flight data learned from FY 2020 flight tests to demonstrate lunar landing capability of Blue Origin's Blue Navigation System.

- Astrobotics will complete environmental testing of Terrain Relative Navigation space flight hardware in preparation for a lunar demonstration.

- The Mars Entry Descent and Landing Instrumentation 2 (MEDLI-2) experiment will occur during the Mars 2020 Mission entry into the Martian atmosphere. After a successful landing and transmission of data, the MEDLI-2 researchers will begin comparisons between analytical models and experimental data. Through these experiments, NASA will reduce landing ellipse uncertainties to improve landing accuracies for future robotic and manned Mars missions.

- NASA will conduct Plume Surface Interaction particle analysis in the Planetary Aeolian Lab at Ames Research Center, utilizing stereo landing cameras and other instruments during hot-fire engine tests to measure effects of lander base ejecta on CLPS landers. The computational models update within three to six months of each test series to continually update the tools being applied to lunar and Mars lander designs.

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TECHNOLOGY MATURATION

Live

- The Mars Environmental Dynamics Analyzer will also be launching via Mars 2020 to prepare for human exploration by providing daily weather reports, including information on the radiation and wind patterns on Mars. The instrument makes weather measurements, including wind speed and direction, temperature, and humidity, and measures the amount and size of dust particles in the Martian atmosphere. Mars Environmental Dynamics Analyzer will take measurements in FY 2021-2022.

- The Chemical Heat Integrated Power Source (CHIPS) project, to demonstrate a combined electrical and thermal power source for survival and surface operations on the Moon, will begin the assembly of the integrated system that includes the reaction control subsystem, the thermal control subsystem, and the thermoelectric converter subsystem, which, once integrated with lunar landers, will enable further operational life.

- NASA will complete the system design for technology that will allow oxygen to be recovered from regolith using ionic fluid. Lunar regolith is more than forty percent oxygen by weight, but there are no mature technologies suitable for in-space use available to recover this oxygen. Ultimately, this technology will be tested through a ground demonstration, followed by a CLPS experiment.

- NASA will complete a Space Synthetic Biology bioreactor that can convert locally-sourced carbon dioxide to organic compounds.

Explore

- In conjunction with the Starling small spacecraft mission, the Distributed Spacecraft Autonomy project at NASA Ames Research Center will develop and demonstrate the capability to command multiple spacecraft as a single entity and scale inter spacecraft communications beyond the Starling demonstration to larger swarms with dozens of nodes.

- NASA will qualify Bulk Metallic Glass planetary and strain wave gears for in-space application with potential to support lunar and Europa surface missions. In FY 2021, the project will finalize material specification and perform environmental testing and life endurance testing of planetary and strain wave gears in the Cold Operable Lunar Deployable Arm payload described further below.

TECHNOLOGY MATURATION

Program Elements

Technology Maturation Budget Estimated by Focus Area

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Rapid, Safe & Efficient Space Transport	75.9	--	**19.1**	19.5	20.5	38.1	43.9
Expanded Access to Diverse Surface Dest	34.3	--	**52.2**	67.8	78.5	88.0	100.0
Sustainable Living & Work Far From Earth	42.2	--	**247.3**	285.0	336.4	388.7	438.2
Transformative Missions and Discoveries	24.3	--	**43.6**	44.8	47.1	52.1	62.7
Lunar Payload, ACO/TP	1.9	--	**77.4**	101.1	135.0	144.0	150.0
Space Tech Management and Integration	22.7	--	**29.5**	33.2	36.5	37.5	41.1
Total Budget	**201.2**	**--**	**469.1**	**551.5**	**654.1**	**748.4**	**835.8**

GO: RAPID, SAFE, & EFFICIENT SPACE TRANSPORTATION

NASA is making critical advancements in power generation and energy storage technologies for exploration missions. Propulsion investments focus on higher thrust and efficiency, including alternatives to traditional chemical propulsion systems for deep space exploration spacecraft systems. Specific investments include:

- The Thruster for the Advancement of Low-temperature Operation in Space (TALOS), a new class of thruster to the aerospace community for deep space missions. These thrusters will use MON-25/MMH propellants, which can provide superior thermal performance due to lower freezing points and mass savings over other thrusters with comparable performance. Through a public-private partnership with Frontier, NASA will build upon the TALOS effort, providing the first flight set of axial thrusters for the Astrobotic mission for integration on the Peregrine Lander.

- Rapid Analysis Manufacturing Propulsion Technology (RAMPT) will develop and advance large-scale, light-weight manufacturing techniques and analysis capabilities required to reduce design and fabrication cycles for regenerative-cooled liquid rocket engine components. RAMPT impacts all phases of the thrust chamber life cycle by reducing design, fabrication, and assembly schedules (by 60 percent) and allowing for reduced parts, increased reliability, and significant weight reduction (by 70 percent). RAMPT will partner with industry through a public-private partnership to design and manufacture component parts of the thrust chamber. This project will culminate in a large scale Thrust Chamber Assembly hot fire test.

- Cryogenic Fluid Technologies project is developing multiple capabilities for zero boil off storage of multiple cryogenic fluids, including liquid hydrogen. These capabilities are enabling to a variety of lunar lander operations, lunar surface operations, and in-space transportation systems, including Nuclear Thermal Propulsion. Technologies being developed include a 90 kelvin cryocooler with 150-watt refrigeration capacity, a 20 kelvin cryocooler with 20-watt refrigeration capacity, reduced gravity transfer lines, and a new class of coatings to reduce solar absorption. Multiple approaches are being pursued for the 90 kelvin/150 watt cryocooler using design concept studies of pulse tube cryocoolers for potential to proceed to prototyping of a150 watt at 90 kelvin Reverse Turbo-Brayton cycle cryocooler. Performance testing of a solar white coating technology will be continued to address optimization of the strength and optical properties of the coating and evaluation of cryogenic thermal performance in different relevant environmental conditions (electrostatic charging and atomic oxygen).

LAND: EXPANDED ACCESS TO DIVERSE SURFACE DESTINATIONS

For NASA to more accurately land more mass on planetary bodies, as well as improve capabilities to return spacecraft from low Earth orbit and deep space, the Agency must develop more capable entry, descent, landing system materials and modeling capabilities. NASA invests in technologies focused on the design, analysis, and testing of advanced materials for thermal protection and aeroshell architectures required for future exploration vehicles and planetary entry missions. Key projects within the Entry, Descent, and Landing Systems include:

- Precision Landing and Hazard Avoidance components (e.g., sensors, computing platform, and algorithms) are being matured for integration and demonstration via investments in Safe and Precise Landing- Integrated Capabilities Evolution (SPLICE) and for infusion into near-term commercial robotic missions for Lunar Demonstrations in the 2024-2026 timeframe, enabling a multitude of future missions to take advantage of the capability to choose a safe landing site within a landing footprint. These missions include:
    - Navigation Doppler Lidar velocimeter is ready for a flight test on Blue Origin Blue Shepard, and will be infused on CLPS, then on human Lunar landers;
    - Hazard Detection Sensor being readied for demonstration on an Earth-based flight opportunity before Lunar lander infusion;
    - Descent and Landing Computer, for processing on Earth-based test platforms, then extended to Lunar demonstration;
    - Terrain Relative Navigation, infusing into both Blue Origin and Astrobotic commercial landers in preparation for near-term lunar landings; and
    - Descent and landing performance simulations development for candidate missions to inform technology investments and timing.
- Safe and Precise Landing Integrated Capabilities Evolution (SPLICE), integrates these precision landing and hazard avoidance technologies to reduce entry uncertainty, leading to a safe and precise landing. By the end of the project, the goal is to reach 200 meters per second with Line of Sight Velocity and greater than four kilometers in Line of Sight Range.
- In collaboration with Science, the Space Technology Mission Directorate completed MEDLI-2 and delivered this second-generation sensor suite for incorporation into the Mars 2020 heat

shield. This effort will further improve our understanding of entry system performance by acquiring flight data from an actual Mars mission, informing NASA designs for future exploration missions. The goals of the sensor suite are to facilitate precise landing and to detect and avoid hazards (natural and manufactured) to support human-rated reliability. Through information obtained from NASA's development and 2022 demonstration of the Low-Earth Orbit Flight Test of Inflatable Decelerator and MEDLI-2, NASA will begin design studies for a landing system capable of landing human-class payloads on Mars.

- Plume Surface Interaction aims to reduce lander risk by improving and validating Plume Surface Interaction models with high-fidelity data from both ground tests and flight instrumentation. Leveraging all relevant flight opportunities, the project will conduct particle analysis in the Planetary Aeolian Lab at Ames Research Center and conduct hot fire tests of stereo landing cameras and other instruments for CLPS landers to measure effects of lander base ejecta. The computational models update within three to six months of each test series, facilitating continuous application of tools to lunar and Mars lander designs.

LIVE: SUSTAINABLE LIVING AND WORKING FARTHER FROM EARTH

Capabilities developed under this thrust area result in routine crewed operations beyond low-Earth orbit. Technologies demonstrated will enable sustainable human presence on the Moon and, eventually, Mars. Additionally, these capabilities provide the ability to reach challenging sites and resources on the Moon and Mars and survive and operate through the lunar night.

Lunar Surface Innovation Initiative

As part of the Lunar Surface Innovation Initiative, NASA will pursue novel technologies needed to increase the viability of oxygen extraction from lunar resources, develop lunar surface power generation and storage capabilities, and improve thermal management. These capabilities are essential for humans and systems to successfully live and operate on the lunar surface. The activities described below include key elements of this initiative along with related efforts.

In-Situ Resource Utilization

In-Situ Resource Utilization (ISRU) must first be demonstrated before it can be mission-critical. This project will target a subscale demonstration of critical technologies on Commercial Lunar Payload Services landers (e.g., excavation, mineral beneficiation, regolith processing) in the early to mid-2020’s. The project will design human mission-relevant scale demonstrations of ISRU mining and processing for oxygen and water, possibly tied to demonstration of nuclear power on the Moon. Following development and maturation of ISRU technologies at the component, subsystem, and system level, the project will demonstrate them in ground-based analog environments to enable production of propellants, other mission consumables, products, and infrastructure from regolith and atmospheric resources at a variety of destinations. Mature ISRU technologies will be brought to a system-level TRL 6 to support future flight demonstration missions. The project objective will be to validate high fidelity ISRU systems' mass, power, and volume data for incorporation into Exploration architecture options analysis.

This effort will be supported through a balance of in-house and external work to mature the technologies and capabilities, with NASA Center involvement responsibilities based on expertise and past/current development efforts. External work will be funded through several contracting mechanisms (SBIR/STTR, solicitations, public-private partnerships) and competitions. This project will also be instrumental in leveraging a potential ISRU institute as well as challenge ideas.

Lunar ISRU technology demonstrations will be key for operational experience and mission validation for Mars. The LSII ISRU demonstrations will develop and test a broad spectrum of core capabilities applicable to Mars ISRU, and at similar scales. Demonstration of integrated ISRU systems on the lunar surface will also provide vital technology maturation to better enable remote and/or autonomous operations, as well as more efficient power utilization, operations, and processes for Mars ISRU systems.

In addition to the core lunar ISRU capability development, Exploration Technology is investing in atmospheric ISRU for Mars missions, building off the Mars Oxygen In-Situ Resource Utilization Experiment flight demonstration on Mars 2020. This includes component and subsystem technology advancement and testing, as well as formulating the chemistry development and relevant ground demonstrations to inform a future atmospheric ISRU plant flight payload. Key objectives include:

- Oxygen/Methane from Mars Atmosphere: integrate dust filtration, carbon dioxide collection, solid oxide electrolysis and/or atmospheric-based processing, and oxygen/methane liquefaction to perform long-duration testing in simulated Mars environment.
- Water from Mars Soil: advance technologies in hydrated mineral water separation and perform long-duration testing under analog and Mars environment chamber testing.

Sustainable Surface Power

NASA is making critical advancements in power generation and energy storage technologies for exploration missions. It is developing solar array technology that can generate energy in extreme environments, including low light intensity and low temperature. In addition, NASA is developing and demonstrating a primary fuel cell system to support initial operations on the lunar surface. Fuel cells will also be needed to support operations with long discharge times, including applications on rovers, powering of habitats, powering in-situ resource utilization systems, and for general energy storage on the Moon. NASA is working toward completion of preliminary design and critical design reviews of an autonomous engineering model for the fuel cell which will lead to a full integration of the regenerative fuel cell for ground testing in FY 2023 in preparation for a potential future demonstration on the lunar surface.

Extreme Environments

NASA is advancing rovers, manipulators, and other systems that can operate throughout the full range of lunar surface conditions, including lunar noon (up to 150 °C), lunar night (down to -180 °C), multiple day/night cycles, and permanently shadowed regions (down to -240 °C). Key technologies include:

- Bulk Metallic Glass: Bulk Metallic Glass gears improve rover mobility performance at low temperatures by eliminating the need for gear lubricant and associated heaters. This project will deliver planetary gears and strain wave gears that will enable planetary surface missions where temperatures drop below the freezing point of typical lubricants.
- The Cold Operable Lunar Deployable Arm payload will significantly improve the utility for lunar landers by providing manipulation capabilities during the lunar night. The payload will integrate

technologies such as bulk metallic glass actuators, cold motor drivers, and a six-axis force torque sensor previously developed.

- Motors for dusty and extremely cold environments: Apollo missions demonstrated that dust was a limiting factor for lunar surface operation and posed a health concern when it penetrated habitable spaces. The Lunar Dust Adhesion Mitigation activity will investigate piezoelectric agitation, surface coatings, plasma lofting, and electrostatic behavior to minimize the impact of lunar dust.

- Planetary and Lunar Environment Thermal Toolbox will develop and improve a host of thermal technologies to ensure the effective operation of future instruments and robotic/human systems in extreme lunar/planetary environments.

Surface Excavation and Construction

NASA will develop and demonstrate technologies that enable affordable, autonomous manufacturing and construction (e.g., of a landing pad, berm, or shielding) using lunar surface materials.

Lunar Dust Mitigation

NASA will develop and demonstrate technologies and concepts to mitigate lunar dust hazards, enabling affordable, sustained operations both on the lunar surface and with transfers to and from the Lunar Gateway or other orbital platforms.

Environmental Control and Life Support Systems

NASA will fundamentally transform spacecraft systems through investment in high payoff technologies that advance atmospheric capture and conversion aspects of closed-loop life support systems and develop capabilities to mitigate space radiation. Key projects within this portfolio include the following:

- Spacecraft Oxygen Recovery: Oxygen recovery systems are critical when oxygen resupply from Earth is not available, and they will enable long-duration human missions. NASA awarded two contracts, one to Honeywell Aerospace and one to UMQUA Research Co., to develop technologies that will increase the oxygen recovery rate aboard human spacecraft to at least 75 percent while achieving high reliability. These technologies may be used by the ISS as a proving ground to retire risk and gain experience with capabilities needed for deep-space exploration.

- Space Synthetic Biology will demonstrate the ability of synthetic biology to impact mission architectures by producing high-value bio-nutrients on demand, minimizing the need for launched resources. The project has begun a five-year flight experiment and demonstration, with the first bionutrient samples being returned from the ISS. This CO2-Based Manufacturing element can convert locally-sourced carbon dioxide to organic compounds that can serve as a microbial substrate for microbial biomanufacturing systems. This capability allows biomanufacturing systems to scale to viable production systems for mission products, such as food components, pharmaceuticals, polymers, fuels, and a range of valuable chemicals.

- Autonomous Medical Operations: The objective of this project is to develop a “medical decision support system” to enable astronauts on long-duration exploration missions independent of Earth contact. Such a system is not intended to replace a “Chief Medical Officer” (CMO), but rather to support the CMO’s medical actions by providing advice and procedure recommendations during emergent care and clinical work. The Autonomous Medical Operations system will enable rapid, assured acquisition and analysis of sensor data to support differential diagnosis, analysis from medical on-board notes and on-board databases (including tailoring to individual astronauts), and automated reasoning using structured and unstructured data.

- The Integrated System for Autonomous and Adaptive Caretaking (ISAAC) effort will build upon FY 2019 formulation and work towards a multi-year project developing and enhancing key technologies for the autonomous operation of complex, space-based infrastructure that provides the capability to support operations where human intervention is limited. ISAAC will provide new capabilities for in-space operations and adaptive vehicle caretaking. At the end of the formulation phase, ISAAC will perform a demonstration to validate the initial Modular Autonomous Systems Technology architecture on analog platform.

In Space Manufacturing

- To provide efficient mission and ground operations with reduced dependence on Earth resources, NASA invests in technologies for in-space manufacturing , including the development of the Multi-Material Fabrication Laboratory (FabLAB) for ISS. The project will complete the following key objectives over the next two years: Refabricator Technology Demonstration installation and activation on the ISS and Technical Interchange Meetings with the FabLAB Phase A awardees. NASA will award Phase B of a space-based, on-demand fabrication capability by partnering with U.S. companies to develop a FabLAB and conduct Critical Design Reviews, leading to an on-orbit FabLAB in the 2025 timeframe.

EXPLORE: TRANSFORMATIVE MISSIONS AND DISCOVERIES

Technologies developed within Explore will enable NASA to reach challenging sites and resources on the Moon and survive and operate through the lunar night and on Mars.

Advanced Avionics, Communications, and Navigation

NASA will fundamentally transform spacecraft systems through investment in high payoff technologies that increase communication data rate and advance deep space navigation and flight avionics. Key projects within this portfolio include the following:

- High Performance Spaceflight Computing (HPSC): HPSC will lead to vastly improved in-space computing performance, energy management, and increased radiation fault tolerance. The new radiation-tolerant microprocessor will offer a 75-times improvement in performance relative to the current state-of-the-art RAD750 processor while requiring the same power. The project includes a chiplet (a multi-core Rad-hard processor), an Advanced Rad-hard Memory (led by the Air Force Research Laboratory), and a NASA-led single board computer. High performance computing solutions require both high-speed processing (via the Chiplet) and high-speed memory storage and access. Precision lunar and other planetary landings, where many high-resolution images need to be processed in seconds, are particularly demanding operations that benefit from HPSC.

- Distributed Spacecraft Autonomy: Distributed Spacecraft Autonomy will develop technology that will demonstrate autonomous decision-making for multi-spacecraft missions and systems due to

TECHNOLOGY MATURATION

latency, bandwidth constraints, and mission complexity, and will significantly increase the effectiveness of missions and systems by operating them as a collective rather than individually.

Servicing, Assembly, & Manufacturing

NASA supports innovation in materials development and low-cost manufacturing that enables increased mission cargo capacity by reduction of structural mass. NASA looks for opportunities to improve the manufacturing technologies, processes, and products prevalent in the aerospace industry. NASA's unique needs enable a network of collaboration and partnerships with industry, academia, and other Government agencies to accelerate innovative manufacturing methods and technologies. Key projects within this portfolio include the following:

- The Super-lightweight Aerospace Composites (SAC) project seeks to scale up the manufacturing and use of high-strength carbon nanotube composite materials. Led by NASA's Langley Research Center in Hampton, VA, a team of researchers is working with other NASA Centers, Government agencies, academia, and industry partners to move this technology forward. If carbon nanotube material was produced at a higher rate than it is currently, carbon nanotube materials could be used to make rocket and spacecraft components. Using a Phase III SBIR contract with Nanocomp Technologies Inc. of Merrimack, NH, NASA is scaling up manufacturing capabilities and lowering production costs of high-strength carbon nanotube yarn, building on previous SBIR awards from the Department of Defense and NASA.

- Deployable Composite Boom: The objective of this project is to mature deployable composite boom technology for use in low-cost, small volume, CubeSat/ESPA class spacecraft. Structurally ridged and thermally stable booms are needed for use in low-cost science and exploration missions where relatively large deployed structures are required for power, communications, and, in some instances, propulsion. These types of booms enable high-power solar arrays, antennas for high data rate communications, and solar sail propulsion systems to be included on small CubeSat/ESPA class spacecraft.

Extreme Access

Exploration Technology demonstrates technologies enabling humans or robotic systems, particularly autonomous systems, to efficiently access, navigate, and explore previously inaccessible lunar or planetary surface or subsurface areas.

- Autonomous Pop Up Flat Folding Exploration Robot (PUFFER): The objective of this project is to enable the PUFFER to operate autonomously, both individually and as a multi-robot team. PUFFER is a miniature mobile robot that is designed as a low-volume, low mass, low-cost mission enhancement for accessing new, high-interest, extreme terrains. PUFFER can support future lunar, Mars, and icy moon missions, as well as work in extreme terrains on Earth.

- Cube Rover: Astrobotic, in partnership with Carnegie Mellon University, was awarded a Tipping Point public private partnership to continue development of their CubeRover, a 2-kilogram rover platform capable of small-scale science and technology demonstrations on the Moon and other planetary surfaces. This small rover platform complements Astrobotic's lunar payload delivery service by providing a low-cost mobility capability to the lunar surface for customers around the world.

TECHNOLOGY MATURATION

ACQUISITION STRATEGY

These critical technology projects are defined as part of the strategic framework and capabilities, through requirements determined by the Federated Team, and through selection by the Space Technology Mission Directorate's annual Strategic Technology Architecture Round-table (STAR) process. In addition, STMD embraces competition and external partnerships; as such, some of the technologies are selected through the annual Tipping Point, Announcements of Collaboration Opportunity, and other NASA solicitations.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
High Performance Spaceflight Computing	Boeing Company	St. Louis, MO

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Independent Review Team	NASA	Jul 2019	Assess progress on current HPSC plans.	Technical review led to project replan in process with STMD and Boeing.	To Be Determined
Standing Review Board	NASA		MEDLI-2 Systems Acceptance Review		Feb 2020

TECHNOLOGY DEMONSTRATION

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Laser Comm Relay Demo (LCRD)	17.2	30.0	**13.6**	0.0	0.0	0.0	0.0
Solar Electric Propulsion (SEP)	48.1	48.1	**48.7**	25.4	9.0	5.8	0.0
Restore & SPIDER (OSAM-1)	192.8	227.2	**133.5**	117.2	59.4	14.6	0.0
Small Spacecraft, Flight Opportunities & Other Tech Demo	158.7	--	**341.4**	413.4	445.0	444.5	525.1
Total Budget	**416.8**	**--**	**537.2**	**556.0**	**513.4**	**464.8**	**525.1**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

The LOFTID Engineering Design Unit of the Aeroshell is seen here at Langley Research Center (LaRC) undergoing mass property testing. The LOFTID project aims to advance hypersonic inflatable aerodynamic decelerator technology by performing orbital velocity atmospheric entry experiment.

The Technology Demonstration portfolio conducts both ground-based testing, to determine feasibility, and space flight demonstrations, to transition new capabilities to NASA exploration missions and potentially to industry and other Government agencies.

Current and future projects in this portfolio enable and enhance NASA's Artemis Moon to Mars Exploration Campaign, with an emphasis on lunar exploration technology needs that enable human landing in 2024 and a sustainable lunar presence. Technology investments include high-power solar electric propulsion for the Artemis Power and Propulsion Element, precision lunar landing and hazard avoidance, cryogenic fluid management, in situ resource utilization and sustainable lunar surface power (contributing to the Lunar Surface Innovation Initiative), advanced communications and navigation demonstrations, and in-space manufacturing and assembly.

While these technologies primarily benefit space exploration, several of these technologies offer the potential for commercial benefits, as well. Where this potential is high, public-private partnerships will be used to enable NASA to share the risk and financial interest with private industry and better leverage Government investments. For example, in-space manufacturing and assembly offers a broad range of potential benefits, enabling transformative missions that cannot currently be performed and would diversify spacecraft development options that are currently limited by launch vehicle shape, size, and mass constraints. Entry, descent, and landing technologies required for exploration could provide the capability to return large payloads to Earth, enabling the re-use of space systems and, potentially, the affordable return to Earth of objects manufactured in space.

TECHNOLOGY DEMONSTRATION

This account also supports platforms that enable technology demonstrations in relevant environments through Flight Opportunities' suborbital flights and to demonstrate capabilities and acquire strategic knowledge through Small Spacecraft platforms (including CubeSats). Examples include using vertical takeoff-vertical landing rockets to demonstrate precision landing and hazard avoidance software and avionics and using CubeSat robotic precursor activities to acquire strategic knowledge about potential destinations for human exploration. One such precursor activity is prospecting for lunar ice.

EXPLANATION OF MAJOR CHANGES IN FY 2021

NASA establishes a new Space Nuclear Technologies portfolio, which will draw upon the lessons learned from both the Kilopower project and the nuclear thermal propulsion work in previous years. This program will place a high-priority on lunar surface power but will also continue to make progress on propulsion capabilities to support future human missions to Mars. The objectives of this effort are described in the Small Spacecraft, Flight Opportunities, and Other Technology Demonstrations section below.

LASER COMM RELAY DEMO (LCRD)

Formulation	Development	Operations

FY 2021 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	BTC	Total
Formulation	169.5	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	169.5
Development/Implementation	71.7	21.6	26.8	**8.5**	0.0	0.0	0.0	0.0	0.0	128.6
Operations/Close-out	0.0	0.0	3.2	**9.3**	0.0	0.0	0.0	0.0	0.0	12.5
2020 MPAR LCC Estimate	**241.2**	**21.6**	**30.0**	**17.8**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**310.6**
Total STMD Budget	**204.8**	**17.2**	**30.0**	**13.6**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**265.6**
Change from FY 2020				**-16.4**						
Percentage change from FY 2020				**-54.7%**						
Total NASA Budget	**241.2**	**21.6**	**30.0**	**17.8**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**310.6**

The Laser Communications Relay Demonstration (LCRD) flight payload was delivered to Northrop Grumman's facility in Sterling, Virginia. There, the payload will be integrated onto the U.S. Air Force's Space Test Program Satellite 6 (STPSat-6) and prepared for launch. LCRD will be NASA's first end-to-end optical relay, sending and receiving data from missions in space to mission control on Earth.

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

PROJECT PURPOSE

The goal of the Laser Communications Relay Demonstration project is to prove the utility of bi-directional optical communications relay services between geosynchronous orbit and Earth. The project supports the advanced communications, navigation, and avionics exploration key focus areas. This effort will prove optical communications technology in an operational setting, providing data rates up to 100 times faster than today's radio frequency-based communication systems. The demonstration will measure and characterize the system performance over a variety of conditions, develop operational procedures, assess applicability for future missions, and provide an on-orbit capability for test and demonstration of standards for optical relay communications. This capability, if successfully demonstrated, could be quickly infused into NASA missions, other Federal agencies, and U.S. satellite

LASER COMM RELAY DEMO (LCRD)

Formulation	Development	Operations

manufacturers and operators given the rising demand for bandwidth. Laser Communications Relay Demonstration will fly as a hosted payload with the U.S. Air Force Space Test Program (STPSat-6). Upon a successful flight demonstration, NASA will provide the communications industry with access to the integrated system to test these new capabilities for commercial applications.

EXPLANATION OF MAJOR CHANGES IN FY 2021

The launch readiness date of the Laser Communications Relay Demonstration payload on the U.S. Air STPSat-6 mission will be delayed by at least 14 months relative to the original baseline commitment Launch Readiness Date (LRD) milestone schedule of November 2019. The new LRD is currently targeted for January 2021. The schedule is delayed primarily because of the need to make modifications to the STPSat-6 spacecraft bus. Limited space launch range availability, which is outside LCRD's control, is also a factor. LCRD has delivered the flight system for integration in January 2020.

PROJECT PARAMETERS

LCRD will conduct a minimum two-year flight demonstration to advance optical communications technology toward infusion into Near Earth operational systems while growing the capabilities of industry sources. Objectives include:

- Demonstrating bidirectional optical communications between geosynchronous Earth orbit and Earth;
- Measuring and characterizing the system performance over a variety of conditions;
- Developing operational procedures and assessing applicability for future missions; and
- Providing an on-orbit capability for test and demonstration of standards for optical relay communications.

ACHIEVEMENTS IN FY 2019

The project successfully performed environmental and payload performance testing and prepared the payload for delivery, including troubleshooting and repair of a modem failure that occurred during integrated testing. Additionally, the project developed and successfully tested the ground communication network with the payload in the loop.

WORK IN PROGRESS IN FY 2020

The project delivered the flight payload to the spacecraft integrator and support integration and testing as a part of the STP-3 mission. The project will support space vehicle integration and test, including end-to-end testing with the LCRD Mission Operations Center. The project will certify the mission operations network that will be used to operate the payload on-orbit.

LASER COMM RELAY DEMO (LCRD)

Formulation	Development	Operations

KEY ACHIEVEMENTS PLANNED FOR FY 2021

The project will support launch readiness, launch in January 2021, and early on-orbit operations.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2021 PB Request
CDR	Dec 2016	Dec 2016
KDP-C	Feb 2017	Feb 2017
System Integration Review	May 2018	Nov 2019
KDP-D	Feb 2020	Feb 2020
Operational Readiness Review	Oct 2020	Oct 2020
KDP-E	Dec 2020	Dec 2020
Launch Readiness Review	Dec 2020	Dec 2020
Launch (or equivalent)	Jan 2021	Jan 2021

LASER COMM RELAY DEMO (LCRD)

Formulation	Development	Operations

Development Cost and Schedule

Below details the current year development cost estimate for STMD ($95.7 million) as well as the NASA total which includes funding from LEO and Spaceflight Operations: Space and Flight Support (SFS)/ Space Communications and Navigation (SCaN) ($32.9 million). Current LCC ($310.5 million) and development cost ($128.6 million) with a launch of January 2021 represent a new baseline report pursuant to section 103 of the NASA Authorization Act of 2005 (P.L. 109-155). The original baseline was for an LCC of $262.7 million, a development cost of $91.8 million, and a launch of November 2019.

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2020	95.7 (STMD)	70%	2020	95.7 (STMD)	0%	Launch	Jan 2021	Jan 2021	0
2020	128.6 (NASA)	70%	2020	128.6 (NASA)	0%	Launch	Jan 2021	Jan 2021	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost. NASA originally baselined LCRD in 2017 and conducted a re-plan in 2019. JCL was not updated in re-plan.

LASER COMM RELAY DEMO (LCRD)

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)*
TOTAL:	**128.6**	**128.6**	**0**
Aircraft/Spacecraft	32.5	32.5	0
Payloads	25.5	25.5	0
Systems I&T	15.6	15.6	0
Launch Vehicle	0.0	0.0	0
Ground Systems	7.3	7.3	0
Science/Technology	6.0	6.0	0
Other Direct Project Costs	41.7	41.7	0

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Program Management	Project Management, LCRD Payload, LCRD Mission Operations Center	Goddard Space Flight Center	N/A
Optical Ground Station	Optical Ground Stations, RF Ground Station and STPSat-6 Mission Control Center	Human Exploration and Operations Mission Directorate (HEOMD)/SCaN	N/A
Technology Transfer	Technology Transfer for Payload	Massachusetts Institute of Technology: Lincoln Laboratory	N/A
Ground Station	Optical Ground Station 1	Jet Propulsion Laboratory	N/A
Spacecraft and Launch Vehicle	STPSat-6 Spacecraft and Launch Vehicle	U.S. Air Force & Northrop Grumman (Spacecraft vendor); ULA (Launch Vehicle)	N/A

LASER COMM RELAY DEMO (LCRD)

Formulation	Development	Operations

Acquisition Strategy

All major acquisitions are in place.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Technology Transfer for Payload and Optical Ground Station	Massachusetts Institute of Technology: Lincoln Laboratory	Lexington, MA

INDEPENDENT REVIEWS

Completed independent assessment prior to KDP-C.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Joint Confidence Level (CL)	Tecolote	Oct 2016	Determine realistic 50/70 percent CL budget and schedule in accordance with Agency requirements	70 percent CL used to define Program-held UFE above project for KDP-C	N/A
Standing Review Board/Independent Readiness Team	Various subject matter experts	Dec 8-9, 2016 (technical presentation); Dec 14, 2016 (Programmatic)	Provide STMD and GSFC Center Director programmatic assessment	Project has sound programmatic and technical approaches, risk plan and milestone deliverables are acceptable LCRD satisfied all review success criteria, and is ready to proceed into implementation phase	Operational Readiness Review (ORR) Currently scheduled for Oct 2021

SOLAR ELECTRIC PROPULSION (SEP)

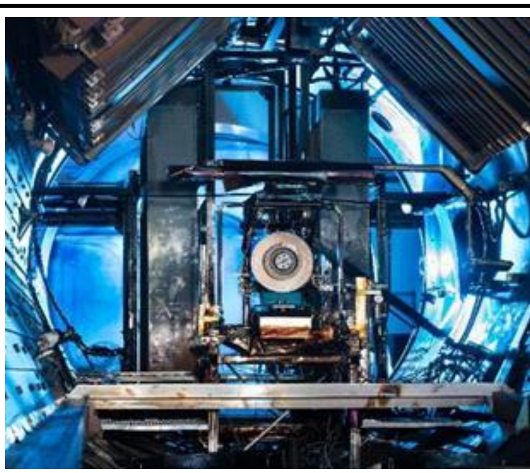
Formulation	Development	Operations

FY 2021 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	BTC	Total
Formulation	131.6	48.1	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	179.7
Development/Implementation	0.0	0.0	67.0	**48.7**	25.4	9.0	5.8	0.0	0.0	155.9
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2020 MPAR LCC Estimate	**131.6**	**48.1**	**67.0**	**48.7**	**25.4**	**9.0**	**5.8**	**0.0**	**0.0**	**335.6**
Total Budget	**131.6**	**48.1**	**48.1**	**48.7**	**25.4**	**9.0**	**5.8**	**0.0**	**0.0**	**316.7**
Change from FY 2020				**0.6**						
Percentage change from FY 2020				**1.2%**						

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.



Electric Propulsion thruster shown here in testing. The project will be conducting a spaceflight demonstration of a 30-50 kilowatt (kW)-class solar electric propulsion system on the Lunar Gateway Power and Propulsion Element.

PROJECT PURPOSE

Through a project at the Glenn Research Center, NASA will continue development of Solar Electric Propulsion (SEP) with higher-power, longer-life thrusters and power processing units. The first demonstration of this system will be through a 50-kilowatt (kW)-class Power and Propulsion Element for Lunar Gateway. This demonstration will provide NASA with experience in electric propulsion maneuvers in the family of orbits around the moon and demonstrate operational approaches and interfaces with visiting crew and robotic vehicles. Solar Electric Propulsion will also enable more efficient orbit transfer of spacecraft and accommodate the increasing power demands for Government and commercial satellites.

The SEP system will not only meet the objectives for future NASA exploration purposes but also will support the growing demand for increased electric propulsion performance for commercial satellites. This development will be integrated with previous NASA advancements in deployable solar array structures. These arrays, with half of the mass and one-

SOLAR ELECTRIC PROPULSION (SEP)

Formulation	Development	Operations

third of the packaging volume compared to the state-of-the-art solar arrays, have already been incorporated into commercial satellite product lines enabling greater payload mass. For example, Maxar and Deployable Space Systems are flight qualifying the Rollout Solar Array (ROSA) for use in their commercial communication satellites, and Northrop Grumman is using a smaller version of technology similar to MegaFlex on the Cygnus cargo vehicle. In addition, the Air Force Research Laboratory sponsored a space demonstration of the NASA-developed ROSA solar array design on the ISS in July 2017.

EXPLANATION OF MAJOR CHANGES IN FY 2021

There are no major changes. This project passed Key Decision Point-C (KDP-C) and has an established cost and schedule baseline. The baseline details are discussed as part of this CJ.

PROJECT PARAMETERS

The goal of the project is to qualify a 30-50 kW-class solar electric propulsion string to be used as primary propulsion for a spaceflight demonstration. Objectives include:

- Develop instrumentation to characterize performance of an integrated system, including thrusters, arrays, bus, and payloads as they operate as an integrated system and as they respond to the in-space environment.
- Qualify high-power SEP technology for use in relevant space environments through demonstration of continuous long-term operation of the system sufficient to characterize and predict the capability and lifetime of the system.
- Qualify electric propulsion string for extended operations in deep space.

ACHIEVEMENTS IN FY 2019

Aerojet Rocketdyne completed the build of engineering test units (hall thruster, power processing unit, and xenon flow controller) and began initial functional and acceptance testing that will support the final design.

WORK IN PROGRESS IN FY 2020

The project continues to perform various tests (e.g., functional, acceptance, vibe, shock). The engineering test units will be integrated and tested to ensure the final design meets performance requirements. A Critical Design Review is planned for late FY 2020.

SOLAR ELECTRIC PROPULSION (SEP)

Formulation	Development	Operations

KEY ACHIEVEMENTS PLANNED FOR FY 2021

The project will begin qualification testing of the Electric Propulsion string. In addition, the Plasma Diagnostic Package (PDP) will be delivered to the Power Propulsion Element (PPE) by summer 2021.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2021 PB Request
Formulation Authorization	Mar 2015 (as part of Asteroid Redirect Robotic Mission [ARRM])	Mar 2015 (as part of ARRM)
KDP-A	Mar 2015 (as part of ARRM)	Mar 2015 (as part of ARRM)
Preliminary Design Review	Aug 2017	Aug 2017
KDP-C	Jun 2019	Jun 2019
Critical Design Review	Sep 2020	Sep 2020
System Integration Review (Plasma Diagnostics Package)	May 2021	May 2021
Deliver Plasma Diagnostics Package for Lunar Gateway for Integration	Jul 2021	Jul 2021

SOLAR ELECTRIC PROPULSION (SEP)

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2020	155.9	70%	2020	155.9	0%	Electric Propul-sion System Life Qual Test Report	Dec 2024	Dec 2024	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**155.9**	**155.9**	**0**
Science/Technology	134.4	134.4	0
Other Direct Project Costs	21.5	21.5	0

SOLAR ELECTRIC PROPULSION (SEP)

Formulation	Development	Operations

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Program Management	Manages Aerojet Rocketdyne contract, thruster development life testing and qualification testing, Plasma Diagnostics Package	Provider: N/A Lead Center: Glenn Research Center (GRC) Performing Center(s): GRC Cost Share Partner(s): N/A	N/A
Thruster Development	Thruster development and life qualification testing support	Provider: N/A Lead Center: Jet Propulsion Laboratory (JPL) Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
Flight Thruster and Power System Design	Flight thruster and power system design and qualification	Provider: Aerojet Rocketdyne Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
N/A	N/A

Acquisition Strategy

All major acquisitions are in place.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Advanced Electric Propulsion System Contract	Aerojet Rocketdyne	Redmond, WA

SOLAR ELECTRIC PROPULSION (SEP)

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
PDR	IRT	Aug 2017	Assess/approve preliminary design	Passed	CDR
CDR	IRT	Sep 2020	Assess/approve final design	TBD	TBD

RESTORE & SPIDER (OSAM-1)

Formulation	Development	Operations

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**192.8**	**227.2**	**133.5**	**117.2**	**59.4**	**14.6**	**0.0**
Change from FY 2020			**-93.7**				
Percentage change from FY 2020			**-41.2%**				

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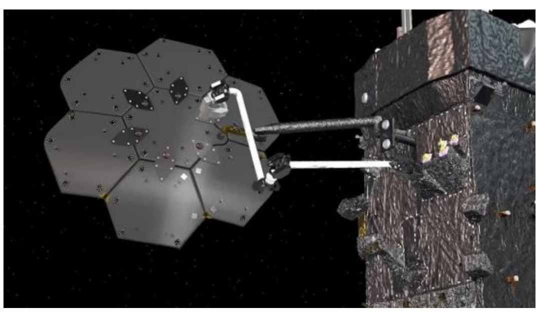

The SPace Infrastructure DExterous Robot will assemble a functional communications antenna and manufacture a spacecraft beam.

PROJECT PURPOSE

On-Orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1) includes satellite servicing technology development to qualify advanced technologies that enable on-orbit satellite life extension and prepares the SPace Infrastructure DExterous Robot (SPIDER) to robotically assemble a communications antenna and manufacture a spacecraft beam in orbit.

Within this budget, NASA will complete critical servicing technologies through qualification before transitioning them to U.S. industry. Technology areas to be qualified include several components of the navigation system, servicing avionics and software, robot arm and software elements, and tool drive system and tools.

NASA will utilize the Maxar spacecraft bus to demonstrate robotic assembly of a functional communications antenna and in-space manufacturing capabilities. Specifically, NASA will assemble multiple antenna reflector elements into one large antenna reflector using SPIDER. This revolutionary process allows satellites, telescopes, and other systems to use larger and more powerful components that would not fit into a standard rocket fairing when fully assembled without complex folding mechanisms. The technologies could enable entirely new architectures and space infrastructure for a wide range of Government and commercial missions, including commercial satellites.

RESTORE & SPIDER (OSAM-1)

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2021

NASA will focus the OSAM-1 mission on qualifying satellite servicing technologies through ground demonstrations, and flight demonstrating in-space assembly and manufacturing technologies. Technologies will be prioritized in collaboration with industry with the intent that industry will commercialize these technologies. The OSAM-1 flight demonstration will enable in-space manufacturing capabilities including the addition of SPIDER as part of its mission.

PROJECT PRELIMINARY PARAMETERS

With application to both commercial and NASA operations, OSAM-1 will advance satellite servicing capabilities and in space assembly and manufacturing capabilities. Objectives include:

- Autonomous, real-time relative navigation system, including sensors, algorithms, and processors, join forces, allowing the spacecraft to inspect and rendezvous safely with its client;
- Servicing Avionics control the spacecraft rendezvous and robotic tasks;
- Autonomous capture of client satellite;
- Dexterous Robotic Arms provide maneuverable arms for executing servicing assignments using telerobotics, including software;
- Advanced Tool Drive and Tools are multifunction tools for executing the servicing tasks;
- Propellant Transfer System delivers measured amounts of fuel to the client at the right temperature, pressure, and rate;
- Relocation of client satellite;
- On-orbit assembly of an antenna; and
- On-orbit manufacture of a beam.

ACHIEVEMENTS IN FY 2019

During FY 2019, the project continued to work toward finalizing its critical design and completion of component and subassembly testing. Additionally, the project advanced its ground systems and concept of operations for the mission, positioning the project to conduct a Critical Design Review, which will include the integration of the SPIDER payload, in 2020.

In February 2019, the International Space Station (ISS) crew successfully installed the Robotic Refueling Mission-3 (RRM3) robotic tools, the tool pedestal, and the interface plate on the Japanese airlock slide table. The hardware remained in the closed airlock until the first set of external robotic operations occurred in April 2019. On April 8, RRM3 experienced an issue that necessitated the venting of the cryogenic fluid contained within the module, but the mission is still projected to carry out the tool operations associated with transferring cryogenic fuel in space, demonstrating the cutting-edge technologies needed to make it possible. The RRM3 robotic operations will focus on the final step of connecting, sealing, and managing the hoses needed to enable cryogenic fuel transfer on-orbit. The first set of these operations was successfully executed on April 14, 2019, and the final set of on-orbit robotic

RESTORE & SPIDER (OSAM-1)

Formulation	Development	Operations

operations are planned for no earlier than February 2020. RRM3 completed an on-orbit demonstration of cryogenic methane storage without boiloff.

To date, NASA has hosted four Industry Days: April 2017, January 2018, December 2018, and most recently, September 18, 2019. The event, previously called Industry Day, is now referred to as On-Orbit Servicing, Assembly, and Manufacturing (OSAM) Technology Transfer Day. During the September 2019 industry day, attendees heard numerous discussions regarding on-orbit servicing, assembly, and manufacturing, received access to a technology catalog of more than 200 items, and toured facilities where technology is tested. Approximately 142 people attended, representing 97 different companies, doubling previous participation. NASA also hosts regular individual meetings with interested companies to provide more specific information on technology as needed. To date, there have been 117 formal requests for information on NASA's satellite servicing technology efforts.

WORK IN PROGRESS IN FY 2020

The project will finalize a plan to incorporate the SPIDER payload as well as continued development of the Restore subsystems with a notional Launch Readiness Date of 2023. The project will complete design, engineering design unit test, validation, and risk mitigation activities and continue ground subsystems critical design reviews. Qualification will begin for those subsystems that have completed Critical Design Review. Restore will proceed to an integrated flight demonstration mission Critical Design Review, which will occur toward the end of 2020.

NASA and Maxar finalized the SPIDER contract on January 30, 2020.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

The project will continue critical design reviews for subsystems and continue ground-based qualification efforts that support commercial on-orbit servicing systems.

Maxar will continue to build and assemble flight systems and initiate payload and integration activities in FY 2021 with a notional SPIDER pallet delivery anticipated in first quarter of FY 2022.

OSAM-1 will continue spacecraft bus and payload development throughout FY 2021.

The project will continue to leverage Technology Transfer mechanisms and pursue partnerships with interested U.S. companies through Space Act Agreements.

RESTORE & SPIDER (OSAM-1)

Formulation	Development	Operations

ESTIMATED PROJECT SCHEDULE

Milestone	Formulation Authorization Document	FY 2021 PB Request
Formulation Authorization		
Key Decision Point-A (KDP-A)	May 2016	May 2016
KDP-B	Jan 2017	Jan 2017
KDP-C	Apr 2018	no earlier than (NET) May 2020
CDR	Nov 2018	NET Sep 2020
System Integration Review	Jul 2019	The project is still in formulation, and these dates will be determined at KDP-C.
KDP-D	Sep 2019	
Operational Readiness Review	Mar 2020	
KDP-E	Nov 2020	
Launch	Nov 2020	

Formulation Estimated Life Cycle Cost Range and Schedule Range Summary

KDP-B Date	Estimated Life Cycle Cost Range ($M)	Key Milestone	Key Milestone Estimated Date Range
Jan 2017	629 - 756	LRD	Jun - Dec 2020

Note: Life Cycle cost estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (KDP-C), which follows a non-advocate review and/or preliminary design review. The values above *do not reflect current estimates but are consistent with the KDP-B decision memorandum.*

RESTORE & SPIDER (OSAM-1)

Formulation	Development	Operations

Project Management & Commitments

Element	Description	Provider Details	Change from Formulation Agreement
Propellant Transfer Subsystem (PTS)	Develop, test, and build of propellant transfer system.	Provider: N/A Lead Center: KSC Performing Center(s): KSC, GSFC Cost Share Partner(s): N/A	N/A
Spacecraft Bus	Build and deliver a spacecraft bus to carry the payload	Provider: Maxar Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	Contract awarded in 2017
Program Management	Project management, payload development and delivery, mission integration	Provider: N/A Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
SPIDER	Build and deliver the SPIDER payload	Provider: Maxar Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): LARC	Contract awarded in 2020

Acquisition Strategy

Element/Component	Acquisition Method	Developer
Robot Arm	In-house development	GSFC with MacDonald, Dettwiler and Associates (MDA) as major sub
Rendezvous & Proximity Ops Cameras	NASA Competition	Neptec Design Group
LIDAR	In-house development	N/A
Vision Sensor Subsystem Cameras	NASA Competition	Malin Space Science Systems
Propellant Transfer System	Competition/Justification for Other than Full and Open Competition	Valve Tech, FHM Aerospace, Vacuum and Air Components Company of America, Hoffer

RESTORE & SPIDER (OSAM-1)

Formulation	Development	Operations

Element/Component	Acquisition Method	Developer
Motors Arm, next generation Tool Drive, Pan/Tilt Unit (camera), Motorized Zoom Lenses	Omnibus Multidiscipline Engineering Services contract	CDA InterCorp, Triump, Avior
SPIDER	Competitively selected via Tipping Point solicitation	Maxar

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Build and delivery of spacecraft bus	Maxar	Palo Alto, CA
Build and delivery of SPIDER payload	Maxar	Palo Alto, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Mission Concept Review (MCR)		Apr 2016	Affirm mission need, examine proposed mission's objectives, and validate the concept for meeting those objectives.	Passed	SRR
System Requirements Review (SRR)	Standing Review Board (SRB)	Oct 2016	Examine the functional and performance requirements and the preliminary project plan. Ensure the requirements and selected concept will satisfy the mission.	Passed	PDR
Joint Confidence Level (JCL)	Tecolote	Nov 2017	Determine realistic 50/70 percent confidence level on reference budget and schedule.	N/A	NET Sept 2020
Preliminary Design Review (PDR)	SRB	Nov 2017	Demonstrate the preliminary design meets all system requirements with acceptable risk and within cost and schedule constraints.	Passed	CDR

RESTORE & SPIDER (OSAM-1)

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Joint Confidence Level (JCL)	TBD	NET Sep 2020	Determine realistic 50/70 percent confidence level on budget and schedule to be approved.		CDR
Critical Design Review (CDR)	SRB	NET Sep 2020	Demonstrate the maturity of the design is appropriate to support proceeding with full-scale fabrication, assembly, integration, and test.		SIR

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Small Spacecraft Technology	25.5	--	**46.0**	46.2	48.2	52.7	57.7
Flight Opportunities Program	20.0	--	**20.0**	20.0	20.0	20.0	20.0
Space Nuclear Program	0.0	--	**100.0**	142.4	168.1	190.0	256.8
Cryogenic Fluid Management	13.8	--	**104.2**	137.0	160.1	137.3	145.5
Green Propellant Infusion Mission	4.4	--	**0.0**	0.0	0.0	0.0	0.0
Terrain Relative Navigation	0.2	--	**0.0**	0.0	0.0	0.0	0.0
LeO-based Flight Test Inflatable Decelerator	20.0	--	**20.1**	10.6	0.0	0.0	0.0
Mars Oxygen ISRU Experiment	6.5	--	**2.3**	1.9	1.6	0.2	0.0
Archinaut	14.7	--	**20.5**	13.6	3.6	0.0	0.0
Deep Space Optical Communications	39.4	--	**10.5**	4.6	1.1	0.1	0.0
Deep Space Atomic Clock	0.6	--	**0.0**	0.0	0.0	0.0	0.0
Tech Demo Management and Integration	4.3	--	**15.1**	37.2	42.4	44.3	45.2
Tech Demo Selected ACO/TP	9.3	--	**2.6**	0.0	0.0	0.0	0.0
Total Budget	**158.7**	**--**	**341.4**	**413.4**	**445.0**	**444.5**	**525.1**

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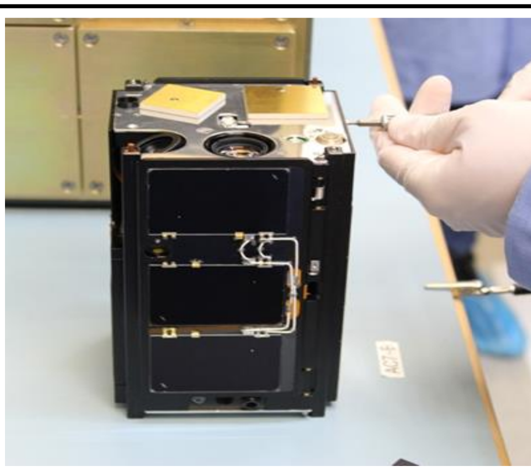


Shown here is one of the two Optical Communications and Sensor Demonstration spacecraft that successfully concluded their demonstration mission in 2019.

SMALL SPACECRAFT TECHNOLOGY

The Small Spacecraft Technology program expands U.S. capability to execute unique missions through rapid development and demonstration of capabilities for small spacecraft applicable to exploration, science and the commercial space sector. Through targeted development and frequent in space testing, the program enables execution of missions at much lower cost than previously possible, substantially reduces the time required for development of spacecraft, enables new mission architectures using small spacecraft, expands the reach of small spacecraft to new destinations and challenging new environments,

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

and enables the augmentation of existing assets and future missions with supporting small spacecraft.

Between 2020 and 2022, the Small Spacecraft Technology program anticipates reaching initial launch readiness for 19 spacecraft across 15 current missions, including the following.

Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment

At the end of 2019, Small Spacecraft Technology awarded a rapid lunar exploration precursor mission to deliver and operate a CubeSat in the lunar near rectilinear halo orbit (NRHO) targeted for Artemis/Gateway. The Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment led by three U.S. small business is expected to be the first spacecraft to operate in the NRHO and will demonstrate how to enter and operate in this orbit, as well as test new peer-to-peer navigation capability. This information will help reduce logistical uncertainty for Gateway as NASA works to return U.S. astronauts to the Moon.

For more information, go to: https://www.nasa.gov/press-release/nasa-funds-cubesat-pathfinder-mission-to-unique-lunar-orbit/

Lunar Flashlight

The Lunar Flashlight mission will precede human explorers to the Moon to prospect for water resources that can be extracted to support sustainable exploration and commercial lunar activity. The CubeSat mission will use near infrared lasers to shine light into permanently shadowed craters at the lunar south pole while the on-board spectrometer measures surface reflection and composition to map water ice deposits and volatiles. The spacecraft is currently planned to launch with the Artemis I mission.

Pathfinder Technology Demonstrator

The missions in the Pathfinder Technology Demonstrator (PTD) series will test the operation of a variety of novel CubeSat technologies in orbit, providing significant enhancements to the performance of these small and effective spacecraft. The spacecraft, payload integration, and operations are provided under a commercial contract with Tyvak Nano-Satellite System, Inc. Launch sequence and timing depends on technical progress and flight partners. The goals of the first three PTD missions are as follows:

- The PTD-1 mission will demonstrate the Tethers Unlimited Inc. (TUI) HYDROS water-fueled thruster. The development of this thruster was supported through a Tipping Point public-private partnership between TUI and NASA. The HYDROS is intended to provide safe, high-performance propulsion for secondary payloads. The propulsion system is launched with only liquid water as the propellant and then uses electrolysis to split the water into gaseous hydrogen and oxygen for a simple bipropellant thruster once deployed on-orbit. In the future, this propulsion technology could be used with water found from lunar soil.

- The PTD-2 mission will demonstrate the Blue Canyon Technologies (BCT) Hyper-XACT attitude determination and control system. The development of this improved attitude determination and control system was supported through a Tipping Point public-private partnership between BCT and NASA. The Hyper-XACT is intended to extend the capabilities of CubeSat attitude control systems for longer duration missions with tighter performance requirements by improving pointing performance, radiation tolerance, reliability, and system life.

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

- The PTD-3 mission will demonstrate the MIT Lincoln Laboratory TeraByte InfraRed Delivery (TBIRD) optical communication system. The TBIRD was funded by NASA's Space Communications and Navigation Program and is intended to achieve an unprecedented 200 gigabit per second (Gbps) data downlink rate. This will be a thousand-fold increase over the current state-of-the-art CubeSat optical downlink demonstrated by the just completed Optical Communications and Sensor Demonstration mission.

Starling

Starling is a technology demonstration mission that will deploy a formation of four CubeSats to test multiple distributed mission technologies. Distributed systems of small spacecraft can responsively provide cost-effective multi-point science data collection, communications, monitoring, and inspection infrastructure in Earth orbit and to support Artemis and explorations destinations beyond. The Starling mission will: test network communication protocols with the goal of demonstrating a network that is resistant to multiple lost nodes and scalable to hundreds of spacecrafts; test formation flight control algorithms; test relative navigation methods that do not rely on Earth-centric resources like GPS; and demonstrate autonomous reactive operations that allow the distributed mission to reconfigure in response to external sensor data. The Starling mission includes contributions from Stanford University and Blue Canyon Technologies.

Tipping Point CubeSat Demonstration Missions

Space Technologies' fourth competitive Tipping Point public-private partnership solicitation included selection of four CubeSat missions including three for development and flight demonstration of efficient and affordable propulsion systems and one in autonomous operations.

- Accion Systems Inc. will mature a propulsion system based on the Tiled Ionic Liquid ElectroSpray thruster to demonstrate attitude control and course corrections capabilities for interplanetary CubeSats with a smaller, lighter, and lower power system than used by the MarCO mission.

- CU Aerospace LLC, NearSpace Launch, and the University of Illinois at Urbana-Champaign will build and test the Dual Propulsion Experiment CubeSat equipped with two different propulsion systems. These systems were developed with NASA Small Business Innovation Research funding and offer high-performance, low-cost and safe pre-launch processing.

- ExoTerra Resource LLC will build, test, and launch a CubeSat with a compact, high impulse solar electric propulsion module. The Courier Solar Electric Propulsion Module will be demonstrated in space as the CubeSat moves from low-Earth orbit to the radiation belts surrounding Earth. This small electric propulsion system could open up cis-lunar space and Mars to more affordable small spacecraft for targeted science and exploration missions.

- As access to space increases, so does the need for ground resources, such as tracking stations. With an in-space demonstration, Blue Canyon Technologies will mature the X-NAV autonomous navigation software solution for CubeSats, so they can traverse space with reduced need for navigational aid from ground stations on Earth.

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

Small Spacecraft Systems Virtual Institute

Small Spacecraft, in partnership with Science, also maintains the Small Spacecraft Systems Virtual Institute, hosted at NASA's Ames Research Center in Moffett Field, California, to leverage the growing small spacecraft community, promote innovation, identify emerging technology opportunities, and provide an efficient channel for communication about small spacecraft systems with industry, academia, and other Government agencies.

Recent and Planned Achievements

In 2019 the program successfully concluded the Optical Communications and Sensor Demonstration (OCSD) mission. This mission demonstrated the first-ever, high-speed laser communication from a CubeSat as well as performing the first semi-autonomous coordinated propulsive maneuver between two CubeSats. Supplemental to the primary objectives of the mission, OCSD also demonstrated a proof-of-concept for CubeSat-to-CubeSat optical communications with the secondary payload on the Integrated Solar Array and Reflectarray Antenna mission that had previously been used to help develop the reflect array technology for MarCO.

The following small spacecraft missions are projected to reach flight readiness in FY 2020:

- The CubeSat Lasercom Infrared Crosslink mission is targeting flight of a risk reduction mission in 2020 ahead of demonstrating full duplex spacecraft to spacecraft optical communications crosslinks between two small CubeSats in FY 2021.
- The third Pathfinder Technology Demonstrator mission will target very high-bandwidth optical downlink at 200 gigabits per second from a CubeSat. The Starling-Shiver distributed spacecraft demonstration mission in partnership with the U.S. Air Force Research Laboratory will launch in 2020 to test formation flight, inter satellite networking, and other enabling capabilities for future mission architectures that use multiple small spacecraft to achieve a coordinated objective.
- The Advanced Composite Solar Sail System mission will demonstrate deployment of an 80 square meters sub-scale composites boom supported solar sail system in low-Earth orbit as pathfinder for a future 500 square meters solar sail system suitable for low-cost deep space missions for heliophysics, small body planetary science, and human space flight support.

With an objective of expanding the capability of small spacecraft to execute missions at new destinations and in challenging new environments, Small Spacecraft Technology anticipates reaching initial launch readiness for 19 spacecraft across 15 current missions between 2020 and 2022.

FLIGHT OPPORTUNITIES PROGRAM

The Flight Opportunities program facilitates rapid demonstration of promising technologies for space exploration and the expansion of space commerce through suborbital testing with industry flight providers. The program matures capabilities needed for NASA missions while strategically investing in the growth of the U.S. commercial spaceflight industry. These flight demonstrations take technologies from ground-based laboratories into relevant environments to increase technology readiness and validate feasibility while reducing the costs and technical risks of future missions. Awards and agreements for flight demonstrations are open to researchers from industry, academia, non-profit research institutes, and other Government organizations. These investments help advance technologies of interest to NASA while supporting commercial flight providers and expanding space-based applications and commerce.

In 2019, the Flight Opportunities program facilitated the commercial suborbital flight testing of 43 technology development payloads across four suborbital reusable launch vehicle flights, one vertical takeoff/vertical lander flight campaign, six high-altitude balloon flights and one parabolic campaign. U.S. commercial vendors providing flight services in 2019 included: Black Sky Aerospace, Blue Origin, Masten Space Systems, Near Space Corporation, Raven Aerostar, Virgin Galactic, World View, and Zero Gravity Corporation. Capabilities across several providers were used to test technologies integral to returning U.S. astronauts to the Moon and enabling future missions to Mars.

For more information, go to: https://www.nasa.gov/directorates/spacetech/flightopportunities/One_Giant_Leap_for_Lunar_Landing_Navigation

By early 2020 the program will have concluded all remaining investments in orbital small launch vehicle development. These investments have provided critical support to multiple U.S. companies entering this globally competitive market. With vehicles entering commercial service, the program is looking to transition from stimulating vehicle development to stimulating the market through the purchase of flight services. In 2020 and 2021, the program will continue to facilitate the use of commercial suborbital vehicles and expand the connection of these opportunities to technology development investments and subsequent orbital flight opportunities to streamline a rapid and affordable path for new technology into flight missions.

Recent and Planned Achievements

In early FY 2019, both Virgin Galactic and Blue Origin flew their first dedicated suborbital space flights for NASA technology demonstrations. These flights carried a series of space exploration and utilization technologies, including research that could: aid future missions in how they interact with the lunar surface to mitigate the impact of dust on humans and equipment; separate gas and liquid for in-situ resource processing and on orbit fuel transfer; and understand plant behavior to potentially grow food for sustained human activity beyond Earth. In February, Virgin Galactic demonstrated four additional payloads, flying for the second time in just three months.

Technology Demonstration Missions will partner with Flight Opportunities to conduct subsystem level testing and technology risk reduction via suborbital testing capabilities. This will allow technology demonstration projects access to U.S. suborbital providers, as well as parabolic and entry, descent, and landing test capabilities to perform risk reduction of component hardware prior to system integration, increasing mission success.

SPACE NUCLEAR TECHNOLOGIES

The Space Nuclear Technologies portfolio integrates NASA's previous technology development efforts for nuclear fission power and propulsion systems to a new path forward to enable long-duration surface missions on the Moon and eventually Mars, shorter duration human transport to Mars, and large payload delivery vehicles to Mars and beyond. The new portfolio will foster partnerships with the U.S. Department of Energy (DOE) and U.S. Department of Defense (DoD) as well as other relevant Government agencies who share interest in reliable and portable, clean energy capabilities, such as a shared investment in a common fuel design and fabrication capability for special purpose power and propulsion reactors.

The foundation for these capabilities is in focused technology development across four major elements:

(1) nuclear fission power to establish electric power reactor designs to support Artemis; and within Nuclear Propulsion:
(2) nuclear fuel and reactor development,
(3) nuclear fission power and propulsion study assessments, and
(4) nuclear fission propulsion subsystem development.

This program will place a high-priority on lunar surface power but will also continue to make progress on propulsion capabilities to support future human missions to Mars. Collectively, these efforts will provide critical demonstrations and system/mission trade studies to guide surface and in-space transportation activities that support human to Mars mission architecture and investment priorities.

Live: Nuclear Fission Power

The goal is to develop a small, lightweight fission power system that could enable long-duration crewed missions to the Moon, Mars and destinations beyond. The intent is to demonstrate the system in an operational mission to verify functionality and performance (e.g., by powering a surface science or ISRU payload). The flight system will optimize the fission reactor heat source, energy conversion, flight radiators, radiation hard flight control electronics, and identify launch safety and security requirements with a target demonstration in the 2027 timeframe. The project will seek to identify design trades and collaborative opportunities with industry, and to the extent feasible take advantage of the interagency investment in a common fuel source for both nuclear power and propulsion systems noted above.

Upon successful demonstration, the technology can be used for long-duration human surface missions on the Moon and eventually Mars and will be capable of addressing the need for continuous power for day and night operations. The technology will enable mission operations in harsh environments, such as permanently shadowed craters. This work is being conducted in collaboration with DOE.

Go: Nuclear Propulsion

Unlike nuclear power, nuclear propulsion is not needed to support NASA's near-term lunar mission but holds potential for future missions to Mars. Similar to nuclear fission power nuclear propulsion efforts will be done in collaboration with the DoD, DOE, and any other relevant Government agencies. NASA will work to the maximum degree to find synergies between nuclear power and propulsion efforts.

Specific activities in FY 2021 will include a focus on nuclear fuel and reactor development to mature fuel systems incorporating non-weapon's grade nuclear materials that provide high-performance, long life, and meet established safety standards for launch and space operations. This effort will focus on materials development, manufacturing, and testing. The prior Nuclear Thermal Propulsion/ fuel element development revealed gaps in all of these areas that must be overcome to achieve a credible reactor fuel system. A key gap is a testing capability that allows prototypic fuel elements to be evaluated under relevant operating conditions that include the combined effects of radiation, temperature, and fluid flow.

The portfolio will also include nuclear fission power and propulsion study assessments to inform future flight demonstrations and mission uses. In FY 2019, NASA initiated a Nuclear Thermal Propulsion/ flight demonstration study to evaluate the most promising flight system options in preparation for a System Feasibility Review to determine whether the technical progress justifies proceeding with the next stage of development. NASA will continue to conduct trade studies needed to define and compare mission capability and technology needs for electric power and in-space propulsion (both nuclear electric and nuclear thermal propulsion), in collaboration with industry and other government agencies.

Going forward, NASA will establish a nuclear fission propulsion subsystem maturation effort that includes design, analysis, and sub-scale ground and flight testing. Candidate Nuclear Thermal Propulsion subsystems requiring further development before use include the propellant feed pumps, valves, engine nozzles, and decay heat removal. Candidate Nuclear Electric Propulsion subsystems requiring further development before use include the power conversion, heat rejection, power management and distribution, and electric thrusters. Subsystems that are common to both Nuclear Thermal Propulsion and Nuclear Electric Propulsion include: radiation shielding, neutron reflectors, reflector drive motors, and radiation tolerant sensors and electronics. The subsystem maturation effort will include widespread industry participation via competed solicitations and commercial product leveraging using either new or existing solicitations, such as Tipping Point and Announcement of Collaboration Opportunity.

NASA continues to develop Hydrogen cryogenic fluid management technologies targeting zero boil-off capabilities needed for in space transportation systems requiring hydrogen (Nuclear Thermal Propulsion) as described below.

Go: Cryogenic Fluid Management

In order to establish a human presence on a planetary surface and to support nuclear propulsion for deep space missions, cryogenic fluid management is an enabling technology to support a variety of NASA exploration missions, including in-space transportation systems to support humans to Mars using Nuclear Thermal Propulsion/ or hybrid propulsion systems; human lander systems; and lunar or Mars surface operations, including in-situ resource utilization. Using the results of an internal NASA road-mapping activity, a Cryogenic Fluid Management Request for Information, and direct discussions with industry partners to formulate the technology demonstration priorities and acquisition approach. The first phase of these technology maturation projects came in the form of Tipping Point public private partnerships that were awarded in late 2018. These proposals will include a lunar lander sub-orbital demonstration and a flight test of an advanced insulation.

The Evolvable Cryogenics (eCryo) project is completing its work with a series of ground demonstrations at Marshall Space Flight Center and Glenn Research Center to validate the performance of propellant storage tanks designed for long-term on-orbit storage. In addition to managing the propellant boil-off by validating the effectiveness of advanced multi-layer insulation, the team is evaluating the reduction of ancillary system mass and complexity. The project has investigated using the remaining boil-off gases to replace existing pressurization and attitude control systems, and to provide electrical power for the Space Launch System (SLS) Exploration Upper Stage and other launch vehicle systems. The team is also developing new cryogenic monitoring instrumentation and analytical models to assist in determining cryogenic system health during in space operations. For NASA, these technologies enable beyond low-Earth orbit exploration missions, while industry will likely infuse the technologies on next generation launch vehicles and on-orbit stages, making them more efficient and capable. By taking an incremental ground test approach, NASA is prioritizing technologies needed by Exploration, including SLS Upper Stage development, and the long-term needs of the aerospace industry. The project will build on the knowledge gained from previous investments and utilize existing Agency assets and test facilities capable of maturing cryogenic propellant transfer and storage technologies.

Go: Green Propellant Infusion Mission

Green Propellant Infusion Mission is a dedicated spacecraft to demonstrate non-toxic propellant propulsion with the goal to provide an alternate to hydrazine propellant applicable to a small to medium-sized spacecraft. Higher performing and safer propellant alternatives are at a tipping point. Once demonstrated in-space, rapid incorporation could occur into a variety of spacecraft. NASA selected AF-M315E as an innovative, low-toxicity monopropellant alternative with improved performance over hydrazine. The AF-M315E propulsion system is expected to improve overall vehicle performance by 40 percent and processing efficiency while decreasing operational costs by reducing health and environmental hazards. The green propellant formula, thrusters, and related systems will perform a series of in-space demonstration tests.

Recent and Planned Achievements

- NASA will complete feasibility studies for surface power and propulsion and development of mission concepts by mid-2020, including conducting trade studies between high assay low enriched uranium and high enriched uranium.

- NASA will continue to work with DOE to formulate system design. Mission concepts for both fission-based power and propulsion are targeted by the end of FY 2020 with lunar surface power prioritized for near-term demonstration.

- The Evolvable Cryogenics (eCryo) project completed its Structural Heat Intercept-Insulation-Vibration Evaluation Rig (SHIIVER) thermal testing in January 2020. This test used both liquid nitrogen and liquid hydrogen to demonstrate the effectiveness of new multi-layer insulation and evaluate the potential benefit of using vapor vented from a propellant tank to intercept heat coming into the tank through structural elements. The result of the test will be shared in Spring 2020.

- NASA launched the Green Propellent Infusion Mission via rideshare on a SpaceX Falcon Heavy All data collected to-date indicate that the propulsion system is performing as expected and that the thrusters are healthy.

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

LAND: EXPANDED ACCESS TO DIVERSE SURFACE DESTINATIONS

Terrain Relative Navigation

The Terrain Relative Navigation project will improve targeting accuracy for landing and provide hazard avoidance to enable access to scientifically compelling sites with acceptable risk. All of NASA's current human and robotic precursor mission architectures for planetary surface exploration require this technology. Using Terrain Relative Navigation, the Mars 2020 powered descent vehicle will estimate its location while descending through the Martian atmosphere. This allows the vehicle to determine its position relative to the ground with an accuracy of approximately 200-feet (60-meters) or less. Upon successful demonstration, this technology will provide capability to land near pre-deployed assets, provide the capability to avoid large scale landing hazards during entry, descent, and landing operations, and will reduce post-landing surface drive distances. This project delivered its flight hardware to Mars 2020 in fall 2018 for mission integration.

Low-Earth Orbit Flight Test of Inflatable Decelerator (LOFTID)

NASA, in partnership with United Launch Alliance, will conduct a flight test of inflatable aerodynamic decelerator technology to determine the feasibility of this technology in supporting high-mass entry, descent, and landing on Mars. The reentry vehicle will be flown as a secondary payload on an Atlas V launch vehicle, used to deliver a primary payload to Earth orbit. After the primary payload is released, the aeroshell will be exo-atmospherically inflated and the Atlas V Centaur upper stage will orient and de-orbit the reentry vehicle. The flight will test high-mass entry, descent, and landing technology at a scale (6-meter) and at atmospheric conditions similar to landing payloads on Mars. This project will also demonstrate capabilities for a high-mass return to Earth from low-Earth orbit, that could enable applications such as flight hardware re-use and return of products manufactured in space for terrestrial use. By conducting this effort with an industry cost-sharing partnership, NASA is significantly reducing the overall cost of this technology while enabling a potential commercial capability to achieve efficient, high-mass return to Earth from low-Earth orbit.

Recent and Planned Achievements

- LOFTID will conduct a critical design review in July 2020 and KDP-D in August 2020. NASA and United Launch Alliance finalized plans to fly LOFTID as a rideshare with the Joint Polar Satellite System-2 (JPSS-2) on the Atlas V, scheduled for March 2022.

- NASA completed several Mars 2020 technology developments including Terrain Relative Navigation (TRN) and the Mars 2020 Entry, Descent, and Landing Instrumentation with deliveries between fall 2018 and spring 2019 to support the Mars 2020 schedule.

LIVE: SUSTAINABLE LIVING AND WORKING FARTHER FROM EARTH

Mars Oxygen In-Situ Resource Utilization (ISRU) Experiment (MOXIE)

The Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE) will demonstrate in-situ resource utilization technologies to enable propellant and consumable oxygen production from the Martian

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

atmosphere for future exploration missions. Specifically, MOXIE will produce oxygen from a Mars atmosphere, demonstrate the feasibility of ISRU on Mars, validate analytical models for scaling up of future ISRU systems, and provide valuable knowledge needed for future mission development. MOXIE will fly on the Science Mission Directorate's Mars 2020 mission.

Recent and Planned Achievements

- MOXIE was delivered for integration into the Mars 2020 Entry, Descent, and Landing Instrumentation with deliveries between fall 2018 and spring 2019 to support the Mars 2020 schedule. The instrument will be delivered to the Mars surface in February 2021 and begin conducting experiments after the mission completes its surface operations transition period.

EXPLORE: TRANSFORMATIVE MISSIONS AND DISCOVERIES

Archinaut (On Orbit Servicing and Manufacturing Demonstration-2)

In partnership with commercial industry, NASA develops and demonstrates technologies required to manufacture, assemble, and aggregate large and/or complex systems in space utilizing robotic and additive manufacturing technology.

Archinaut (Made in Space, Moffett Field, CA) was awarded in July 2019 to develop a flight demonstration model of their Phase I ground demonstration technology. Once deployed and positioned in orbit, a small spacecraft will 3D-print two beams that extend nearly 33-feet from each side of the spacecraft. As it continues to manufacture the hardware, these beams will unfurl solar arrays that can generate up to five times more power than traditional solar panels on similar-sized spacecraft. This disruptive capability could transform the traditional spacecraft-manufacturing model by enabling in-space creation of large spacecraft systems. No longer will developing, building, and qualifying a spacecraft focus so heavily on an integrated system that must survive launch loads and environments. Archinaut could also greatly reduce cost while increasing capabilities for both NASA and commercial space applications.

Deep Space Optical Communication

Deep Space Optical Communication technologies are considered essential for future human missions to Mars and have a wide range of applications for planetary science missions including those to Mars and the Jovian systems. The Deep Space Optical Communications project led by the Jet Propulsion Laboratory (JPL) will develop key technologies for the demonstration of a deep space optical flight transceiver and ground receiver that will provide greater than 10 times the data rate of a state-of-the-art deep space RF system (Ka-band). This capability will enable advanced instruments, live high definition video, telepresence that allow for deep space human exploration of the solar system.

NASA successfully completed and reduced significant risks on technologies including a low mass spacecraft disturbance isolation assembly, a flight qualified photon counting detector array, a high efficiency flight laser amplifier, and a high efficiency photon counting detector array for the ground-based receiver. Deep Space Optical Communication will demonstrate the high bandwidth flight laser optical communication terminal on the Science Mission Directorate's Psyche mission.

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

Deep Space Atomic Clock

The Deep Space Atomic Clock project led by JPL has the objective to validate a miniaturized, mercury-ion, atomic clock that is 100 times more accurate than today's state-of-the-art space clocks used for spacecraft navigation systems. Launched in June 2019, the Deep Space Atomic Clock is demonstrating ultra-precision timing in space and its benefits for one-way radio-based navigation. If successful, it will free up precious deep space communications bandwidth to perform greater scientific data return. The enhanced navigation and increased communications bandwidth permitted by the new clock will dramatically improve the exploration mission requirement for advanced communication capabilities. Precision timing and navigation provided by the new clock will also have the potential to improve the Nation's next generation GPS system. The demonstration launched via rideshare on a SpaceX Falcon Heavy (STP-2) in June 2019 and is funded in a partnership with SCaN.

Recent and Planned Achievements

- NASA will build on its ground demonstration of In-Space Robotic Manufacturing and Assembly through the continued use of public-private partnerships to conduct a flight demonstration for new technologies used to build large structures in a space environment. NASA awarded a Phase 2 Tipping Point to Made in Space in July 2019. Along with Northrop Grumman, Made in Space will build and demonstrate the Archinaut, an IRMA system under this contract. NASA also awarded a Phase 2 to Maxar to build the SPace Infrastructure DExterous Robot (SPIDER), a robotic beam to be delivered to OSAM-1. Archinaut will conduct a preliminary design review in March 2020.

- Deep Space Atomic Clock was successfully activated and continues to operate normally. On Orbit commissioning is complete and has entered the performance testing phase. The Ultra-Stable Oscillator (USO) was powered on the week of November 25, 2019 and the remainder of the DSAC payload was powered on December 5, 2019.

- Deep Space Optical Communications held KDP- C in June 2019 and completed its Critical Design Review for its targeted delivery to Psyche by June 2021.

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

Acquisition Strategy

These critical technology projects are defined as part of the strategic framework and capabilities, and through requirements determined by Federated Team, and through the Space Technology Mission Directorate's Strategic Technology Architecture Round-table (STAR) (STAR) process. In addition, Space Technology embraces competition and external partnerships, as such some of the technologies are selected through annual Tipping Point, Announcement of Collaboration Opportunity, and other NASA solicitations.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Archinaut	Made in Space	Moffett Field, California

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Standing Review Board (SRB)	NASA	Dec 2019	DSOC Flight Critical Design Review	Passed	Jun 2020
SRB	NASA	Mar 2019	LOFTID Preliminary Design Review	Passed	Jul 2020

SBIR AND STTR

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**207.2**	**--**	**402.8**	**478.7**	**542.6**	**544.8**	**481.1**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

NASA selected Astrobotic, shown above, to deliver payloads to the Moon in 2021 as part of the Artemis mission. The company developed its Peregrine Lander for delivering payloads to lunar orbit and the lunar surface with NASA SBIR and STTR awards.

NASA's Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs leverage the Nation's innovative small business community to support research and development in support of NASA's mission in human exploration, science, and aeronautics. In particular, this program will support NASA's the Moon to Mars objectives by identifying and accelerating relevant technologies drawn from the SBIR portfolios through post Phase II awards. These programs provide the small business sector with an opportunity to develop technology for NASA and to commercialize that technology to spur economic growth.

The Agency actively works to facilitate the infusion of NASA-funded SBIR and STTR technologies into its missions and projects. Research and technologies funded by SBIR and STTR contracts have made important contributions to the Agency's mission. Examples include:

- An intelligent rover wheel with integrated sensing and perception subsystems to improve mobility on the Moon and planetary bodies that could also be used on Earth for autonomous tractors and other off-road vehicles;
- Solar panels that deploy like Venetian blinds and a lightweight, deployable solar panel that leverages recent advancements in thin film solar cell technology;
- Technology that enables autonomous and safe operations of unmanned aircraft systems over long periods of time in cluttered, complex environments;
- A simulation to screen, test, and validate commercial off-the-shelf hardware that could be used for high-performance computing systems that help mission managers efficiently select onboard electronics; and
- A high-resolution X-ray instrument to analyze surface rocks and core samples on planets and asteroids to advance our understanding of the Moon, Mars, and even Earth.

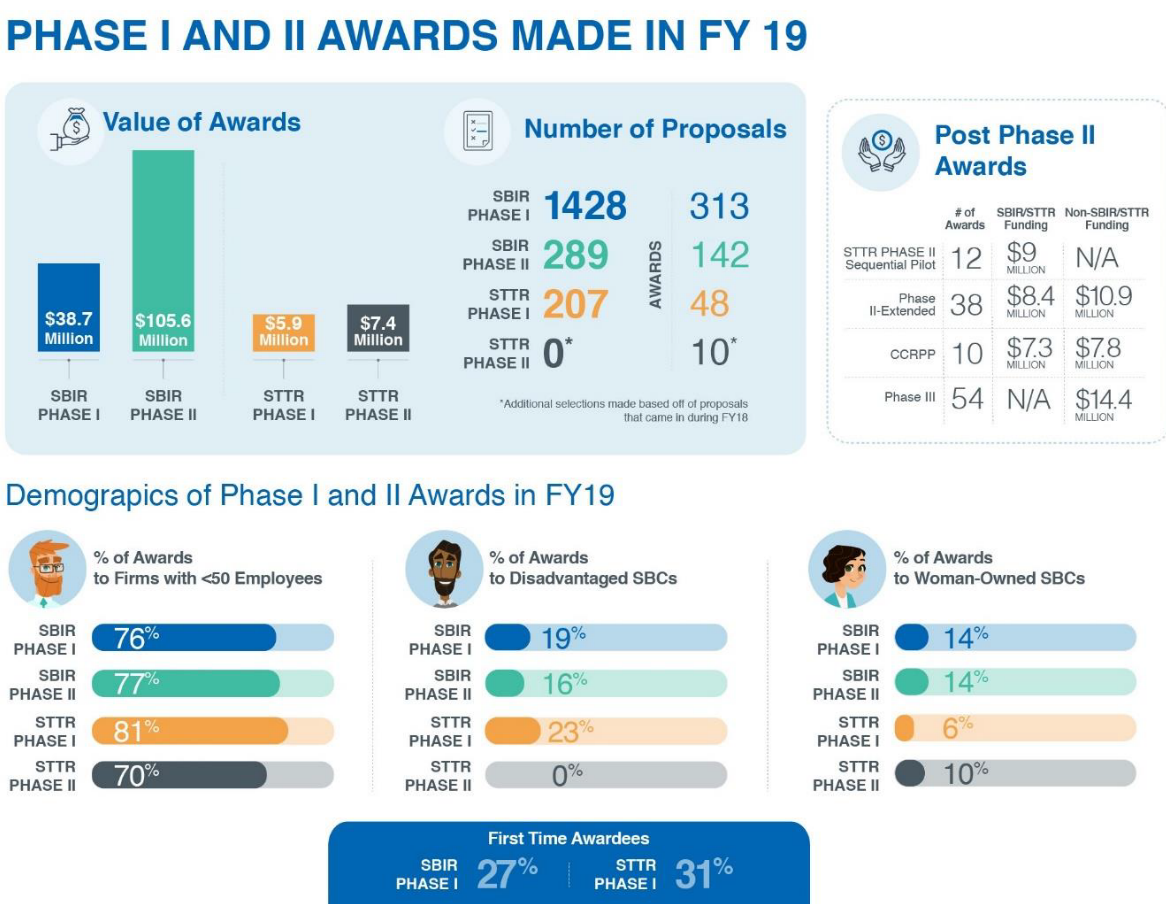
SBIR AND STTR

These investments seek to achieve the program's vision of empowering small businesses to deliver technological innovation that contributes to NASA's missions, provides societal benefit, and grows the U.S. economy.

EXPLANATION OF MAJOR CHANGES IN FY 2021

NASA will prioritize technologies relevant to the exploration mission through all phases of SBIR/STTR awards.

ACHIEVEMENTS IN FY 2019



The FY 2019 review and selection process was streamlined to recover as much time as possible from the delay imposed by the Government lapse in funding and to reduce the burden of the Phase I process on reviewers and rankers so as to honor our commitment to the small businesses that participate in our program.

SBIR AND STTR

WORK IN PROGRESS IN FY 2020

- The FY 2020 annual solicitation was released in January 2020. In June 2020, NASA plans to announce approximately 360 new SBIR/STTR Phase I selections, valued at $45 million, from this solicitation. In addition, NASA announced Phase II selections - 22 STTR from the FY 2018 solicitation with an approximate value of $16.5 million - in November 2019 and will award approximately 140 SBIR, with an approximate value of $105 million, from the 2019 solicitation in May 2020.

- To increase technology transitions and commercialization, NASA will continue to offer Post-Phase II award opportunities through vehicles such as the Phase II E program, the Civilian Commercialization Readiness Pilot Program (CCRPP), and an expanded Phase II Sequential program for both SBIR and STTR. The program will pilot a SBIR Phase II sequential vehicle focused on developing existing Phase II technologies related to the Agency objectives to return to the Moon and on to Mars.

- In Partnership with the National Science Foundation (NSF), NASA will continue to make I-Corps training grant awards for Phase I awardees to encourage commercialization of technology.

- NASA will continue to seek small business feedback to increase collaboration with small businesses through an annual industry day and Requests for Information. It will also modernize its business capabilities to reduce barriers to entry for firms, increase the quality of proposals, and improve the value proposition for firms.

- NASA will continue to pilot opportunities to accelerate NASA efforts in deep space exploration and those of the commercial aerospace sector, including continuing our initiative with the NSF SBIR program to support growth-oriented commercial space entrepreneurs.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

- The SBIR and STTR program office will continue to work with the other NASA mission directorates, Centers, and industry to identify subtopics, with a strong emphasis on technologies to support human exploration to the Moon and eventually Mars. NASA plans to release the annual SBIR and STTR solicitations in early 2021 and award new Phase I and Phase II selections the following summer.

- In particular, this program will support NASA's the Moon to Mars objectives by identifying and accelerating relevant technologies drawn from the SBIR portfolios through post Phase II awards. Pending appropriations, the programs will institutionalize the use of Phase II sequential awards to accelerate the use of SBIR technologies with a priority to support the Artemis campaign.

- NASA will implement new legislative authorities, as signed into law, such as direct to Phase II awards and expanded CCRPP.

- The program office will explore ways to accelerate award timelines and improve the approachability of our program to entrepreneurial aerospace companies and underrepresented communities.

SBIR AND STTR

Program Elements

SBIR

The SBIR program was established by statute in 1982 and was most recently reauthorized in 2016 to increase research and development opportunities for small businesses. The program stimulates U.S. technological innovation, employs small businesses to meet federal research and development needs, increases the ability for small businesses to commercialize innovations they derive from federal research and development, and encourages and facilitates participation by socially disadvantaged businesses. The SBIR program is supported at a level of at least 3.2 percent of NASA's extramural research and development budget. The current maximum value for an SBIR Phase I contract will be $125,000 for a period of performance of six months. For Phase II, the maximum total value of an SBIR award will be $750,000 over a 24-month period of performance. NASA also supports several post-Phase II vehicles:

- Phase II Extended (II-E) contract options with incentives for cost sharing to extend the research and development efforts of the current Phase II contract.
- Civilian Commercialization Readiness Pilot Program (CCRPP) contracts with incentives for cost sharing to extend the research and development efforts of the previous Phase II contract with strong customer pull for technology maturation.
- Phase II sequential options to help raise the Technology Readiness Level value of technologies to the point that other investors will then advance the technology or to rapidly advance the TRL of a technology to enable NASA's Artemis program.
- NASA also supports I-Corps training grants for Phase I awardees to enable small businesses to commercialize their innovations through an Interagency Agreement with the National Science Foundation.

STTR

The STTR program was established by statute in 1992 and was most recently reauthorized in 2016 to award contracts to small businesses for cooperative research and development with a non-profit research institution, such as a university. NASA's STTR program facilitates transfer of technology developed by a research institution through the entrepreneurship of a small business, resulting in technology to meet NASA's core competency needs in support of its mission programs. Modeled after the SBIR program, STTR is funded based on 0.45 percent of the NASA extramural research and development budget. The maximum value for an STTR Phase I contract is $125,000 for a period of performance of 13 months. For Phase II, the maximum total value of an STTR award is $750,000 over a 24-month period of performance. Phase II-E, CCRPP, Phase II sequential contract options, and I-Corps are also available to STTR participants.

SBIR AND STTR

Program Management & Commitments

Program Element	Provider
SBIR and STTR	Provider: Various Small Businesses and their research partners Lead Center: NASA HQ; Level 2: Ames Research Center (ARC) Performing Center(s): All Centers play a project management and implementation role. Cost Share Partner(s): SBIR/STTR Phase II-E matches cost share funding with SBIR and STTR up to $375,000 of non-SBIR and non-STTR investment(s) from a NASA project, NASA contractor, or third-party commercial investor to extend an existing Phase II project to perform additional research. SBIR/STTR CCRPP matches cost share funding up to $1,000,000 of non-SBIR and non-STTR investment(s) from a NASA project, NASA contractor, or third-party commercial investor to continue a former Phase II project to perform additional research for strong customer pull for the technology maturation.

Acquisition Strategy

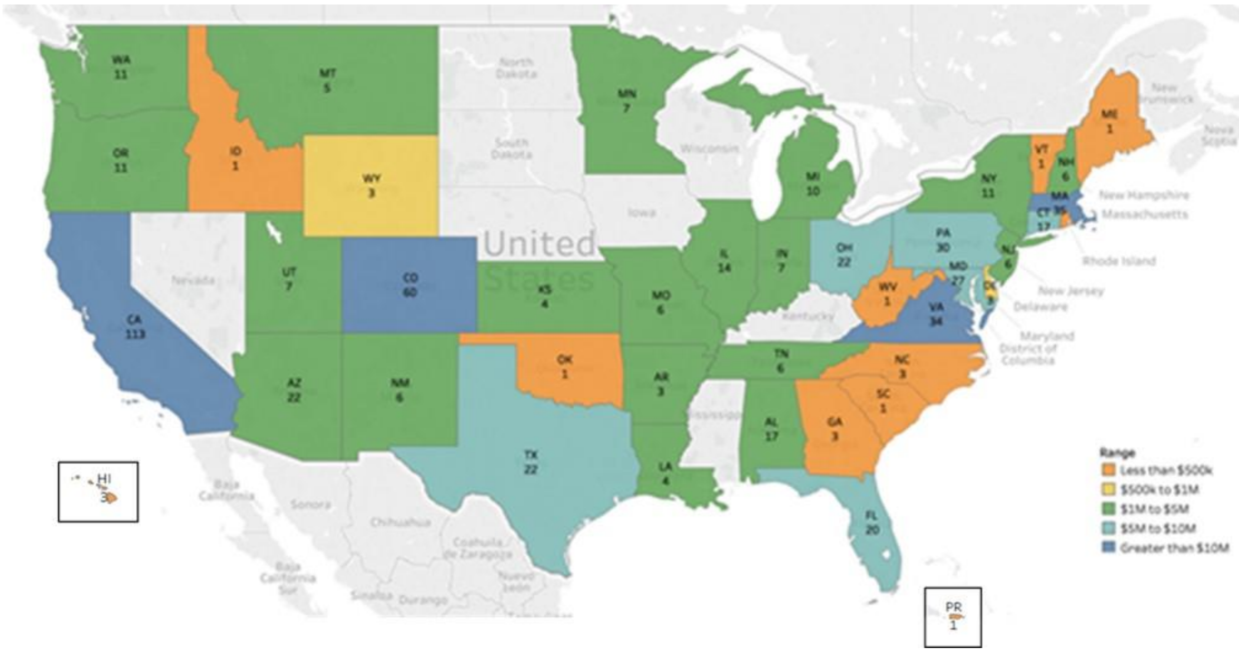
NASA issues annual SBIR and STTR program solicitations, setting forth a substantial number of topic areas open to qualified small businesses. There are three phases for SBIR and STTR funding awards. Phase I awards give small businesses the opportunity to establish the scientific, technical, and commercial merit of the proposed innovation in alignment with NASA interests. The most promising Phase I projects are selected for Phase II awards through a competitive selection process based on scientific and technical merit, expected value to NASA, and commercialization potential. Phase II awards focus on the development, demonstration, and delivery of the proposed innovation. Phase II Extended (II-E) and the Civilian Commercialization Readiness Pilot Program support advancement of innovations developed under Phase II. Phase III supports the commercialization of innovative technologies, products, and services that result from a Phase I or Phase II contract. Commercialization includes further development of technologies and getting feedback to discover infusion opportunities into NASA programs, other Government agencies, or the private sector. Phase III contracts receive funding from sources other than the SBIR and STTR programs and may be awarded without further competition.

SBIR and STTR program management works collaboratively with NASA Center Chief Technologists (for STTR) and the Mission Directorates (for SBIR) during the SBIR and STTR acquisition process. This collaboration, from topic development through proposal review and ranking, supports final selection of proposals of high value to NASA. Mission Directorates and NASA Center program personnel interact with SBIR and STTR award winners to maximize alignment and implementation of the SBIR and STTR products with NASA’s future missions and systems. Topics and subtopics are written to address NASA’s strategic priorities.

SBIR AND STTR

Award Distribution

The map below represents the FY 2019 SBIR and STTR investments through Phase I, Phase II, Phase II-E, and CCRPP awards.



LEO AND SPACEFLIGHT OPERATIONS

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
International Space Station	1490.3	--	**1400.7**	1390.7	1338.4	1314.1	1319.2
Space Transportation	2109.7	--	**1877.8**	1771.4	1826.8	1848.7	1843.4
Space and Flight Support (SFS)	1000.4	--	**758.7**	810.2	782.1	784.5	784.7
Commercial LEO Development	40.0	--	**150.0**	175.0	200.0	200.0	200.0
Total Budget	**4640.4**	**4140.2**	**4187.3**	**4147.3**	**4147.3**	**4147.3**	**4147.3**

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LEO AND SPACEFLIGHT OPERATIONS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
International Space Station	1490.3	--	**1400.7**	1390.7	1338.4	1314.1	1319.2
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Space and Flight Support (SFS)	1000.4	--	**758.7**	810.2	782.1	784.5	784.7
Commercial LEO Development	40.0	--	**150.0**	175.0	200.0	200.0	200.0
Total Budget	**4640.4**	**4140.2**	**4187.3**	**4147.3**	**4147.3**	**4147.3**	**4147.3**
Change from FY 2020			**47.1**				
Percentage change from FY 2020			**1.1%**				

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

NASA astronauts Kate Rubins (left) and Jeff Williams (right) are shown here preparing to grapple the SpaceX Dragon supply spacecraft from aboard the International Space Station.

The low-Earth orbit (LEO) and Spaceflight Operations account, comprised of the International Space Station (ISS), Space Transportation, Space and Flight Support, and Commercial LEO Development themes, enables NASA to better plan both Government and commercial access to space, and it lays the foundation to support commercial operations in LEO. These activities, which support existing and future space operations, commercialization, and space and flight support capabilities for both NASA and non-NASA missions, are a catalyst for economic development. Additionally, these activities advance scientific knowledge and foster new technologies that improve our lives.

NASA's Commercial LEO Development effort is intended to stimulate both the development of commercially owned and operated LEO destinations from which NASA can purchase services and the continued growth of a commercial ecosystem in LEO. As those commercial LEO destinations are available, and without a gap in a U.S. presence in LEO, NASA intends to implement an orderly transition from current ISS operations to the new commercial enterprise as laid out in NASA's ISS Transition Report, dated March 30, 2018.

The International Space Station is an example of American leadership in global space exploration, enabling a U.S.-led multinational partnership to advance shared goals in space. As a testbed for deep space exploration, the station is helping us learn how to keep astronauts healthy during long-duration space travel and demonstrating technologies for human and robotic exploration beyond LEO, to the Moon, and to Mars. ISS enables commercial industry, academic institutions, U.S. Government agencies, and other diverse users to access a unique research platform for developing and demonstrating new technologies, treatments, and products for improving life on Earth.

The Crew and Cargo Program manages transportation services provided by both international partners and domestic commercial providers. Through the program, NASA continues to advance commercial spaceflight and supports American jobs.

Commercial Crew Program (CCP) partnerships with the private sector are working to develop and operate safe, reliable, and affordable crew transportation systems capable of carrying humans to and from space, including the ISS. Working with industry to develop and provide human transportation services to and from space will lay the foundation for more affordable and sustainable future human space transportation. These partnerships bolster American leadership in space, reduce our current reliance on foreign providers for this service, help stimulate the American aerospace industry, and allow NASA to focus on building the capabilities and expertise necessary for missions to the Moon and Mars.

The Space and Flight Support Program continues to provide mission critical space communications, launch and test services, and astronaut training to support its customer missions. The Space Communications and Navigation Program provides communication to missions in LEO and ISS utilizing the Space Network. The Near Earth Network communicates with suborbital missions and some lunar orbits, while the Deep Space Network communicates with the missions most distant from Earth. The Communication Services Program focuses on demonstrating the feasibility of using commercially provided data relay services to support NASA missions. The Launch Services Program provides expertise and active launch mission management for more than 40 NASA and other Government missions in various stages of development. The Rocket Propulsion Test Program manages a wide range of facilities capable of ground testing rocket engines and components under controlled conditions, a critical foundation for the success of NASA and commercial rocket programs. The Human Space Flight Operations Program provides the training and readiness to ensure crew health and safety and mission success.

For more information, go to: https://www.nasa.gov/directorates/heo/index.html

INTERNATIONAL SPACE STATION PROGRAM

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
ISS Systems Operations and Maintenance	1085.3	--	**1049.8**	1047.8	1007.5	983.1	983.1
ISS Research	405.0	--	**350.9**	342.9	330.9	331.0	336.1
Total Budget	**1490.3**	**--**	**1400.7**	**1390.7**	**1338.4**	**1314.1**	**1319.2**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

The International Space Station as photographed in October 2018.

The International Space Station (ISS) is the largest and most complex space-based research facility ever constructed, enabling distinct research opportunities, including research vital to the Artemis human lunar exploration missions and future Mars human exploration programs. Returns from the ISS research investment are not limited to scientific discovery and technology advancement. ISS is a collaborative venture with our international partners, including the Canadian, European, Japanese, and Russian space agencies. Engineers, scientists, and managers from around the world have directed their resources for the peaceful use of space and are now reaping the benefits to humanity. The ISS partnership has established new processes and relationships, which will continue to provide a cooperative foundation for the global enterprise of space exploration. The partnership allows members to collectively allocate resources and manage operational risks in a way that benefits all parties.

The ISS's crewmembers orbit the Earth about every 90 minutes and have continuously occupied the facility since 2000. Once U.S. commercial crew launch services become available, NASA will be able to permanently increase the crew size on the U.S. Orbital Segment (USOS) to four astronauts. The USOS is the portion of ISS operated by the U.S. and its Canadian, European, and Japanese partners. Russia exclusively operates the Russian segment. The ISS spans the area of a U.S. football field (with end zones) and weighs more than 465 tons (930,000 pounds). Its solar arrays, which help power the vehicle, are longer than a Boeing 777's wingspan at 240 feet. The ISS has eight docking ports for visiting vehicles delivering crew and cargo. Orbiting Earth 16 times per day at a speed of 17,500 miles per hour, the ISS maintains an altitude that ranges from 230 to 286 miles. The complex has more livable room than a conventional five-bedroom house, with two bathrooms, a fitness center, a 360-degree bay window, and

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state-of-the-art scientific research facilities. In addition to external test beds, the U.S. operating segment of the ISS houses three major science laboratories (U.S. Destiny, European Columbus, and Japanese Kibo).

The four major focus areas of activity for the ISS program include: (1) returning benefits to humanity on Earth through space-based research and technology development; (2) serving as a key stepping stone on the pathway to deep space exploration; (3) enabling the development and advancement of a commercial marketplace in low-Earth orbit (LEO); and (4) maintaining U.S. global leadership of space exploration. Through its international and domestic partnerships, the program continues to build relationships to further expand expertise in a myriad of scientific fields to benefit humanity.

NASA will continue research and technology efforts in LEO using the ISS to enable exploration with humans to the Moon and to Mars, while continuing to perform research that benefits humanity and leads to a robust ecosystem in LEO and supporting ISS National Laboratory research by private industry and other organizations. NASA is working to implement a step-wise transition of ISS from the current model of NASA sponsorship and direct NASA funding to a model where NASA is one of many customers purchasing services from a LEO human spaceflight enterprise via the Commercial LEO Development Program. NASA will gradually transition from current ISS operations to this new model to ensure that the U.S. always has a human presence in LEO.

The ISS plays an essential role in facilitating the expanding sphere of human space exploration from LEO to the Moon via the Artemis program and eventually to Mars. The ISS is currently the only microgravity platform capable of long-term testing of new life support and crew health systems, advanced habitation modules, and other technologies needed to expand our exploration horizons. Over the next several years, the research program will continue to focus on capabilities needed to maintain a healthy and productive crew in deep space, informing the Artemis missions. Manifested, or planned, experiments and demonstrations to enable human exploration at the Gateway, lunar surface, and into deep space include: tests of improved long-duration life support; advanced fire safety equipment; on-board environmental monitors; techniques to improve logistics efficiency; in-space additive manufacturing; advanced exercise and medical equipment; radiation monitoring and shielding; human-robotic operations; and autonomous crew operations. The facility enables scientists to identify and quantify risks to human health and performance and to develop and test preventative techniques and technologies to protect astronauts during extended time in space. The ISS platform and future commercial LEO destinations provide a rich environment for endless research possibilities in the areas of fundamental biological and physical sciences.

The ISS program aims to provide direct research benefits to the public through its operations, research, and technology development activities. As a National Laboratory, the U.S. segment of the ISS enables partners in Government, academia, and industry to utilize its unique environment and advanced facilities to perform investigations. The ISS National Laboratory is managed by the Center for the Advancement of Science in Space (CASIS). The focus of CASIS is to provide ISS access to academia, the commercial sector, and other Government agencies through partnerships, cost-sharing agreements, and other arrangements for research, technology development, LEO commercialization, and education. Observing from and experimenting aboard the ISS provides the opportunity to learn about Earth, life, and the solar system from a very different perspective. NASA and its partners also use this unique reference point to advance Science, Technology, Engineering, and Mathematics (STEM) education efforts to inspire youth to pursue those fields. The results of the research completed on the ISS can be applied to many areas of science, improving life on Earth, and furthering the experience and increased understanding necessary to journey to other worlds.

For more on the ISS program, go to: https://www.nasa.gov/mission_pages/station/main/index.html

For specific information on the many experiments conducted on ISS, go to: https://www.nasa.gov/mission_pages/station/research/experiments_category.html

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

ISS SYSTEMS OPERATIONS AND MAINTENANCE

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	1085.3	--	1049.8	1047.8	1007.5	983.1	983.1

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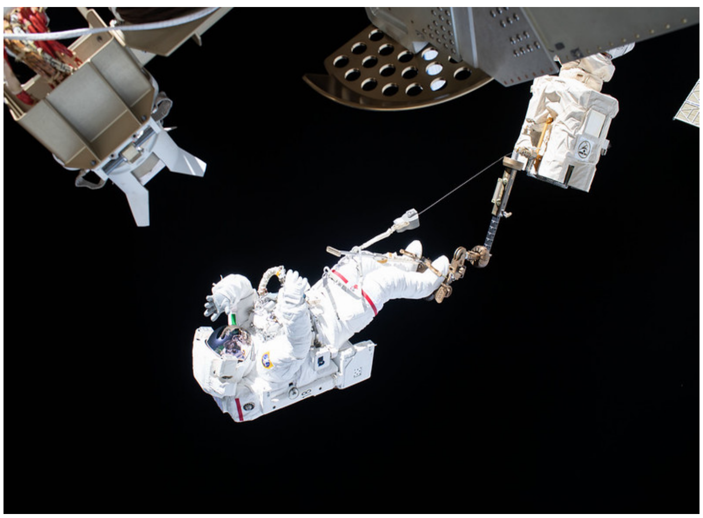

Astronaut Luca Parmitano of ESA (European Space Agency) is shown here attached to an articulating portable foot restraint at the end of the Canadarm2 robotic arm during the second spacewalk to repair the International Space Station's cosmic particle detector, the Alpha Magnetic Spectrometer on November 22, 2019.

The International Space Station (ISS) is a complex research facility and human outpost in low-Earth orbit (LEO) developed in a collaborative, multinational effort led by the United States with partners in Canada, Europe, Japan, and Russia. It is supported by the commercial industry via the Crew and Cargo Program and Commercial Crew Program. The facility's primary goals are to advance exploration of the solar system, enable unique scientific research, and promote commerce in space with industry partners as new commercialization concepts are explored. The Operations and Maintenance (O&M) project supports vehicle operations in the harsh conditions of space with constant, around-the clock-support. The ISS systems operate in extreme temperatures, pressures, and energies that challenge engineering techniques with minimal margin for error. The risks associated with operating the ISS are significant and must be effectively managed to protect against catastrophic consequences to mission success and human life. Successful risk mitigation activities on ISS in LEO pave the way for a more successful Artemis program and then to Mars.

Safely operating the ISS in the severe conditions of space and ensuring the crew always have a sufficient supply of food, water, oxygen, and repair parts demands precise planning and logistics. The 465-ton vehicle requires routine maintenance and is subject to unexpected mechanical failures, given its highly complicated systems and the harshness of space. Resolving problems can be challenging and often requires the crew to make repairs in space with support from ground teams on Earth. Astronauts aboard the ISS must rely on the materials available to them onboard. This requires the support team on Earth to

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monitor and meticulously plan for replacement parts and consumables, such as filters and gas, as well as Orbital Replacement Units (ORUs) like Inlet De-ionizing Bed, Microbial Check Valves, and Multi-Filtration Beds, which are key components of the Regenerative Environmental Control Life Support System (Regen ECLSS). The coordination and support necessary for the ISS crew to live and work comfortably in space requires intensive Earth-based mission operations. Ground teams continually monitor the ISS performance, provide necessary vehicle commands, and communicate with the crew.

Even before the astronauts leave Earth, the Systems O&M project, in conjunction with the Human Space Flight Operations (HSFO) program, provides the crew training to prepare them for their stay aboard the ISS. One example includes operation of the Neutral Buoyancy Laboratory (NBL), an indoor underwater training facility, where astronauts, in a safe environment, can simulate specific extravehicular (EVA) activities to repair, replace, or install new instruments and operational systems. During training exercises, neutral-buoyancy diving is used to simulate the weightlessness of space operations. To achieve this effect, suited astronauts or pieces of equipment are lowered into the pool using an overhead crane and then weighted in the water by support divers so that astronauts experience minimal buoyant force and minimal rotational moment about their center of mass.

The ISS program considers all aspects of the mission when developing operations plans to meet program objectives. These include scheduling crew activities, choreographing docking and undocking of visiting crew and supply ships, evaluating supplies of consumables, managing flight plan variability, and resolving stowage issues. The Systems O&M project ensures the ISS is always operational and available to perform its research mission.

Because the ISS is an international partnership, program decisions are not made in isolation; they require collaboration with multiple countries to ensure all technical, schedule, and resources supply considerations are taken into account. The experience NASA is gaining through integration with its ISS partners is helping the Agency to better prepare for future partnerships in human space exploration, such as on the Gateway or the lunar surface.

A critical component of the Systems O&M project is immediate emergency services and analyses conducted by mission control teams on Earth, known as vehicle and program anomaly resolution. Engineers and operators diagnose system failures and develop solutions, while program specialists respond to changing program needs and priorities through re-planning efforts. These teams ensure appropriate redundancy, training, and procedures are in place to respond to any type of failure at any time. The project requires sparing and repairing nine highly complex on-orbit systems made up of hundreds of unique ORUs. Additionally, software sustainment manages and executes millions of lines of flight code to support operation and control of the ISS.

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

ACHIEVEMENTS IN FY 2019

The ISS System O&M project continued to maintain resources both on-orbit and on the ground to operate and utilize the ISS. The O&M project funded the Mission Control Center (MCC) which operates 24/7

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with primary responsibility for safety of crew and integrity of ISS. This required maintaining success in providing all necessary resources, including power, data, crew time, logistics, and accommodations, to support research while operating safely with a crew of six astronauts. The O&M project supported the arrival and departure of 16 flights, both domestic and international crew and cargo missions, to the ISS. This resulted in supporting one flight approximately every three weeks. Each flight required extensive planning and analyses to support on-orbit operations, as well as launching, docking, undocking, berthing, unberthing, deorbiting, packing, manifesting, hardware processing, and the on-orbit configuration.

NASA ground teams continued to monitor overall vehicle health and oversee general maintenance and performance of all the ISS vehicle systems, including command and data handling, communication and tracking, crew health care, environmental control and life support, electrical power, extravehicular activities (EVAs), robotics, flight crew equipment, propulsion, structures and mechanisms, thermal control, guidance, navigation, and control. In FY 2019, ISS had the following significant anomalies requiring critical contingency response, plus additional on-orbit troubleshooting/planning:

- Battery Charge/Discharge Unit (BCDU);
- Lithium-Ion Battery 4A3;
- Main Bus Switching Unit (MBSU) 3 failure;
- Flight/truss jumper EVA planning;
- ESA Life Support Rack; and
- Thermal Amine Scrubber troubleshooting.

All these anomalies happened within a three-week period. Typically, the ISS Program supports three to four anomalies of this magnitude per year. Troubleshooting efforts led to the development of various products, including those required to replace the failed Lithium Ion battery with the old Nickel Hydrogen batteries, to regain functionality.

In addition to the hardware anomalies, the ISS Program provided immediate response to the Russian 60 Soyuz docking abort. The 60 Soyuz (60S) flight experienced a communications anomaly, which required significant on-orbit re-planning to ensure a successful 60S docking re-attempt, 59S relocation, and SpaceX 18 departure. Efforts included the successful re-evaluation of several different vehicle traffic models (based on Russian planning data), provision of updated solar array, loads, and thermal analyses within a 36-hour period (versus a nominal period of two to four weeks).

The team supported two Russian EVAs and four U.S. EVAs in FY 2019. The two U.S. EVAs in March supported the lithium-ion battery installation. The EVA in August 2019 installed ISS Docking Adapter (IDA) 3. IDA 1 and IDA 3 enable visiting vehicles to attach to the ISS without the use of the robotic arm. With installation complete, these two common ports have enabled expanded opportunities for visiting vehicles, including the new spacecraft designed to carry humans for NASA's Commercial Crew Program, as well as further enhancing the commercialization of LEO.

The current nickel-hydrogen batteries on the ISS are nearing their end of life. The O&M project will continue replacing current nickel-hydrogen batteries with more efficient lithium-ion batteries over several years using multiple EVAs. Astronauts replaced the first three batteries in January 2017. The next set of lithium-ion batteries were delivered to ISS in September 2018 on H-II Transfer Vehicle (HTV) 7 and

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were installed via EVA in March 2019. Another set of lithium-ion batteries were delivered to the ISS on HTV 8 in September 2019.

WORK IN PROGRESS IN FY 2020

Throughout the year, NASA ground teams will continue to monitor overall vehicle health and oversee general maintenance and performance of all the ISS vehicle systems. The O&M project will continue to manage resource requirements and changes, including vehicle traffic, cargo logistics, stowage, and crew time. The O&M project is expected to support three Progress flights, one HTV flight, one crewed Soyuz flight, and five U.S. Commercial Resupply Flights (CRS) for a total of 10 flights; plus U.S. Commercial Crew or one additional Soyuz flight (as necessary).

The team plans to support two Russian EVAs and up to 15 U.S. EVAs in FY 2020. Three U.S. EVAs were completed in October 2019. The first two EVAs started the Port Side Truss (P6) lithium-ion battery installation in continuation of replacing the aging batteries with more efficient lithium-ion batteries. The other EVA completed in October 2019 replaced the failed P6 Battery Charge Discharge Unit (BCDU). In December 2019, the Expedition 61 crew completed the third in a series of complex spacewalks to install a new cooling system for the Alpha Magnetic Spectrometer (AMS). The AMS is a particle physics experiment module mounted outside ISS and measures antimatter in cosmic rays. This information is valuable for our understanding of the formation of the Universe and informs the search for evidence of dark matter and dark energy. These first three spacewalks completed the primary task to install the upgraded cooling system, complete power and data cable connection for the system, and connect all eight cooling lines from the AMS to the new system. The intricate connection work required making a clean cut for each existing stainless-steel tube connected to the AMS; then connecting it to the new system through a process of metalworking known as swaging. Meanwhile, the Flight Control Team on Earth initiated power-up of the system and confirmed it is now receiving power and data. The fourth spacewalk, planned for January 2020, will conduct leak checks for the AMS' refurbished cooling lines and complete the work to resume operations of the cosmic ray detector. The other two January EVAs are for the continuation of battery upgrades.

The early April EVAs will install the Columbus Ka-Band (ColKa) system to the Columbus Module. This communication system will enhance and add new capabilities to the existing Columbus on-orbit and ground communications systems and create an additional bi-directional Ka-Band data transmission for the ISS. The second EVA in late April will install the Bartolomeo external payload platform on the Columbus Module of the ISS. The Bartolomeo platform will allow new, unique payload hosting opportunities and will offer the ISS' only unobstructed view of Earth and space. An additional EVA is planned for late April to complete pre-installation activities for the ISS Roll Out Solar Array (ROSA). In June, the NanoRacks Bishop Airlock will be installed via EVA. This is the first privately funded commercial airlock and it will increase the capability of the ISS for transferring equipment, payloads, and deployable satellites. Commercial opportunities through this Airlock begin with CubeSat and small satellite deployment from the ISS and include a full range of additional services to meet customer needs from NASA and the growing commercial sector. Currently, CubeSat and small satellites are deployed through the government-operated Japanese Kibo Airlock. Additionally, the crew on board should be able to assemble payloads typically flown in soft-stowage ISS Cargo Transfer Bags into larger items that cannot currently be handled by the Kibo Airlock.

ISS SYSTEMS OPERATIONS AND MAINTENANCE

The final six EVAs planned in September 2020 will install the next round of lithium-ion batteries, which will be delivered on HTV 9 in May 2020.

The ISS O&M project worked closely with the Commercial Crew Program (CCP) to support the un-crewed Boeing CST 100 Orbital Flight Test (OFT) in December and will assist the SpaceX Dragon 2 and Boeing CST 100 crewed test flights, as well as any additional follow-on crew rotation missions with U.S. astronauts that occur in this fiscal year.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

The ISS Program will continue to support the CCP and commercial crew partners to ensure any challenges with the initial missions are addressed with minimal impact to ISS operations and research. NASA plans to work with international partners to maintain a continuous ISS crew member capability by coordinating and managing resources, logistics, systems, and operational procedures. The O&M project will continue to manage resource requirements and changes, including vehicle traffic, cargo logistics, stowage, and crew time. In addition to providing anomaly resolution and failure investigation (as needed), they plan and provide real-time support for activities, such as EVAs and visiting vehicles. The O&M project plans to support approximately 10 flights in FY 2021.

The team will support three Russian EVAs and two U.S. EVAs in FY 2021. The U.S. EVAs will install the ISS ROSA. These six solar arrays will augment the ISS power production and ensure all power requirements are met through the life of the ISS.

PROJECT SCHEDULE

The table below provides a schedule for potential EVAs. However, the ISS conducts near-term, real-time assessments of EVA demands, along with other program objectives, to efficiently plan all required ISS activities. NASA remains postured to conduct EVAs on short notice in response to specific contingency scenarios. In addition, the ISS program balances routine maintenance EVAs against overall astronaut availability to maintain focus on utilization and research.

Date	Significant Event
Oct 2019	Three U.S. EVAs
Nov 2019	Two U.S. EVAs
Dec 2019	U.S. EVA
Jan 2020	Three U.S. EVAs
Feb 2020	Russia EVA
Apr 2020	Two U.S. EVAs
Jun 2020	Four U.S. EVAs
Oct 2020	Russia EVA

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Date	Significant Event
Nov 2020	Two U.S. EVAs; two Russia EVAs
Jan 2021	Two U.S. EVAs; two Russia EVAs

Project Management & Commitments

While NASA maintains the integrator role for the entire ISS, each partner has primary authority for managing and operating the hardware and elements they provide. Within NASA, Johnson Space Center (JSC) in Houston, TX, leads project management of the ISS Systems O&M.

Acquisition Strategy

The current Boeing vehicle sustaining engineering contract extends through September 30, 2020. Requirements of this contract include sustaining engineering of U.S. on-orbit segment hardware and software, technical integration across all the ISS segments, end-to-end subsystem management for most of the ISS subsystems and specialty engineering disciplines, and U.S. on-orbit segment and integrated system certification of flight readiness. The program is currently negotiating a contract extension to 2024 with the current provider.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
U.S. on-orbit segment Sustaining Engineering Contract	The Boeing Company	JSC

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	NASA Advisory Council (NAC)	Nov 2019	Provides independent guidance for the NASA Administrator.	No new formal recommendations or findings from the May 2019 report. Still awaiting the November 2019 report.	2020

ISS Systems Operations and Maintenance

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	NASA Aerospace Safety Advisory Panel (ASAP)	Sep 2019	Provides independent assessments of safety to the NASA Administrator.	The panel encouraged NASA to develop contingency plans for continuity of the U.S. Operating Segment (USOS) operations and consider adjusting ongoing Soyuz and commercial crew seat assignments to reduce risk for any launch delays for either launch vehicle.	2020

ISS RESEARCH

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**405.0**	**--**	**350.9**	**342.9**	**330.9**	**331.0**	**336.1**

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Expedition 60 Flight Engineer Christina Koch (NASA) is shown here activating the new BioFabrication Facility to test its ability to print cells on August 2, 2019. Researchers are exploring whether the weightless environment of space may support the fabrication of human organs in space. An incubator houses the tissue samples to promote cohesive cellular growth over several weeks. Earth's gravity inhibits 3-D bioprinters and incubators from recreating and growing complex organic structures.

The International Space Station (ISS) is an orbiting platform that astronauts and researchers use to develop technologies and understand the effects of space on human health for future human exploration missions. The unique microgravity environment enables scientific investigation of physical, chemical, and biological processes in an environment very different from Earth. As a U.S. National Laboratory, ISS provides the only current capability for human-assisted space-based research and is a foundation for efforts to expand commercialization of low-Earth orbit.

November 2, 2020 will mark the 20th anniversary of continuous human presence in space aboard ISS. In that span, this orbiting platform has evolved into a dynamic laboratory that hosts an increasing variety of government and commercially-owned science facilities, external testbeds, and observatory sites. The research conducted aboard ISS, supported by this budget line item, is aligned to goals set by the National Academies of Science in the Decadal Survey on Life and Physical Sciences Research at NASA, while the technology demonstrations also support future programs such as Artemis. At the conclusion of Expedition 60 in September 2019, more than 4,000 investigators from 108 countries have performed more than 2,800 research investigations and technology demonstrations utilizing ISS. Over 1,804 papers have been published in scientific journals and magazines based on results of these investigations.

The ISS Research budget supports a broad portfolio of research and technology development to enable future human exploration, pioneer scientific discovery, expand our understanding of the universe and our home planet, and benefit our economy and life on Earth. ISS Research supports multi-user systems

ISS RESEARCH

support (MUSS) activities, which provide strategic, tactical, and operational support to all ISS research, whether sponsored by NASA, international partners, or the ISS National Lab. MUSS supports new capabilities and technologies that benefit multiple ISS users and operation of in-orbit and ground control research facilities. ISS Research also supports research and applications funding to the external scientific community in support of research in biological and physical sciences that is relevant to exploration and seeks scientific discovery in the unique microgravity environment.

ISS research supports the development of technologies that can be used in exploration campaigns, such as Artemis, and even longer-duration missions to Mars and beyond. ISS provides the best existing means to demonstrate technology and system readiness for use on a human occupied exploration vehicle by documenting performance in a spacecraft environment with humans-in-the-loop, piloting operational procedures and training requirements, determining logistics requirements, safety, and interoperability concerns with respect to overall space systems infrastructure. Examples of key exploration technology demonstrations on ISS include:

- Roll out Solar Array (ROSA) technology improves the power density, stowage efficiency, and scalability of previously-used rigid panel arrays. ROSA was tested on ISS for strength, structural dynamics, and operations and will be used as part of the Gateway's Power and Propulsion module. In addition, this technology will be used to upgrade ISS power systems as soon as FY 2021.

- Sextant used the ISS x-ray observatory, NICER, to successfully demonstrate a navigation system based on known positions of pulsars - deep space objects which emit regular bursts of radiation. Sextant showed that pulsar-based navigation systems could be used for exploration missions throughout the solar system like the satellite-based GPS systems we use on Earth.

- Zero Boil-Off Tank (ZBOT) tested the use of active heat removal and forced jet mixing to minimize the "boil-off" loss of cryogenically-stored fuel. Long-term storage of cryogenic fluids is necessary for spacecraft propulsion and life support. The ability to reduce or eliminate losses for rocket fuels will greatly reduce the amount of fuels needed for exploration missions to the Moon and Mars.

- SAFFIRE is a series of experiments looking at flame growth and propagation on Cygnus cargo vehicles after they depart the ISS; and is funded in the Advanced Exploration System (AES) program. The experiment studies how fire behaves in microgravity. Results have informed NASA's choice of flame-resistant materials and provided crucial data on how fires spread in microgravity.

ISS Research contributes to Agency efforts for the commercialization of low-Earth orbit (LEO) to enable a sustained U.S. presence in this region of space. Research facilities onboard ISS continue to evolve from primarily government funded and operated to commercially owned and operated. Since 2012, commercial research facilities have greatly increased the breadth and volume of ISS-supported research, with 17 such facilities in operation at the start of FY 2020. In June 2019, NASA announced a set of policy directives intended to foster the growth of the U.S. commercial space sector. NASA's plans for expanding commercial activities in LEO build on and apply the lessons learned from over a decade of work and experience with commercial companies.

ISS RESEARCH

The enabling of commercial cargo, research, and research facilities on ISS continues to spur innovative public-private partnerships. For example, the Center for the Advancement of Science in Space (CASIS), a single purpose non-profit non-government organization (NGO), manages the ISS U.S. National Laboratory, which allows non-NASA users to conduct Research and Development (R&D) activities on ISS that benefit life on Earth and foster commerce in space. Non-NASA users of the ISS National Laboratory include academia, industry, and government agencies beyond NASA. Since 2012, over 450 payloads have flown under the ISS National Laboratory allocation. Within the current ISS National Laboratory portfolio, 75 percent are new-to-space customers and 52 percent are from industry customers, which are promising indicators that the National Laboratory is beginning to broaden demand for LEO activities.

Promoting the full and open sharing of data with research communities, private industry, academia, and the general public is one of NASA’s long-standing core values and is another way in which use of scientific data generated from ISS research is maximized. ISS is the primary science platform for the Open Science Initiatives of GeneLab for biological sciences data and Physical Sciences Informatics for physical sciences data. These initiatives enable next generation research by creating publicly available open-access data resources.

ISS research also supports investigations in human physiology and crew health and performance, led by NASA's Human Research Program (HRP). As NASA’s only current long-duration crewed orbital testbed, the ISS is used by researchers to study the effects of long-duration exposure to the space environment on the crew and devise and test countermeasures to offset health risks. This research is critical as the U.S. prepares for deep space human exploration. Research on model systems, spanning from cell culture to rodents, also benefit from the long-term microgravity environment and yield insights to help ensure that the highly applied risk reduction R&D strategy of HRP can understand underlying mechanisms and connect rapidly advancing biomedical research on earth to the mechanisms of the unique hazards and risks of human spaceflight.

ISS research funded through this line item continues to generate new knowledge. For example, data from the Alpha Magnetic Spectrometer (AMS-02), a cosmic-ray observatory housed on ISS, reveals a level of high energy positrons in excess of that predicted. This may indicate an additional source involving interactions with dark matter. Already five years beyond its original life-expectancy, maintenance to this instrument scheduled for FY 2020 is expected to extend its use through the duration of the life span of the ISS, providing additional years of data collection to potentially shed more light on this cosmic mystery.

EXPLANATION OF MAJOR CHANGES IN FY 2021

ISS is funding the Synchronized Position Hold, Engage, Reorient, Experimental Satellites activity which was previously funded out of Advanced Exploration Systems.

ACHIEVEMENTS IN FY 2019

FY 2019 saw new research facilities and Earth observation instruments come online, new capabilities piloted, and an increasingly diverse portfolio of commercial, fundamental science, and technology demonstration investigations conducted. The ISS Research budget supported, either directly or through MUSS integration services, 471 active investigations across all ISS partners. NASA and the ISS National

ISS Research

Laboratory combined to sponsor 243 U.S. research investigations, an increase of 8 percent from the previous fiscal year. For the ISS National Laboratory, the number of newly awarded projects (62) increased by 25 percent and the number of payloads delivered (87) to ISS increased by 16 percent.

For more information, go to:

https://www.nasa.gov/mission_pages/station/research/index.html

https://www.issnationallab.org/

This increase in U.S. research came despite the abort of flight 56S, which limited USOS crew to two for over five months. A total of 2,130 crew hours were dedicated to utilization for an average of 52.2 hours per week, which is only three hours per week less than FY 2018. Real-time data access for investigators and ground-control capabilities of commercial facilities also increased as data transfer bandwidth doubled to 600 megabits/second (Mb/s) both to and from the ISS. Overall, this resulted in an increased capacity for research which lessened the impact of the reduction in available crew time.

The ISS National Laboratory continued to drive upward trends for industry involvement in supply, demand, and investment related to its R&D portfolio. More than 75 percent of the 87 payloads represented R&D from the private sector. R&D activities onboard the ISS National Laboratory in FY 2019 included projects from industry - Goodyear, AstraZeneca, Time, Adidas, Nalco Champion, Budweiser, six startup companies funded in collaboration with Boeing, and others. Other projects were conducted from research entities such as MIT, Frederick National Laboratory, Johns Hopkins, U.S. Army, DARPA, Michael J. Fox Foundation, National Cancer Institute, Scripps Research Institute, University of California San Diego, and the University of Toledo.

Industrial Biomedicine encompasses regenerative medicine, tissue engineering, protein crystal growth, rodent research, and other biomedical R&D areas. Industrial Biomedicine projects enable advancements with a defined pathway for translation from scientific research to industrial or clinical applications. More than half of newly selected projects in FY 2019 fall into this category.

Two FY 2019 examples investigations within Industrial Biomedicine include:

- LambdaVision conducted studies on the ISS National Laboratory to improve the manufacturing process for its protein-based retinal implant capable of restoring vision in patients with retinal degeneration, which affects millions of people on Earth. LambdaVision's retinal implant consists of multiple layers of a light-activated protein. However, when produced on Earth, gravity interferes with the uniformity of the layers.

- The National Stem Cell Foundation is studying neurodegenerative disease in space using cells derived from patients with Parkinson's Disease and Multiple Sclerosis. This research focuses on the physics of how cells interact using a brain organoid. The research team expects to learn new information about how the cells communicate, integrate, and differentiate within a representative replica of human tissue.

Advanced Materials projects develop next-generation production methods, improve understanding of mechanisms involved in material transformations, advance fundamental materials discovery, and test processes or manufacturing methods of novel design and synthesis pathways. Previous research partners have evaluated combustion studies, complex fluid flow, unique substance interaction, materials degradation, and in-orbit manufacturing, among others. Approximately 10 percent of the ISS National Laboratory R&D portfolio falls in this category, with more than 30 payloads launched to-date in support of these projects, supported by 10 commercial implementation partners.

Examples of research within Advanced Materials include:

- Two ISS National Laboratory investigations focused on the production of ZBLAN optical fiber in ISS—one project from FOMS, Inc. and one from Physical Optics Corporation. These projects are piloting approaches to commercialize the production of ZBLAN fiber in space for use back on Earth. The in-orbit manufacturing promises to produce fibers with fewer imperfections, enabling lower-signal-loss optical communications for applications such as repeater-less transoceanic transmission, sensors used in the aerospace and defense industries, and improved medical devices (such as laser scalpels). FOMS (San Diego, CA), one of the companies who conducted testing in FY 2019, holds the first patent for technology to produce ZBLAN fibers in space.

- Several companies are leveraging the Solidification Using a Baffle in Sealed Ampoules (SUBSA) hardware onboard the ISS to synthesize materials for use in radiation detection to meet growing technological demands of the U.S. Department of Homeland Security and the U.S. Department of Energy. Illinois Institute of Technology completed their in-orbit operations in FY 2019 and announced preliminary positive results. If a certain quality threshold is reached, the university has a relationship with industry partner RMD to explore commercialization of a product.

Two new commercially operated facilities, SlingShot and BioFabrication Facility, expanded the supply side of spaceflight R&D onboard the ISS National Laboratory in FY 2019. Not only do these facilities open up more R&D opportunities, they mitigate business risk, serving as a training ground for private industry in learning how to conduct business in space.

As noted previously, the NASA GeneLab and Physical Science Informatics open science databases are increasing the use and value of results from ISS research. In FY 2019, 12 additional publications were generated demonstrating the power of analyzing from multiple spaceflight investigations in aggregate, and the utility of open-access databases in multiplying the benefits derived from biological space research.

Examples of research accomplishments in FY 2019, representing both NASA and ISS National Laboratory efforts, include:

- In FY 2019, startup company Orbit Fab successfully completed the first test of its Furphy tanker on the ISS, demonstrating the ability to transfer propellant between two small satellites. This new tanker technology has two patents pending and went from concept to flight onboard the ISS National Laboratory within one year. Based on this successful mission, the company raised $3 million in venture capital in the first quarter of FY 2020.

- The ability to grow and use plants is critical for future exploration programs. A variety of investigations were conducted to understand critical factors in plant growth in microgravity and to address future food system and nutritional risk for long duration crews. This applied work was

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supported by a comprehensive study of the differences in genetics, metabolism, photosynthesis, and gravity sensing between plants grown in space and on Earth.

- The SPHERES-Slosh investigation provided data on the behavior of fluids in microgravity crucial to maximizing the performance and reliability of liquid-fueled propulsion systems in space. Fluids models based on this data have been used on satellite missions from NOAA and NASA and have been distributed to launch vehicle providers (e.g., United Launch Alliance (ULA), SpaceX, Northrup Grumman).

- SEOPS LLC's SlingShot, a small satellite deployer system, became operational, enabling small satellite deployment from Northrup Grumman's Cygnus cargo vehicle. SlingShot was used by DoD, DARPA, NASA, and private industry customers including UbiquitiLink. Since their technology demonstration, UbiquitiLink has raised $12 million toward their goal of providing satellite-based internet and cellular access for devices in areas without ground-based connectivity.

- Techshot Inc.'s BioFabrication Facility (BFF) is a 3D printer for biological material began operation on ISS. Bioprinting in microgravity is beneficial because scaffolding is not needed to keep printed structures from collapsing, allowing scientists to overcome what has been a significant hurdle in ground-based biomanufacturing of tissues and organs.

- Made in Space's Additive Manufacturing Facility (AMF) has produced more than 100 tools and other objects in orbit. In FY 2019, Made in Space secured a $74 million NASA contract for Archinaut, a program to manufacture and assemble spacecraft components in LEO—to support space exploration and commercialization technology needs.

- The Global Ecosystem Dynamics Investigation (GEDI) began acquiring science data on March 25, 2019. The GEDI system uses lasers to generate precise measurements of forest canopy height, vertical structure, and surface elevation to characterize important nutrient cycling processes, biodiversity and habitat. This data is valuable for application in weather forecasting, forest management, glacier and snowpack monitoring, and generation of more accurate digital elevation models.

- The Orbiting Carbon Observatory-3 (OCO-3) initiated a three-year mission to observe how carbon dioxide concentrations change throughout the day. In addition, OCO-3 can observe a type of radiation from plants called solar-induced fluorescence which could improve understanding of the photosynthesis in the carbon cycle in forests.

- The first results of the landmark Twins Study involving astronaut Scott Kelly and his brother Mark were published in April 2019. Changes identified through the rigorous biochemical and gene expression data collected may be useful clues to unraveling the mysteries of spaceflight changes such as immune system and vision changes which are of critical concern for future long-duration missions.

- The Cold Atom Laboratory (CAL) was installed and is producing clouds of ultracold atoms known as Bose-Einstein condensates (BEC). The experiment provides a unique opportunity to probe long-standing problems in quantum physics (the study of the universe at the very smallest scales) and explore the wavelike nature of matter.

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- Electromagnetic levitation of metals and bulk metallic glasses in the microgravity environment in FY 2019 provided data for: (1) better manufacturing of cast superalloy components to improve efficiency, safety, and reliability of rocket and jet engines; (2) understanding formation of Bulk Metallic Glasses, which are an emerging class of materials with applications such as cryogenic gears for planetary exploration; and (3) investigating thermophysical properties of high-temperature materials to allow more efficient and reliable production of metallic parts using these alloys.

- Through the RR-9 experiment, Space Biology research was able to determine that retinal damage and blood-retinal barrier disruption while in microgravity confirms the need for countermeasure development for long-term human spaceflight. Astronauts may be at risk for retinal damage and late degeneration.

- Additional highlights from education and outreach initiatives include: Felix and Paul Studios filmed scenes for "The ISS Experience," a cinematic virtual reality (VR) series that documents life and research aboard the space station, making the human interaction between astronauts more tangible for audiences on Earth.

- More than 5 million people were reached by ISS National Laboratory STEM initiatives in FY 2019, doubling FY 2018 metrics. More than 50 percent were students participating in 23 currently active programs. Partner programs with the more expansive reach included Story Time From Space (in collaboration with American Girl) and the Public Broadcasting Service (PBS) Twin Cities Public Television (via the SciGirls in Space program).

WORK IN PROGRESS IN FY 2020

FY 2020 planned activities will continue to increase the number of research facilities. Those facilities will be enabling an increasingly diverse portfolio of commercial, fundamental science, and technology demonstration investigations. In the first half of FY 2020 alone, 192 investigations are scheduled to be active, 119 of which are NASA and ISS National Laboratory sponsored. Of these investigations, 52 are new.

Several new technologies and systems supportive of Artemis exploration missions are scheduled for demonstration on ISS in FY 2020, including upgrades to the Universal Waste Management System, improvements to carbon dioxide removal, and a brine processor. Also, astronaut Christina Koch will break Scott Kelly's record for the longest stay on the ISS by a U.S. astronaut generating new medical data critical to identifying health risks, and formulating countermeasures, for future long-duration exploration missions. Planning for conducting additional one-year U.S. missions beginning in FY 2021 is underway.

In FY 2020, ISS National Laboratory investigations from the first rodent research "Reference Missions" will begin to share results with the community of researchers. Reference missions adapt a standard rodent research format to maximize scientific research opportunities and resource utilization by providing multiple investigators access to biospecimens from a single mission. As part of their agreement for award of biospecimens, all investigators agree to share their data and publish their results after mission completion. These reference missions align with GeneLab and Physical Sciences Informatics databases

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discussed above and similarly multiply the opportunity for new knowledge gained and lower the barriers for new researchers with ideas about applications in biomedicine to investigate the use of ISS.

New facilities anticipated to launch in FY 2020 include Airbus's Bartolomeo and NanoRacks's Bishop Airlock. An airlock is a module used to transfer payloads, including CubeSats, between the interior and exterior of the space station. Bishop is the first commercial airlock to operate on ISS and is expected to increase capabilities in both R&D as well as station operations. This airlock will have five times more capacity than the current airlock, will increase ISS capacity to downlink data from external instruments, and will accommodate the deployment of larger satellites (up to 150 kilograms). Technology development and proof-of-concept missions using highly subsidized or free (to the user) access to ISS capabilities have contributed significantly to the rapid maturation of small satellite capabilities and helped to spur the rapid growth in this new commercial market.

Highlights of research planned in FY 2020, representing both NASA and the ISS National Laboratory efforts include:

- Testing of a Thermal Amine Scrubber, which removes carbon dioxide (CO_2) from air aboard the ISS using actively heated and cooled amine beds. The system includes elements that reduce loss of water vapor and recover CO_2 for use in electrolysis to produce oxygen.

- The Fluid Boiling and Condensation Experiment will study large scale two–phase fluid flows to characterize heat transfer mechanisms that will contribute to thermal management designs for long-duration exploration.

- The Biosentinel investigation will use living cells as biosensors to test the radiation environment of ISS as a pathfinder for radiation biosensors that could be used on future exploration platforms. On ISS, the biosensor will seek to measure DNA damage-and-repair response to space radiation in living cells for long-term space exposure; and correlate biological response with physical dosimeter data to validate models of radiation effects on biology.

- The Turbine SCM is a commercial in-space manufacturing device that will add to Made In Space's capabilities for additive manufacturing on ISS. This device allows manufacturing of single-piece superalloy turbine blisk (blade/disk combination) in microgravity for commercial use on Earth. If produced successfully in microgravity, additional gains can be made in the areas of part mass, residual stress and fatigue.

- The Spectrum Multi-Fluorescence Spectral Imager (Spectrum) was launched on the NG-12 mission. Using Spectrum, scientists can examine genes in biological cells which may provide a key to understanding to how biological organisms respond and adapt to the stresses of spaceflight.

- Science Module 3 (SM3) for the Cold Atom Laboratory (CAL), will enable the first-ever implementation in space of a powerful scientific tool called atom interferometry. Atom interferometry splits and recombines atomic waves to create patterns of interference in a manner similar to light waves, with the essential difference that atoms, unlike photons, have mass and hence have inertia and are sensitive to gravity. The first use of SM3 will be to conduct tests of the Einstein Equivalence Principle with quantum matter which holds that all masses fall with the same acceleration.

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- The packed bed reactor experiment (PBRE) will test the effect of high gas flows through glass beads and perform the first of a series of experiments in support of the Advanced Environmental Systems (AES) to improve the performance of water recycling systems in space.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

NASA will finish implementing new processes for payload development and integration that are focused on sending investigations to ISS as soon as they are ready, as opposed to the traditional process of being assigned to a specific flight that could be up to a year away. The improved timelines offered by these processes will better meet the demands of its users, resulting in quicker payload deliveries to ISS (within months in some cases). Thus, private sector users looking to leverage space-based activities to accelerate time to market for product enhancements will have a rapid path from project concept to flight. This bolsters the value proposition for space-based R&D. Similarly, R&D sponsored by NASA, by commercial entities, or by non-NASA government agencies can be executed within a timeline that enhances the relevance of the research projects. For these cutting-edge projects, scientific discovery and technological advancement moves quickly and will benefit by optimized timelines to flight.

Under the streamlined payload development and integration processes, the full flight manifest for FY 2021 is still in development. However, upcoming investigations expected to fly in FY 2021 include:

- The beginning of additional 1-year missions for Human Research, with corresponding six-month missions and shorter missions enabling the comprehensive understanding of the effect of duration on the human risks of spaceflight.

- Plant research investigations will focus on bioregenerative food production of pick and eat crops such as mizuna and tomatoes. Sierra Nevada Corporation (SNC) will test a new plant growth system on the ISS, eXposed Roots On Orbit Technology (XROOT). This will be the first test of aeroponics, a plant-cultivation technique in which the roots hang suspended in the air while nutrient solution is delivered to them in the form of a fine mist.

- Rodent Research topics will include the role of specific genes in stopping bone regeneration that is observed during microgravity exposure, the role of antioxidants in retinal disorders and neurovascular disease.

- Tissue engineering and regenerative medicine improve human health and longevity, and FY 2021 flight projects from multiple sponsors, including both NIH and NSF, will explore a range of related topics from stem cell biology to 3D printing.

- Hnu’s Mobile SpaceLab will provide a tissue and cell culturing facility to perform sophisticated microgravity biology investigations. Biology experiments can be performed for up to a month without the need for crew operations.

- Fluid physics will focus on questions applicable to thermal management designs for long-duration exploration including heat transfer in large scale two–phase fluid flows.

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- Combustion experiments will evaluate the effects of flame structure on soot inception and flame extinction to better understand how to reduce soot and nitrogen oxides that contribute to sources of air pollution, such as in the formation of smog and acid rain, and study solid fuel burning to improve knowledge of fire ignition and extinction mechanisms in reduced gravity.
- Materials processing experiments will seek to improve processing in microgravity and identify optimal materials to use for joining hard metals in microgravity.
- Continued operation of numerous external instruments in Earth and Space science.
- Continued demonstration of performance and reliability of next generation exploration technologies.
- LaMont Aerospace's RM3S small-satellite dispenser will further expand the small satellite capabilities of ISS by providing capability to deploy constellations of nano-satellites (1–10 kilograms) and small satellites (200–500 kilograms) using an externally mounted system. This will reduce crew time requirements, airlock cycles, long-duration deployment windows, intravehicular activity safety compliance, and similar payload subsystem issues.

Project Schedule

An increment, or expedition, is a period of time for ISS operations that spans from one crew return mission to another. Three to five expeditions typically span a calendar year and each consists of cargo ship arrivals and departures, extensive research investigations, as well as standard crew maintenance and logistical tasks. The table below outlines tentative start dates for the upcoming increments to ISS.

Date	Significant Event
Oct 2019	Increment 61
Feb 2020	Increment 62
Apr 2020	Increment 63
Oct 2020	Increment 64
Dec 2020	Increment 65
Apr 2021	Increment 66
May 2021	Increment 67
Sep 2021	Increment 68
Nov 2021	Increment 69

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Project Management & Commitments

The ISS Program Office meets commitments to international partners for utilization access under the ISS Intergovernmental Agreements, and follows the guidance of the NASA Authorization act in providing access to on-orbit capabilities for National Laboratory research. The ISS Program interfaces with the National Laboratory and personnel from a wide variety of NASA organizations to integrate objectives into strategic plans and implement research.

Within NASA, mission directorates also prioritize their research investments for ISS based on exploration roadmaps for technologies needed to support NASA's exploration goals, the Human Research path to risk reduction, and recommendations from the relevant National Academies of Science decadal surveys. These are demonstrated in non-ISS budgets of the Human Research Program (HRP), some activities in the Space Technology Demonstration Mission Directorate (STMD), and in specific Science Mission Directorate (SMD) projects.

The Space, Life, and Physical Sciences Research and Applications Division at NASA Headquarters manages Biological and Physical Sciences (BPS) research and applications funded under ISS Research, primarily through grants to academic institutions and with implementation by multiple NASA Centers. Recommendations from experts at the National Academy of Sciences drive NASA's strategy for implementing BPS research, as reflected in two publications: "Recapturing a Future for Space Exploration, Life and Physical Sciences Research for a New Era" and "Assessment of Implementation of the Decadal Survey on Life and Physical Sciences at NASA." A new decadal survey is expected to be completed in FY 2021.

Element	Description	Provider Details	Change from Formulation Agreement
Biological and Physical Sciences	This element includes selection and implementation of NASA-sponsored biological and physical research	Provider: NASA Centers, contractors, and principal investigators Lead Center: Headquarters (HQ) Performing Center(s): Ames Research Center (ARC), Glenn Research Center (GRC), Jet Propulsion Laboratory (JPL), Marshall Space Flight Center (MSFC), Kennedy Space Center (KSC) Cost Share Partner(s): N/A	N/A
MUSS	MUSS activities support all research on ISS (NASA sponsored and non-NASA sponsored)	Provider: ISS program and contractors Lead Center: Johnson Space Center (JSC) Performing Center(s): MSFC, ARC, GRC, KSC, JPL Cost Share Partner(s): N/A	N/A
National Laboratory Cooperative Agreement	Manages the ISS U.S. National Laboratory	Provider: Center for the Advancement of Science in Space	N/A

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Acquisition Strategy

NASA awards contracts and grants for conducting research on ISS. NASA prioritizes ISS research based on recommendations from the National Academies and the Decadal Survey on BPS in Space. NASA has selected CASIS to manage non-NASA ISS Research activities through the ISS National Laboratory.

Peer review is the means to ensure a high-quality research program. Engaging leading members of the research community to assess the competitive merits of submitted proposals is essential to ensuring the productivity and quality of ISS Research. BPS research uses both traditional and open science NASA Research Announcements to provide researchers, selected by peer review, the opportunity to develop complete flight experiments and allow universities to participate in flight and ground research involving their scientists. CASIS also conducts independent reviews of science merit and economic valuation in selecting experiments for use of the ISS as a National Laboratory.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Vehicle Sustaining Engineering Contract	The Boeing Company	Houston, TX
Huntsville Operations Support Center	COLSA Corporation	Huntsville, AL
Mission Operations and Integration (MO&I) Contract	Teledyne Brown Engineering	Huntsville, AL
ISS National Laboratory Management Entity	CASIS	Melbourne, FL

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	National Academy of Science	Jan 2018	Review progress on 2011 Decadal Survey for life and physical sciences research and recommend adjustments to BPS portfolio.	Several findings and recommendations for HEOMD to increase the scientific productivity of ISS research.	2021

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Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	NASA Aerospace Safety Advisory Panel (ASAP)	Oct 2018	Provides independent assessments of safety to the NASA Administrator.	Due to the potential for delays in the schedule for the first CCP flights with crew, senior NASA leadership should work with the Administration and the Congress to guarantee continuing access to ISS for U.S. crewmembers until such time that U.S. capability to deliver crew to ISS is established.	TBD
Other	NASA Advisory Council (NAC)	Nov 2018	Provides independent guidance for NASA Administrator.	No new formal recommendations or findings for ISS.	TBD
One-time Independent Review Board (IRB)	IRB	Jan/Feb 2020	IRB to evaluate the ISS Nat'l Lab, managed by CASIS, to ensure we are on mission and appropriately resourced to produce breakthroughs that improve lives on Earth, including commercialization and Moon to Mars efforts.	TBD	N/A

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HISTORICAL PERFORMANCE

In FY 2019, NASA estimates ISS partners performed 486 research and technology investigations, including 233 new investigations. During this period, NASA estimates that NASA performed 233 investigations, including 149 new investigations. The charts below display historical data, by partner agency, for research investigations performed on ISS since 1998, and a comparison of NASA-sponsored and National Lab-sponsored investigations.

Investigations by Research Discipline

SPACE TRANSPORTATION

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Crew and Cargo Program	1895.6	--	**1778.1**	1708.1	1763.6	1784.1	1778.7
Commercial Crew Program	214.1	--	**99.7**	63.2	63.2	64.6	64.6
Total Budget	**2109.7**	**--**	**1877.8**	**1771.4**	**1826.8**	**1848.7**	**1843.4**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

The SpaceX Dragon space freighter is shown here approaching ISS as the Canadarm2 robotic arm is poised to reach out and grapple the commercial resupply ship (July 27, 2019).

Space Transportation's objective is to transport U.S. astronauts and cargo safely to and from space, including the International Space Station (ISS). This theme includes the Commercial Crew Program (CCP) and the Crew and Cargo Program. Maintaining ISS requires a fleet of vehicles and launch locations to transport astronauts, science experiments, critical supplies, and maintenance hardware; replenish propellant; and dispose of waste.

CCP partners with the U.S. commercial sector to develop and operate safe, reliable, and affordable crew transportation to low-Earth orbit (LEO). NASA awarded Commercial Crew Transportation Capability (CCtCap) contracts to Boeing and Space Exploration Technologies Inc. (SpaceX) in September 2014. Through its certification efforts, NASA will ensure the selected commercial transportation systems meet NASA's safety and performance requirements for transporting crew to ISS.

Within the Crew and Cargo Program, NASA purchases cargo transportation to ISS under Commercial Resupply Services (CRS) contracts with Northrop Grumman, Sierra Nevada Corp., and SpaceX. NASA is transitioning from purchasing crew transportation to ISS from the Russian Roscosmos State Corporation, known as Roscosmos, to purchasing from commercial providers Boeing and SpaceX. The budget also supports other space transportation-related activities, such as integration work required to ensure that these visiting vehicles can safely dock or berth to ISS and the development of hardware like the NASA docking system.

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

CREW AND CARGO PROGRAM

Formulation	Development	Operations

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	1895.6	--	1778.1	1708.1	1763.6	1784.1	1778.7

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The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

The Northrop Grumman Cygnus resupply spacecraft is shown grappled by the Canadarm2 robotic arm following its detachment from the Unity module and just before release. Behind the robotic arm, the SpaceX Dragon is seen still attached to the ISS Unity module (August 6, 2019).

Maintaining the International Space Station (ISS) requires a fleet of launch vehicles to sustain a constant supply line of both crew and cargo that is crucial to ISS operations and research. Deliveries not only provide science experiments, supplies, and maintenance hardware, but also rotate crewmembers, return research and equipment for repair, and dispose of waste.

The Crew and Cargo Program manages transportation services provided by both international partners and domestic commercial providers. NASA’s commercial service contracts to resupply the ISS have changed the way the Agency does business in low-Earth orbit (LEO). With these contracts, NASA continues to advance commercial spaceflight, while supporting the American jobs created by this industry.

Currently, NASA purchases cargo delivery to the ISS from Northrop Grumman (formerly Orbital ATK) and Space Exploration Technologies Inc. (SpaceX) under the original Commercial Resupply Services (CRS) contracts, which will end in 2020. These vehicles provide between 2,200 - 3,500 kilograms (kg) of cargo to ISS each mission. The cargo provided to the ISS includes crew supplies, operations hardware, and numerous science research and technology demonstration investigations.

Northrop Grumman, SpaceX, and Sierra Nevada are working under the follow-on CRS-2 contracts for missions beginning in 2020. Under CRS-2, SpaceX and Sierra Nevada will launch CRS missions from Cape Canaveral, FL, as Space-X does today. Both of these providers also have or will have the capability to return science experiments to Earth. SpaceX uses its Falcon 9 rocket to launch the Dragon-2 docking

CREW AND CARGO PROGRAM

Formulation	Development	Operations

cargo vehicle, while Sierra Nevada will use the Atlas V rocket to launch its Dream Chaser berthing cargo vehicle. Northrop Grumman primarily launches its Cygnus berthing cargo vehicle on the Antares rocket from the Mid-Atlantic Regional Spaceport at NASA's Wallops Flight Facility (WFF) in Virginia. Northrop Grumman provides trash disposal and conducts additional experiments before the Cygnus spacecraft burns up in the atmosphere after leaving ISS. These capabilities enable studies of fire suppression, the launching of small satellites at high altitude, and other experiments not suited for ISS on-board operation. The Crew and Cargo Program budget supports all milestone payments for these contracted flights to provide cargo transportation for a multitude of users, including transportation for National Laboratory science research payloads.

The CRS contract vehicle is among NASA's most successful public-private partnerships. NASA used a series of fixed-price, milestone-based Space Act Agreements to support the development of several companies' efforts to develop commercial cargo resupply capabilities. As a result, NASA is now able to purchase these commercial services from several providers using fixed-price contracts, which offer more predictable budget requirements and provide cost savings to the Federal Government. This arrangement has resulted in a stronger U.S. space launch industry, redundancy in the cargo resupply mission area that has increased mission assurance, and robust private sector employment. NASA is leveraging these lessons learned in this program to expand science and research capabilities that these vehicles provide for CRS-2 missions. The CRS contract vehicle has been used as an example by other programs, such as Gateway and the Human Lander System, to expand the successful use of public-private partnerships.

Crew transportation is currently provided using the Russian Soyuz vehicle. NASA will continue to purchase Soyuz seats for crew transportation until a domestic capability is available. NASA has purchased Soyuz crew transportation services through both the Russian Roscosmos State Corporation and the Boeing Company.

The Commercial Crew Program (CCP) manages the Commercial Crew transportation Capability (CCtCap) contracts with Boeing and SpaceX to develop and provide domestic crew transportation to the ISS. CCP is funding the first Post Certification Missions (i.e., crew missions) to the ISS for each provider; the Crew and Cargo Program is funding the second and all subsequent missions. The first Post Certification Mission to ISS is scheduled for 2020.

The Crew and Cargo Program also funds activities supporting visiting vehicles that provide transportation for the ISS, including integration activities and the LEO version of the NASA docking system.

As of December 2019, NASA had allocated approximately $19 billion towards the commercial crew and cargo program. These funds have supported the completion of two cargo vehicles, the ongoing development of two crew vehicles, and 31 successful cargo flights to ISS. Of that amount, NASA contributed $6 billion towards the development of the commercial crew and cargo systems. This is the amount NASA refers to as “investment” in the systems, and it includes NASA’s share of the commercial cargo development costs, as well as all NASA Commercial Crew Program development costs (Commercial Crew Development [CCDev] phases 1 and 2, the Commercial Crew Integrated Capability [CCiCap] initiative, Certification Products Contract [CPC], and CCtCap). The remaining amount of $13 billion is the amount NASA has contracted for services, i.e., the transportation of cargo and crew to the ISS. This amount includes the current contract values for both CRS-1 and CRS-2 cargo contracts, as well as CCtCap crewed missions to the ISS. Within the current maximum contract value, NASA can still award another $10 billion under the CRS-2 contracts. Of the $19 billion NASA has allocated to these programs, $14 billion has been paid to the companies to date.

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

ACHIEVEMENTS IN FY 2019

Northrop Grumman completed nine CRS milestones in support of seven commercial resupply flights, including milestones for successful completion of two flights in FY 2019. SpaceX completed 17 CRS milestones in support of 10 commercial resupply flights, including milestones for the successful completion of three flights in FY 2019. Under the CRS-2 contract, Northrop Grumman, Sierra Nevada, and SpaceX performed integration milestones required to demonstrate new contract capabilities and design enhancements to support science and payload research objectives. SpaceX and Northrop Grumman have completed all seven integration milestones. Sierra Nevada has completed five of eight integration milestones with the completion of its functional interface/demonstration testing.

The program funded CCtCap contract milestones for crew missions that will be flown by Boeing and SpaceX. More information on CCtCap progress can be found under the CCP portion of this document.

On October 11, 2018, the Soyuz 56S (MS-10) spacecraft launched from the Baikonur Cosmodrome in Kazakhstan carrying American astronaut Nick Hague and Russian cosmonaut Alexey Ovchinin. Shortly after launch, there was an anomaly involving the first-stage booster, and the launch ascent was aborted, resulting in a ballistic landing of the spacecraft. As designed, the vehicle's launch abort system was initiated, enabling the safe return of the crew. A thorough investigation was completed by a Roscosmos commission, identifying the cause of the anomaly as the deformation of a contact sensor damaged during the rocket's assembly at the Cosmodrome in Kazakhstan. NASA was kept informed of the progress of the commission. NASA established its own team that worked alongside our Russian partners. The Soyuz successfully returned to flight on December 3, 2018, with Soyuz 57S.

In total, the program supported five crewed Soyuz launches, including the aborted mission, and one uncrewed Soyuz launch. The uncrewed Soyuz launch was a test flight to test a modification of the launch abort system for integration with the Soyuz-2.1a launch vehicle prior to flying crew missions. The program also supported three launches of Progress, a Russian cargo vehicle, and one launch of H-II Transfer Vehicle (HTV), a Japanese cargo vehicle, not funded by NASA.

WORK IN PROGRESS IN FY 2020

NASA expects five commercial resupply flights to deliver research and logistics hardware in FY 2020, including the first CRS-2 flights with Northrop Grumman and SpaceX. Northrop Grumman plans to launch two flights and complete 10 milestones in support of six CRS-2 flights. SpaceX plans to launch

CREW AND CARGO PROGRAM

Formulation	Development	Operations

three flights and complete 13 performance milestones in support of eight CRS/CRS-2 flights. SpaceX plans to launch its first CRS-2 mission in August 2020. Sierra Nevada plans to complete two performance milestones in support of two CRS-2 flights. Sierra Nevada will complete two integration review milestones towards completion of their vehicle testing and final safety review work.

To achieve these planned FY 2020 cargo flights, NASA personnel are reviewing and concurring on vehicle design solutions through a series of integration reviews. In addition, NASA personnel are verifying spacecraft requirements are met by reviewing test and analysis data provided by the CRS-2 contractors.

The program will also continue funding CCtCap contract milestones for crew missions with Boeing and SpaceX. Currently those missions are planned to begin in 2020 after successful completion of the test flights and NASA certification. However, NASA's experience with new transportation systems has shown the difficulties associated with achieving first flights on time. Typically, problems have been discovered during test flights. For example, an anomaly on the Orbital Flight Test of the Boeing CST-100 Starliner was experienced in December 2019. Should the new transportation systems follow the same pattern, there is risk that the U.S. would not be able to provide ISS crew for a period. The absence of U.S. crewmembers at any point would make the U.S. Orbital Segment (USOS) inoperable and would diminish ISS operations to a very limited operational state; having only one U.S. crewmember would diminish ISS research, eliminate the possibility of EVAs for research or maintenance purposes, and make it much more challenging to address internal time-sensitive maintenance contingencies. The consequences of no U.S. crew on ISS warrant the consideration of alternate transportation opportunities. To ensure a stable crew plan as a contingency option in the event that commercial crew providers experience additional delays, NASA is considering contracting with Roscosmos for an additional Soyuz seat and associated services.

Once U.S. commercial crew launch services become available, NASA will be able to permanently increase the crew size on the USOS to four astronauts. On average, this increase will double the total number of hours of crew time allocated to perform research on board the ISS each week. After the initial flights, the regular flight plan will provide for two commercial crew flights per year carrying four crew each flight. However, the first two flights for each provider may be scheduled in a shorter timeframe to reduce risk and accomplish more research.

The program will support one Soyuz launch. The program will also support three Progress launches and one HTV launch that are not funded by NASA.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

The Crew and Cargo Program will enable continued research and technology development by providing a stable crew and cargo flight plan.

NASA expects five commercial resupply flights, including the first Sierra Nevada CRS-2 flight, to deliver research and logistics hardware in FY 2021. Northrop Grumman plans to launch two commercial resupply flights and complete 11 performance milestones in support of five CRS-2 flights. SpaceX plans to launch two commercial resupply flights and complete 13 performance milestones in support of seven

CREW AND CARGO PROGRAM

Formulation	Development	Operations

CRS-2 flights. Sierra Nevada plans to launch one commercial resupply flight and complete five performance milestones in support of three CRS-2 flights. Prior to its launch, Sierra Nevada will complete three integration review milestones, which will complete its vehicle testing and safety reviews. These resupply flights will be vital for delivering not only the day-to-day supplies needed, but also the experiments that will enable the astronauts to continue important research on ISS. The flights will also support the increased number of research and science investigations enabled by the additional astronauts once commercial crew is available.

To achieve these planned FY 2021 flights, NASA personnel are reviewing and concurring with vehicle design solutions through a series of integration reviews to ensure new CRS-2 contract capabilities are being met. In addition, NASA personnel are verifying all spacecraft requirements are met by reviewing test and analysis data provided by the CRS-2 contractors.

The program will also continue funding CCtCap contract milestones for crew missions with Boeing and SpaceX. NASA is planning for at least one Boeing and one SpaceX mission. The flight schedule also includes three Soyuz launches and three Progress launches that are not funded by NASA.

Project Schedule

Maintaining a regular rate of cargo delivery on a mix of NASA and partner vehicles ensures the ISS can sustain nominal operations and maintenance, while allowing the program to respond to any anomalies that might occur. The table below shows scheduled ISS flight plans for FY 2020 and FY 2021. While NASA is currently expecting commercial crew vehicles to begin flying in FY 2020, those dates are under review and not included in the table below. NASA funds SpaceX (SpX), Northrop Grumman (NG), and Sierra Nevada Corporation (SNC) cargo missions, Boeing and SpaceX crew missions, as well as Soyuz seats related to USOS crew requirements. The planned spacing of the Soyuz crew rotation flights ensures a continuous crew presence on the ISS and smooth transitions between crews.

Date	Significant Event
Nov 2019	NG-12
Dec 2019	SpX-19
Dec 2019	Progress 74P
Feb 2020	NG-13
Mar 2020	SpX-20
Apr 2020	Soyuz 62S
Apr 2020	Progress 75P
May 2020	HTV-9
Jul 2020	Progress 76P

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Formulation	Development	Operations

Date	Significant Event
Aug 2020	SpX-21
Oct 2020	Soyuz 63S
Oct 2020	NG-14
Nov 2020	3R (Russian Proton launch of Multipurpose Laboratory Module)
Dec 2020	Progress 77P
Jan 2021	SpX-22
Mar 2021	Progress 78P
Apr 2021	NG-15
Apr 2021	Soyuz 64S
May 2021	SpX-23
Jun 2021	6R (Russian Proton launch of Russian Segment-Node)
Jul 2021	Progress 79P
Sep 2021	SNC-1
Sep 2021	Soyuz 65S

CREW AND CARGO PROGRAM

Formulation	Development	Operations

Project Management & Commitments

Johnson Space Center (JSC) is responsible for management of the Crew and Cargo Program.

Element	Description	Provider Details	Change from Formulation Agreement
Crew transportation	Until a domestic capability is available, Soyuz seats will be purchased for crew transportation to ISS either though Roscosmos or Boeing. Once available, commercial crew transportation will be provided by Boeing and SpaceX and managed by the Commercial Crew Program.	Provider: Roscosmos; Boeing; SpaceX Lead Centers: JSC, Kennedy Space Center (KSC) Performing Center(s): N/A Cost Share Partner(s): Canadian Space Agency (CSA), European Space Agency (ESA), and Japan Aerospace Exploration Agency (JAXA)	N/A
Cargo transportation	Northrop Grumman, SpaceX, and Sierra Nevada will provide cargo transportation to the ISS via the major contracts described below. JAXA will provide additional cargo transportation as part of the ISS partnership. Roscosmos will also provide nominal cargo transportation via Soyuz purchased for crew transportation.	Provider: Northrop Grumman, SpaceX, Sierra Nevada, JAXA, and Roscosmos Lead Center: JSC Performing Center(s): Goddard Space Flight Center (GSFC), KSC Cost Share Partner(s): CSA, ESA, and JAXA	N/A

Acquisition Strategy

The ISS program competitively procures all ISS cargo transportation services, excluding services obtained via barter with our international partners or nominal cargo transportation provided by Soyuz. On January 14, 2016, NASA competitively awarded CRS-2 contracts to Orbital ATK (now Northrop Grumman), Sierra Nevada, and SpaceX, with cargo transportation services that began in November 2019. Like the current CRS contracts, CRS-2 contracts are milestone-based, fixed-price indefinite-delivery-indefinite-quantity (IDIQ) contracts.

In September 2014, NASA's CCP awarded CCtCap contracts to Boeing and SpaceX for commercial crew transportation services that are planned to begin in FY 2020. CCP is funding milestones on the first Post Certification Missions for each provider. The Crew and Cargo Program will fund the second and all subsequent missions. These crewed vehicles will provide a minimum of 220 pounds of cargo as specified by the ISS program.

CREW AND CARGO PROGRAM

Formulation	Development	Operations

NASA purchased, through Boeing, crew transportation, rescue, and related services for one USOS crew member on Soyuz in FY 2017 and one in FY 2018. The contract with Boeing also provided Soyuz crew transportation services for three USOS crew members in 2019. NASA purchased two additional crew launches from Roscosmos through March 2020 and crew rescue and return through early October 2020. If commercial crew services are not available by March 2020, NASA will only have one USOS crew member on ISS. NASA is considering contracting with Roscosmos to ensure a stable crew plan until domestic commercial crew services are available.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Crew transportation	Roscosmos	Moscow, Russia
Crew transportation	Boeing	Houston, TX
Crew transportation	SpaceX	Hawthorne, CA
Cargo transportation	Northrop Grumman	Dulles, VA
Cargo transportation	Sierra Nevada	Louisville, CO
Cargo transportation	SpaceX	Hawthorne, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	NASA Advisory Council	May 2019	Provides independent guidance for the NASA Administrator	The panel provided no new formal recommendations or findings for the ISS.	2020
Other	NASA Aerospace Safety Advisory Panel	Sep 2019	Provides independent assessments of safety to the NASA Administrator	The panel encouraged NASA to develop contingency plans for continuity of USOS operations and consider adjusting ongoing Soyuz and commercial crew seat assignments to reduce risk of any launch delays for either launch vehicle.	2020

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FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	214.1	--	99.7	63.2	63.2	64.6	64.6

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

SpaceX Crew Dragon spacecraft is the first uncrewed Commercial Crew vehicle to visit the International Space Station. Here it is pictured with its nose cone open revealing its docking mechanism while approaching the station's Harmony module following its Demo-1 launch (March 2019).

Boeing CST-100 Starliner spacecraft atop the two-stage United Launch Alliance Atlas V rocket lifts off from Space Launch Complex 41 at Cape Canaveral Air Force Station in Florida for Boeing's Orbital Flight Test, an uncrewed mission of NASA's Commercial Crew Program (December 2019).

With technical guidance and oversight from NASA, the U.S. private sector is working to develop and operate safe, reliable, and affordable crew transportation to space, including to the International Space Station (ISS). Partnering with the commercial space industry for access to ISS and other low-Earth orbit (LEO) destinations bolsters American leadership, reduces our current reliance on foreign providers for this service, and helps stimulate the American aerospace industry. Crew transportation is currently provided using the Russian Soyuz vehicle. By supporting the development of U.S. human spaceflight capabilities, NASA is also contributing to the foundation of a more affordable and sustainable future for human spaceflight in LEO and beyond.

Through the Commercial Crew Program (CCP), NASA provides technical insight and financial support to industry partners during development of their crew transportation systems using milestone-based contracts, and will certify them to carry astronauts to and from the ISS. Under this acquisition model, NASA defines requirements upfront and pays the partner only once contract milestones are successfully completed. This approach shifts financial risk from taxpayers to the private sector, incentivizes increased cost-control, and decreases the cost of developing the systems.

The first phase of the development effort, which began in 2010, was a series of competitively awarded Space Act Agreements (SAAs) partnering NASA with domestic companies capable of contributing to the development of a U.S. human spaceflight capability.

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These included Commercial Crew Development (CCDev and CCDev2) and Commercial Crew integrated Capability (CCiCap). Concurrently with the SAAs, the first phase of a two-phased certification plan began in 2012 with the Certification Products Contracts (CPCs). The CPC effort allowed the partners to gain insight into NASA human spaceflight requirements and gave NASA early insight into partner designs and approaches.

CCP entered the final certification phase in late 2014 with the award of two Commercial Crew transportation Capability (CCtCap) contracts to Boeing and Space Exploration Technologies Inc. (SpaceX). CCtCap requires both partners to complete design, development, test, evaluation, and certification of an integrated Crew Transportation System. The completed transportation systems will support four NASA or NASA-sponsored crew on each flight, and provide emergency crew return, transport/return of pressurized ISS cargo, and crew safe haven while docked to the ISS.

There are numerous benefits associated with the CCtCap acquisition strategy (e.g., controlling costs in the long term and maximizing crew safety) as reinforced in statements by the Government Accountability Office (GAO), Aerospace Safety Advisory Panel, and NASA Office of Inspector General (OIG). The CCtCap contracts incorporate higher-level requirements than past development efforts, enabling the partners to be innovative and creative in their designs. Additionally, having more than one commercial partner creates competition and does not leave the Government dependent on a sole partner, thereby providing a strong incentive to perform, generally controlling long-term costs and schedules, and mitigating the risk of failure of an individual partner. Additionally, under this model, NASA ensures that companies retain commercial rights to intellectual property, which will allow these crew transportation systems to serve a much larger market than only NASA.

The 2014 CCtCap awards represented a significant milestone in U.S. human spaceflight, with the goal of ending our reliance on foreign crew transportation to the ISS and certification of safe, cost-effective U.S. commercial crew transportation systems. In addition, this approach helped stimulate growth of new space transportation industry capabilities available to all potential customers, strengthened America’s space industrial base and provided a catalyst for future business ventures that can capitalize on affordable, globally competitive U.S. space access. Returning these launches to American soil has significant economic benefits, with more than 1,000 suppliers working across nearly every state on commercial crew spacecraft systems.

NASA measures partner progress against fixed-price milestones, based on performance of agreed upon entrance and success criteria. Although the content varies by partner, milestones are designed to demonstrate progress toward completing crew transportation system development, such as risk reduction testing, design reviews, hardware development, and flight tests. The Government pays for milestones only after completion. Also, the partners will own and operate their completed transportation systems. As mentioned in the Crew and Cargo program section, CCP manages the CCtCap contracts. In addition to funding the development and risk mitigation work, CCP also funds each partner's initial Post Certification Mission (PCM). Subsequent PCMs, currently planned for FY 2021 and beyond, are funded by the Crew and Cargo program. A total of six PCMs have been awarded to each partner.

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

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ACHIEVEMENTS IN FY 2019

NASA's CCP completed its first uncrewed flight test in FY 2019, advancing NASA's goal of returning human spaceflight launches to U.S. soil on commercially-built and operated U.S. rockets and spacecraft. Under CCtCap development activities, Boeing and SpaceX continued to develop, test, and integrate their unique space transportation systems.

In March 2019, the world witnessed SpaceX's Demo-1 mission, an uncrewed flight test of Crew Dragon that launched aboard a Falcon 9 rocket to the ISS and autonomously docked to station. After five days, it returned to earth, splashing down in the Atlantic Ocean. The Demo-1 mission was the first commercially-built and operated American crew spacecraft and rocket to dock with the ISS. It was also the first autonomous docking of a U.S. spacecraft to the ISS and brought the program a significant step closer to launching crew once again from Florida's space coast.

Boeing completed initial production of three CST-100 Starliner spacecraft inside the company's Commercial Crew and Cargo Processing Facility at NASA's Kennedy Space Center (KSC) in Florida. The Starliner is designed for landing on land, making it reusable up to 10 times with a six-month turnaround time between launches. Boeing conducted environmental qualification testing to validate Starliner's ability to withstand the harsh environments of launch, ascent, and spaceflight. Starliner's propulsion system was put to the test at White Sands Test Facility in New Mexico during an integrated service module hot fire test in April 2019. Boeing also completed the initial qualification series of parachute drop tests using a high-altitude balloon, and, working with NASA, completed a series of lawn dart drop tests to continue proving the reliability of Starliner's parachute systems. In June 2019, the United Launch Alliance (ULA) Atlas V rocket arrived in Cape Canaveral, Florida in preparation for Boeing's uncrewed and uncrewed test flights. Boeing, ULA, NASA, and the Department of Defense (DoD) teamed up for integrated rehearsals of mission phases and various emergency escape and recovery scenarios. By the end of FY 2019, Boeing completed 36 of 44 milestones.

SpaceX continued manufacturing its Crew Dragon spacecraft inside the company's headquarters facility in Hawthorne, California. The company conducted a series of parachute tests that provided unique insight into parachute loading, behavior, and reliability, and helped to further refine the design. Teams from NASA, SpaceX and DoD continued to rehearse launch day operations, mission phases, and communication in both normal and emergency scenarios. Teams also practiced removing astronauts from Crew Dragon on the company's recovery boat, rehearsing steps they will take after splashdown of SpaceX's Demo-2 mission, which will be the company's first with crew onboard. By the end of FY 2019, SpaceX completed 22 of 32 milestones.

The nine U.S. astronauts selected for commercial crew missions continued to work closely with Boeing and SpaceX to ensure they are prepared for any situation that may arise during their mission and to live and work aboard the ISS. The astronauts will be the first humans launched from the United States since 2011.

WORK IN PROGRESS IN FY 2020

While technical challenges remain, CCP will actively engage with the providers as they continue space hardware manufacturing, critical testing, and qualification and verification events. Boeing and SpaceX are planning to complete several significant CCtCap milestones necessary to perform the flight test of their

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crew transportation systems. To meet NASA's requirements, the commercial partners must demonstrate that their systems are ready to begin regular flights to ISS.

Boeing flew its Orbital Flight Test 1 (OFT-1) in December 2019. The test was able to demonstrate a successful launch and landing as well as some of on-orbit operations; however, an anomaly prevented fully completing on-orbit, rendezvous, and docking test objectives. Boeing will continue the production and outfitting of their three spacecraft crew modules and multiple service modules inside the Commercial Crew and Cargo Processing Facility at KSC. In addition, Boeing and ULA will make final preparations to the launch pad to ready the Atlas V complex for human spaceflight. Boeing will also perform their Pad Abort Test to validate end-to-end performance and functionality of the launch abort system.

SpaceX conducted their final CCiCap milestone, an In-flight Abort Test. SpaceX will continue design, development, and test and evaluation work on their Crew Dragon spacecraft modules which the company currently has in various stages of production and testing.

Boeing and SpaceX will complete final parachute and landing systems testing for the Starliner and Crew Dragon, respectively, as well as perform final spacesuit qualification and validation testing to ensure suits function as designed. Both industry partners plan to complete demonstration missions in FY 2020. After completion of both the uncrewed and crewed flight tests, NASA will review flight data to verify the systems meet certification requirements and are ready to begin regular servicing missions to the ISS.

NASA purchased crew launches from Roscosmos through March 2020, and crew rescue and return through early October 2020. If the commercial crew transportation services are not available by March 2020, NASA will only have one United States Orbital Segment crewmember on the ISS. NASA is considering contracting with Roscosmos for one additional Soyuz seat and associated services to ensure a stable crew plan until domestic commercial crew services are available.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

Once CCtCap development and certification is complete, both partners' space transportation systems will begin regularly flying astronauts to and from the ISS. These missions will represent major milestones in the return of human spaceflight from the United States. CCP will transition to sustaining operations at a level needed to safely operate with two commercial providers. CCP will continue to manage the CCtCap contracts, including providing technical oversight and managing modifications and upgrades to the transportation systems.

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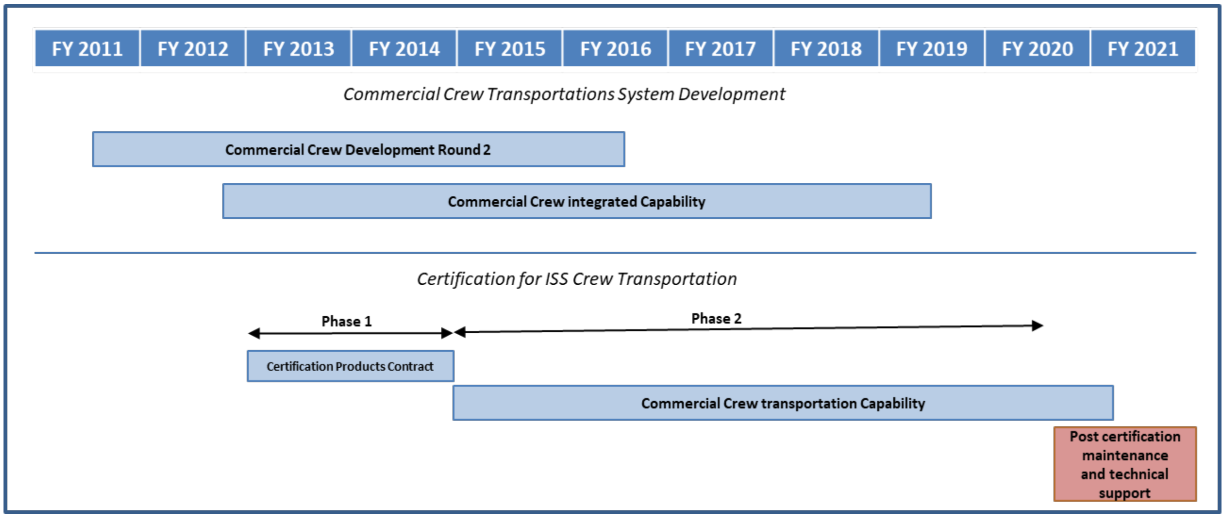
Program Schedule

The following chart depicts the progression of Commercial Crew development efforts.



Program Management & Commitments

The Human Exploration and Operations Mission Directorate (HEOMD) team at NASA Headquarters performs strategic management and oversight of Commercial Spaceflight, while KSC is responsible for CCP management, in collaboration with the Johnson Space Center (JSC). CCP partners with industry leaders and is utilizing a combination of SAA and Federal Acquisition Regulation (FAR)-based fixed-price contracts to stimulate efforts to develop and demonstrate crew transportation capabilities.

Program Element	Provider
Commercial Crew Program	Providers: Blue Origin, Boeing, Sierra Nevada, SpaceX Lead Center: KSC Performing Center(s): All Cost Share Partner(s): Industry Partners (shown above)

Acquisition Strategy

CCP facilitates development of a U.S. commercial crew space transportation capability with the goal of achieving safe, reliable, and cost-effective access to and from space and the ISS. Under the partnership approach, NASA engineers have insight into a company's development process and evaluate the systems for overall safety, reliability, and performance. The Agency's technical expertise and resources are also accessible to a company. Because companies are only paid a fixed amount, they are incentivized to reduce costs and to apply their most efficient and effective manufacturing and business operating techniques throughout the process. Additionally, the companies own and operate their own spacecraft.

In the early lifecycle stages, CCDev activities focused on stimulating industry efforts that successfully matured subsystems and elements of commercial crew spaceflight concepts, enabling technologies and capabilities. This was followed by CCDev2, which addressed new concepts to mature design and development of primary elements, such as launch vehicles or spacecraft. Subsequently, NASA continued this effort with CCiCap to continue partner progress in their integrated design and development efforts. For these initial efforts, NASA utilized SAAs, which provided maximum flexibility to the provider and maximum affordability to the Government. Concurrently with CCiCap agreements, NASA awarded CPCs to industry to begin the process of NASA certifying their crew transportation systems. The scope of the CPCs included the submittal and technical disposition of specific, early development certification products. The current and final stage of the acquisition lifecycle began with the award of two FAR-based fixed-price CCtCap contracts in September 2014 for the development, test, evaluation, and final NASA certification of a Crew Transportation System. CCtCap contracts include demonstration of crewed ISS missions and subsequent service missions, assuming sufficient budget and technical progress. The contracts also include a Special Studies Services section for special studies, tests, or analyses, as needed by NASA, to reduce Program risk. NASA's FAR based fixed-price contracts during this phase allow for compliance with NASA's existing mission and safety requirements for transporting crew to and from ISS.

Major Contracts/Awards

Element	Vendor	Location (of work performance)
CCDev2 (follow-on)	Blue Origin	Kent, WA
CCtCap	Boeing	Houston, TX
CCiCap	Sierra Nevada	Louisville, CO
CCiCap/CCtCap	SpaceX	Hawthorne, CA

Independent Reviews

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	Standing Review Board (SRB)	Nov 2018	Assess funding and schedule reserve requirements, cost effectiveness during development and impacts to future sustaining operations, and efforts required for successful program implementation	While the SRB identified some risks, issues, and concerns, it found that the program has made good progress in the last year proceeding towards the production and test phase of the program	Not currently scheduled
Other	Aerospace Safety Advisory Panel	Sep 2019	Provide independent assessments of safety to the NASA Administrator	No new formal recommendations or findings	2020
Other	NASA Advisory Council	Oct 2019	Provide independent guidance for the NASA Administrator	No new formal recommendations or findings	2020

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Historical Performance

The tables below represent historical performance through FY 2019, as of September 30, 2019, and only include funded milestones.

Commercial Orbital Transportation System (COTS) Partner	No. of Milestones	Total Potential Value (in $M)	No. Milestones Completed	Funding for Completed Milestones (in $M)	% Milestones Completed	% Funding Completed	Status
SpaceX	40	396.0	40	396.0	100%	100%	Completed
Orbital	29	288.0	29	288.0	100%	100%	Completed
Rocketplane-Kistler	15	206.8	3	32.1	20%	16%	Terminated

CCDev1 Partner	No. of Milestones	Total Potential Value (in $M)	No. Milestones Completed	Funding for Completed Milestones (in $M)	% Milestones Completed	% Funding Completed	Status
Sierra Nevada	4	20.0	4	20.0	100%	100%	Completed
Boeing	36	18.0	36	18.0	100%	100%	Completed
Blue Origin	7	3.7	7	3.7	100%	100%	Completed
Paragon Space Development Corporation	5	1.4	5	1.4	100%	100%	Completed
United Launch Alliance	4	6.7	4	6.7	100%	100%	Completed

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CCDev2 Partner	No. of Milestones	Total Potential Value (in $M)	No. Milestones Completed	Funding for Completed Milestones (in $M)	% Milestones Completed	% Funding Completed	Status
Sierra Nevada	13	105.6	13	105.6	100%	100%	Completed
Boeing	15	112.9	15	112.9	100%	100%	Completed
SpaceX	10	75.0	10	75.0	100%	100%	Completed
Blue Origin	10	22.0	10	22.0	100%	100%	Completed

CCiCap Partner	No. of Milestones	Total Potential Value (in $M)	No. Milestones Completed	Funding for Completed Milestones (in $M)	% Milestones Completed	% Funding Completed	Status
Sierra Nevada	11	227.5	11	227.5	100%	100%	Completed
Boeing	20	480.0	20	480.0	100%	100%	Completed
SpaceX	15	460.0	14	445.0	93%	97%	Active

CCtCap Partner	No. of Milestones	Total Potential Value (in $M)*	No. Milestones Completed	Funding for Completed Milestones (in $M)	% Milestones Completed	% Funding Completed	Status
Boeing	44	2,190.0	36	1,701.8	82%	78%	Active
SpaceX	32	1,206.9	22	951.6	69%	79%	Active

** Total Potential Value cited is limited to the design, development, test, and evaluation portion of the contracts. Excludes post certification mission and special studies milestones.*

SPACE COMMUNICATIONS AND NAVIGATION

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Space Communications Networks	499.0	--	**388.2**	388.6	372.6	372.6	372.6
Space Communications Support	103.5	--	**117.8**	128.8	114.5	108.5	108.5
Total Budget	**602.5**	**--**	**506.0**	**517.4**	**487.1**	**481.1**	**481.1**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

DSS-56, shown here, is one of two new 34-meter antennas being built in the Madrid Deep Space Communications Complex.

NASA's Space Communications and Navigation (SCaN) capabilities provide mission-critical communications and navigation services required by all NASA human and robotic missions. These missions range from high-altitude balloons, to the International Space Station (ISS) in low-Earth orbit (LEO), to Voyager 1, which is currently more than 13 billion miles from Earth, making it the most distant manmade object. SCaN retrieves science, spacecraft, and crew health data for all these missions, uploads commands, and sends data to individual control centers. Navigation services determine the precise location of a satellite to control its trajectory through space, gather valid scientific data, and avoid space debris or other spacecraft.

Without services to move data and commands between spacecraft and Earth, space assets worth tens of billions of dollars would be little more than orbital debris. SCaN provides secure, reliable, and adaptable communication services to NASA missions, as well as external customers who rely on space communications services on a daily basis. External customers include foreign governments, international partners, commercial entities such as launch service providers, and non-NASA U.S. missions to which SCaN provides services on a reimbursable basis.

SCaN's three communications networks - the Space Network (SN), Near Earth Network (NEN), and Deep Space Network (DSN) - currently provide these critical services to customers. Both the NEN and the SN primarily support LEO, Earth Science missions. The SN is unique from the NEN and DSN because of its utilization of relay spacecraft, which allows for near real-time, low latency support that supports human spaceflight operations. The NEN and the DSN both utilize ground assets that transmit and receive data when they are within line of sight of the missions they support. The service range for the NEN is from near Earth to the vicinity of the Moon, while the DSN supports communications from the vicinity of the Moon and beyond.

SPACE COMMUNICATIONS AND NAVIGATION

All three networks will support Commercial Crew providers, launches of the Space Launch System (SLS), and the upcoming Artemis lunar missions.

The SN allows SCaN to offer 24/7 global telecommunication services for telemetry, tracking, and command for LEO spacecraft. The SN is a data communication system comprised of a constellation of Tracking and Data Relay Satellites (TDRS) and various ground terminals. The SN provides services to missions such as the Hubble Space Telescope and provides constant communication with the ISS, as well as its commercial and international partner servicing vehicles. The SN provides continuous communication services for every launch vehicle that carries a U.S. Government payload to space.

The NEN primarily provides support to Earth Science missions and LEO polar orbiting satellites. NEN also supports an extensive and diverse customer base from suborbital to Lagrangian orbits by providing direct-to-ground data transfer from spacecraft at S, X, and Ka-band frequencies up to data rates of gigabits per second. The NEN utilizes a mix of Government, university, and commercial ground antennas to maximize the network's geographic coverage, minimize the impact of weather-related communications disruptions, and effectively manage financial resources.

The DSN is a keystone of NASA exploration of the solar system. It provides reliable, high-performance, and cost-effective telecommunications and tracking services to planetary missions. The DSN is an international network of 34-meter and 70-meter antennas that supports interplanetary spacecraft missions and radio and radar astronomy observations for the exploration of the solar system and the universe. The DSN currently consists of three deep-space communications facilities placed approximately 120 degrees apart around the world: at Goldstone, in California's Mojave Desert; near Madrid, Spain; and near Canberra, Australia.

NASA uses the SCaN-provided Goldstone Solar System Radar to track and characterize near Earth objects that pass within nine million miles of Earth and to determine their orbits for use by the Science Mission Directorate’s (SMD) Planetary Science Division in assessing the probability of a possible collision with Earth. The installation of new radar equipment, planned for completion in FY 2025, will extend the radar's capability to a distance of 42 million miles, which increases the time to develop viable solutions to avoid orbital collision for planetary defense.

The three networks require maintenance, replenishment, modernization, and capacity expansion to ensure continued operation and to meet new mission needs. Human exploration of the Moon requires communications to support video, telemedicine, and advanced instruments that locate and identify exploitable resources on the Moon, such as subsurface ice. SCaN constantly monitors newly announced lunar missions to determine whether its capabilities will meet the new mission needs.

The SCaN program also includes support to ground communications links that move data among ground stations, NASA Centers, data centers, and mission operation centers.

Space Communications Support provides efficient planning and integration of current and future network capabilities to meet customer mission needs while reducing costs. It provides systems engineering, architecture planning, communications data standards, technology development, testbeds for future capabilities, radio frequency spectrum management, and navigation policy.

Operating in space requires significant international coordination. SCaN participates in several international organizations that coordinate compatibility and interoperability in space communications and navigation. SCaN's standards development and management activity maintains a portfolio of international interoperability standards that enable joint space missions with other nations. SCaN also promotes new technologies and provides technical leaders and domain experts who ensure appropriate space communication standards are available to NASA missions. The research and technology avenues within SCaN aim to predict the needs of future communications missions in a manner that will yield initiatives with performance advancements and a reduction in costs.

Amid soaring demand for wireless broadband, such as 5G mobile services, radio frequency spectrum management has become increasingly critical to the world's spacefaring nations. SCaN coordinates nationally and internationally to protect radio frequencies critical to NASA space and science missions.

For more information, go to http://www.nasa.gov/scan

EXPLANATION OF MAJOR CHANGES IN FY 2021

The Disruption Tolerant Network activity previously funded under the Advanced Exploration Systems program was transferred to SCaN.

The NASA Communications Services Office (CSO) budget will be transferred to the Office of the Chief Information Officer under the Safety, Security, and Mission Services account to better align with its management structure. The CSO mission network provides mission-critical routed data services to programs and projects across the Agency. This activity is managed by the OCIO. However, unlike other OCIO activities which are funded in the Safety, Security, and Mission Services account, the CSO budget is held within the Space Communications and Navigation (SCaN) program. This creates a misalignment between the budget and management structure.

SPACE COMMUNICATIONS NETWORKS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**499.0**	**--**	**388.2**	**388.6**	**372.6**	**372.6**	**372.6**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

DSS-53 reflector lift completed in August 2019 at the Madrid Deep Space Communications Complex, part of NASA's Deep Space Network, shown above.

The Space Communication and Navigation (SCaN) networks are the Space Network (SN), Near Earth Network (NEN), and Deep Space Network (DSN). Together they provide a 24/7 global, near-Earth and deep-space communications system, plus tracking and navigation services to more than 100 NASA programs and other U.S. Government, international civil space agencies, and commercial missions. This capability ensures NASA's ability to have continuous communication with its spacecraft.

SCaN supports new spacecraft that are increasingly powerful, complex, and capable of acquiring ever increasing amounts of mission data, as well as missions launched more than 40 years ago that are still returning valuable science data. Each network supports a different set of customer requirements for spacecraft orbit, signal strength, and real-time coverage. All networks provide service to customer missions at a proficiency of more than 99 percent. To continue providing this level of support, each network requires regular maintenance, modernization and capacity expansion, and IT security upgrades to combat the ever-growing cybersecurity threats toward U.S. assets.

NASA’s space communications networks provide ongoing services to Agency and customer missions, averaging approximately 600 tracking passes per day. Without these capabilities, customer missions like Parker Solar Probe (PSP), Joint Polar Satellite System (JPSS), Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight), Ice, Cloud and land Elevation Satellite (ICESat-2), Commercial Crew, and Transiting Exoplanet Survey Satellite (TESS) would not be able to deliver key science data or advance NASA's exploration goals. These networks will support the Artemis program as the Agency aims toward the goal of landing the first woman and next man on the Moon by 2024. Future investments will be focused on supporting the Artemis Program. Human exploration of the Moon requires communications to and from the Moon to support video, telemedicine, and advanced instruments to locate and identify exploitable resources on the Moon, such as subsurface ice.

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The SN provides continuous global coverage to NASA missions in low-Earth Orbit (LEO) and to launch vehicles during their launch and ascent phase. This global, low latency, high data rate coverage is provided by a fleet of dedicated relay spacecraft. It is the primary U.S. communications link to the International Space Station (ISS), as well as for ground and balloon research in remote locations, such as the South Pole. The SN consists of NASA's Tracking and Data Relay Satellite (TDRS) system of communications satellites in geosynchronous orbit and a set of space-to-ground link terminals at NASA's White Sands Complex in New Mexico. SN space-to-ground link terminals are also located in Guam and Blossom Point, MD. The ground systems operate the TDRS fleet and route customer mission data between TDRS and ground terminals. Maintaining and modernizing this network is one of SCaN's top priorities. The SN provides continuous communication services for every launch vehicle that carries a U.S. Government payload to space. The upgrades to the SN ground stations are managed by the Space Network Ground Segment Sustainment (SGSS) project.

The NEN provides direct-to-ground space communications to missions in LEO, geosynchronous, lunar, and highly elliptical Earth orbits, as well as from certain suborbital launch locations. While the SN provides global coverage via relay satellites, the NEN provides its global coverage via a mix of Government, university, and commercially operated ground stations. This geographic distribution minimizes the impact of weather-related communications disruptions by having assets located throughout the world. The NASA owned network's ground stations are located at White Sands in New Mexico; U.S. McMurdo Antarctic Station; and Wallops Flight Facility (WFF) in Chincoteague, VA. University operated ground stations are located at the University of Alaska in Fairbanks, AK. The NEN also purchases commercial services from providers in Hawaii, Norway, Sweden, Singapore, South Africa, Australia, and Chile. NEN supports an extensive and diverse customer base from suborbital to Lagrangian orbits by providing direct-to-ground data transfer from spacecraft at S, X, and Ka-band frequencies up to data rates of gigabits per second.

The NEN has recently augmented its ground station network with the addition of the Launch Communications Segment (LCS). This addition culminated with a ribbon cutting ceremony for one of its components, the Kennedy Uplink Station (KUS), on November 19, 2019. LCS will provide launch communications services for Orion and the Space Launch System (SLS).

The DSN, which has been in operation for more than 50 years, provides communication and tracking services to approximately 35 NASA and non-NASA missions beyond geosynchronous orbit (more than 26,000 miles above the Earth's surface). The DSN is an international network of 34-meter and 70-meter antennas that supports interplanetary spacecraft missions and radio and radar astronomy observations for the exploration of the solar system and the universe. The DSN currently consists of three deep-space communications facilities placed approximately 120 degrees of longitude apart around the world: at Goldstone in California's Mojave Desert; near Madrid, Spain; and near Canberra, Australia. The sites are separated such that they ensure that any spacecraft in deep space can communicate with at least one station at all times as the Earth rotates. The DSN supports NASA's exploration of the solar system and beyond by providing reliable, high-performance, and cost-effective telecommunications and tracking services to planetary missions.

In addition, NASA uses the SCaN-provided Goldstone Solar System Radar to track and characterize near-Earth objects that pass within nine million miles of Earth and helps determine their orbits for use by the Science Mission Directorate's (SMD) Planetary Science Division in assessing the probability of a

SPACE COMMUNICATIONS NETWORKS

conjunction. Investments in this system are underway to increase the capability in support of mission planning and planetary defense.

The ongoing DSN Aperture Enhancement Project (DAEP) modernizes and upgrades the DSN's ground stations to enhance capacity, improve flexibility to support customer missions, and reduce operations and maintenance costs. The project will augment the 70-meter antennas in California, Spain, and Australia with arrays of four 34-meter Beam Waveguide (BWG) antennas by 2025. Antenna arraying combines the signals received by multiple antennas to function as a single large antenna – in this instance as a 70-meter antenna or less (as required). The BWG antennas are less complicated, more flexible, and more cost-effective to maintain than conventional antennas. In addition, they provide the same or better performance as the 70-meter antennas. When missions do not require all four antennas be arrayed, the 34-meter antennas can support multiple spacecraft (as needed) individually or by arraying two or three of the 34-meter antennas. Construction efforts, such as the new 34-meter antennas, use Construction of Facilities funds appropriated in NASA's Construction and Environmental Compliance and Restoration account.

For more information, go to: http://www.nasa.gov/scan

EXPLANATION OF MAJOR CHANGES IN FY 2021

The Disruption Tolerant Network activity previously funded under the Advanced Exploration Systems program was transferred to SCaN.

The NASA Communications Services Office budget will be transferred to the Office of the Chief Information Officer under the Safety, Security, and Mission Services account to better align with its management structure. The CSO mission network provides mission-critical routed data services to programs and projects across the Agency. This activity is managed by the OCIO. However, unlike other OCIO activities which are funded in the Safety, Security, and Mission Services account, the CSO budget is held within the Space Communications and Navigation (SCaN) program, creating a misalignment between the budget and management structure.

ACHIEVEMENTS IN FY 2019

Consistent with prior years' successes, the three space communications networks provided approximately 245,000 tracking passes while maintaining an extremely high level of proficiency (approximately 99.95 percent or higher), which is above the 95 percent required by the SCaN Program Commitment Agreement.

The SN began working transition activities with customers in preparation for the completion of SGSS. Activities included support to SGSS for project integration, testing, deployment, training, and transition to operations. In August 2019, SN successfully transitioned TDRS-9 to SGSS to support level 6 testing. Systems integration activities progressed with SGSS completing a provisional acceptance test, which determined whether the system met functionality and performance requirements, a key milestone before the initial Operation Readiness Review (ORR). SGSS is currently testing with TDRS and user missions to ensure functionality and performance requirements.

SPACE COMMUNICATIONS NETWORKS

NEN completed Depot Level Maintenance on an 18-meter antenna at the White Sands facility. Activities included proactively inspecting and replacing cables and mechanical systems reaching their failure threshold and not otherwise addressed by preventative maintenance. NEN also continued Ka-Band upgrades at the Alaska Satellite Facility scheduled for completion in FY 2020. NEN established KUS perpetual facility infrastructure support task.

DSN completed the critical design review for the Three Links per Operator efficiency task and began implementation, allowing the DSN to maintain the same level of operators as additional antennas continue to be added to the operational network. These planned efficiencies, including Follow-the-Sun Operations, and cost controls allowed for critical reinvestment into the network. Past reinvestments have included additional assets and replacement of obsolete equipment.

In Madrid, Spain, the DAEP completed antenna fabrication for Deep Space Station (DSS)-56 and began installation, integration, and test activities in July 2019 in preparation for operations in FY 2020. The project also began installation, integration, and test activities on DSS-53. The project completed the reflector lift in August 2019 and continued installation work on the antenna's lower pedestal shroud and panels. DAEP began the actuator study for DSS-23 at the Goldstone Deep Space Communications Complex to identify candidate actuators for the final Radiofrequency (RF)-Optical configuration.

WORK IN PROGRESS IN FY 2020

SCaN Networks will continue providing communications, tracking and navigation services to more than 100 NASA, U.S. Government, civil space agency, and commercial missions at a 95 percent or higher proficiency rate. This service includes providing launch support on all new human spaceflight, Commercial Launch Vehicle (CLV), and robotic missions. All three networks will continue to identify and implement methodologies and processes, as well as upgrade equipment, to achieve improvements over historical operational efficiencies and goals.

The SN began working transition activities with customers in preparation for the completion of SGSS in FY 2021. In January 2020, SGSS will complete the initial ORR milestone, which is required to achieve the Final Acceptance Review. The SN will complete software training on the SGSS system following the level 6 test completion, which will provide opportunities for additional SN hands-on training. Post level 6 testing will be led by the SN and supported by SGSS personnel in preparation for the 2nd ORR, which is currently scheduled for August 2020. In October 2019, SN successfully completed GEN-III TDRS equipment moves from Space-Ground Link Terminals (SGLT)-5 to SGLT-3, a first step toward supporting Artemis I. SN is also completing final preparations for the ORR with the SN Legacy Enhancement for Artemis I.

NEN's ribbon cutting for the Launch Communication Segment (LCS) occurred in November 2019. LCS stations are a critical link between the astronauts and mission controllers on crewed flights as well as a key component for the US Air Force eastern range in enabling next-generation space missions and launch vehicles departing to or from the Florida spaceport. NEN will complete Ka-band upgrades at the Alaska Satellite Facility. Upgrades at the Alaska Satellite Facility are expected to support future polar orbiting missions, such as NASA Indian Space Research Organization (ISRO) Synthetic Aperture Radar (NISAR), in their requirement for high-data rate support. The NEN will support NISAR at 3.5 Gigabytes

SPACE COMMUNICATIONS NETWORKS

per second, which is the highest data rate ever supported for a NASA mission, far exceeding NEN's current maximum data rate support of 300 Megabytes per second.

DSN will complete the ORR and begin operations of the Three Links per Operator efficiency task in FY 2020. This will be the final phase of the Follow-the-Sun Operations task, which will further increase operational efficiency of the networks. Three Links per Operator also allows for the operation of additional assets, such as the two new antennas at Madrid, Spain, without increasing operational costs.

The DAEP installation, integration, and test activities will also begin on DSS-53, scheduled for completion in FY 2021. These new antennas will transmit and receive across a wide range of radio frequencies for deep space communication with interplanetary robotic spacecraft to provide required capabilities for the expected growth of deep space missions launching over the next decade. DSS-56 will be transitioned into operations and begin supporting missions.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

SCaN Networks will continue to provide communications, tracking, and navigation services to more than 100 NASA, U.S. Government, civil space agency, and commercial missions at 95 percent or higher proficiency rate. This service includes launch support on all new human spaceflight, CLV, and robotic missions. All three networks will continue to identify and implement methodologies and processes, as well as upgrade equipment, to achieve improvements over historical operational efficiencies and goals.

The SGSS project will complete readiness criteria required for Final Acceptance Review. SGSS will complete level 6 hand off, verifying requirements and validating capabilities, external interfaces, and system-level end-to-end operating procedures that can be accomplished through TDRS spacecraft shadowing (not commanding), while supported by SGSS Operations subject matter expert personnel. SN will augment the SGSS team with SN subject matter experts in front-end processors, modems, and receivers to characterize performance, troubleshoot and resolve problems, and perform regression testing. SN will also augment the SGSS development team with White Sands Complex (WSC) software engineering personnel.

NEN will implement Delay Tolerant Networking Operations in support of future missions, including the Artemis program. The DAEP will complete installation, integration, and test activities of DSS-53. Both DSS-53 and DSS-56 will be transitioned into operations and ready to provide mission support.

SPACE COMMUNICATIONS NETWORKS

Project Schedule

The table below includes significant SCaN network milestones in FY 2020 and FY 2021.

Date	Significant Event
Q1 FY 2020	Deep Space Network (DSN) complete Operations Readiness Review of Three Links per Operator
Q1 FY 2020	DSN Aperture Enhancement Project (DAEP) release request for proposal for Deep Space Station (DSS)-23 excavation, pedestal, and antenna
Q2 FY 2020	Space Network Ground System Sustainment (SGSS) complete formal trainings 5-10
Q2 FY 2020	DAEP continues DSS-53 Ka-band installation integration and testing
Q2 FY 2020	SGSS Initial Operational Readiness Review (ORR)
Q3 FY 2020	DSN operational use of 3 Link Per Operator task begins
Q4 FY 2020	SGSS manufacturing prep for Post Incremental Technical Support
Q4 FY 2020	SGSS White Sands Complex integration and testing level 5 & 6 dry run
Q4 FY 2020	SGSS 2nd ORR
Q4 FY 2020	DAEP DSS-56 DSN Service Readiness Review to Operational
Q1 FY 2021	Space Network (SN) Space Test Program-6 Launch Readiness Date
Q2 FY 2021	SN Optical 2 Orion Ground Segment ORR
Q3 FY 2021	DAEP DSS-53 DSRR to Operational
Q4 FY 2021	Near Earth Network Initiative for Ka-band Advancement (NIKA) Operations Readiness Review

SPACE COMMUNICATIONS NETWORKS

Project Management & Commitments

Element	Description	Provider Details	Change from Formulation Agreement
Space Network	Communication and navigation services to customer missions in low-Earth Orbit and launch vehicles	Provider: Space Network Project Office Lead Center: Goddard Space Flight Center (GSFC) Performing Center(s): N/A Cost Share Partner(s): Non-NASA customers	N/A
NEN	Communication and navigation services to customer missions in low Earth, highly elliptical, and lunar orbits	Provider: NEN Project Office Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): Non-NASA customers	N/A
DSN	Communication and navigation services to customer missions in deep space	Provider: DSN Project Office Lead Center: Jet Propulsion Laboratory (JPL) Performing Center(s): N/A Cost Share Partner(s): Non-NASA customers	N/A
SGSS	Replace outdated and deteriorating ground systems at Space Network ground terminals	Provider: SGSS Project Office Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): Non-NASA U.S. Government partners	N/A

Acquisition Strategy

The major acquisitions for the networks are in place. NASA uses reimbursable, international, and barter agreements, as well as competitive procurements. NASA's JPL provides the management of the DSN.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
DSN	JPL/California Institute of Technology	Pasadena, CA
Space Network Operations	Peraton	Herndon, VA
NEN Operations	Peraton	Herndon, VA

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Element	Vendor	Location (of work performance)
SGSS	General Dynamics Mission Systems	Scottsdale, AZ

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
SCaN	Standing Review Board	Jun 2018	Program Implementation Review with focus on interdependencies, implementation planning, and risk gaps or shortfalls	Success criteria met; major strengths, observations, concerns, and issues were identified	FY 2020

SPACE COMMUNICATIONS SUPPORT

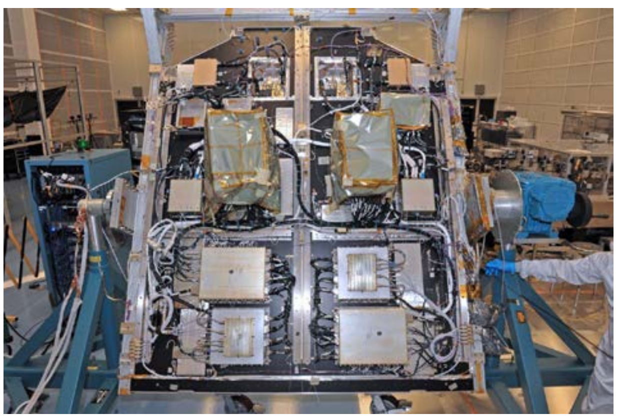
Formulation	Development	Operations

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**103.5**	**--**	**117.8**	**128.8**	**114.5**	**108.5**	**108.5**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.



The Laser Communications Relay Demonstration (LCRD) payload, shown here, is completed and in storage in the clean room at NASA Goddard Space Flight Center. Scheduled to launch in 2020, LCRD will simulate communications support after validating optical communications for two years with a test payload on the International Space Station and two dedicated ground stations in California and Hawaii.

The Space Communications Support project supports NASA and the Space Communications and Navigation (SCaN) program through communications and navigation planning, management, and technology development.

Evolving space communication systems will transform future NASA mission capabilities. SCaN’s technology development effort invests in leading-edge communications technologies that will enable, improve, and mature available spacecraft communication and navigation technologies for both ground- and space-based use. Technology items are created and tested in laboratory settings before they are taken into space for further testing. Demonstrable technologies have proven themselves in laboratory tests and have begun experimentation and testing in space. Key technologies that SCaN is currently developing are wideband tunable modems and software-defined radios for use with commercial satellite communications (SATCOM) providers and cognitive networking. These technologies will demonstrate use of a common radio to provide cross-service support for NASA, commercial, and Department of Defense networks.

Another key space communication technology is optical (i.e., laser) communications. NASA's Space Technology Mission Directorate (STMD) and SCaN are jointly developing the Laser Communications Relay Demonstration (LCRD). SCaN is funding ground operations and STMD is funding the payload. LCRD will be NASA's first long-period optical communications project that will demonstrate benefits for both deep space and near-Earth missions. To transmit a 30 centimeter resolution map of the entire

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

Martian surface (at one bit/pixel) would take current radiofrequency (RF) systems two years, while a laser communications system operating at projected capacity would be able to complete transmission in nine weeks.

Deep Space Optical Communications (DSOC) is another critical technology being developed through a joint SCaN/STMD collaboration. DSOC will conduct optical communications from deep space, demonstrating key capabilities related to pointing and implementation of the High Photon Efficiency signaling standard. SCaN sponsors the ground network, including the five kilowatt uplink beacon at Table Mountain and a superconducting single-photon-sensitive nanowire detector and real time receiver at the Palomar Observatory.

SCaN and STMD collaborated on the Deep Space Atomic Clock (DSAC) demonstration, which was launched in June 2019. DSAC is currently in a post-launch checkout phase and will operate for a one year demonstration period. SCaN continues to invest in DSAC technology to mature designs for future mission use. DSAC technology will allow a spacecraft to calculate its own timing and navigation data in real-time. With existing technology, a spacecraft can navigate autonomously to the top of the Martian atmosphere with a one to two kilometers uncertainty. It is expected that DSAC will enhance deep space navigation and reduce positional uncertainty to 100 meters, an improvement of a factor of 10 to 20 over today's capabilities, which will save fuel and enable more accurate scientific measurements. DSAC may also enable on-board navigation for both robotic and crewed missions.

SCaN is an active member of multiple international organizations (e.g., Interagency Operations Advisory Group [IOAG], Consultative Committee for Space Data Systems [CCSDS]) that coordinate space communication and navigation compatibility and interoperability, as well as the development of communications and data systems standards for spaceflight. Space communications data standards enable the world space agencies to support each other, reducing mission risk and reducing or eliminating the need to build and deploy their own space and ground assets. These standards provide significant cost savings to NASA without reducing services or coverage to space missions.

Electromagnetic spectrum is a valuable and limited natural resource that all NASA missions and most operations require for communications, navigation, remote sensing, and data services in the areas of Earth science, space science, human space exploration, and aeronautical research. All forms of wireless communication systems used by the U.S. Federal Government or by commercial entities use the electromagnetic spectrum, so the spectrum must be carefully controlled and coordinated. SCaN is responsible for ensuring access to the portions of the electromagnetic spectrum necessary to support NASA's mission needs. This responsibility includes ensuring interference-free operations and bandwidth availability. SCaN serves as the Agency's Spectrum Manager and provides NASA representatives to advocate for NASA's requirements at domestic spectrum governing bodies, including the Interdepartment Radio Advisory Committee at the National Telecommunications and Information Administration within the Department of Commerce. Internationally, NASA provides a U.S. delegate to multiple forums, the most important of which are the World Radiocommunication Conferences (WRCs), which convene every three to four years and include delegates from more than 150 nations. NASA's delegates play leading roles in several key WRC working groups and regional committees throughout the year. Among the purposes of these conferences is to review and revise the International Telecommunication Union's Radio

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

Regulations, which govern the international use of the electromagnetic spectrum. In both the domestic and international arenas, NASA continues to engage with the commercial sector to identify more flexibility in the use of spectrum resources that will meet mission objectives for the entire space community.

NASA spacecraft in Earth's orbit employ Global Positioning System (GPS) timing signals for precision positioning and navigation for vehicles in space, allowing NASA to minimize the network communications and tracking burdens while maximizing spacecraft autonomy and operations. SCaN manages NASA's policy on GPS use and plays a role in developing national and international position, navigation, and timing policy, helping to ensure compatibility and interoperability among U.S. and other spacefaring nations, promoting common definitions and specifications, and mitigating threats to the GPS spectrum.

For more information, go to: https://www.nasa.gov/scan

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

ACHIEVEMENTS IN FY 2019

SCaN continued its work with STMD on LCRD. SCaN completed both Optical Ground Station-1 (OGS-1) at Jet Propulsion Laboratory's Optical Communication Telescope Laboratory facility (in California) and OGS-2 (in Hawaii) to support the LCRD launch. The LCRD payload was completed and is currently in storage awaiting shipment to be integrated as a hosted payload aboard the U.S. Air Force's Space Test Program Satellite-6 (STPSat-6). The availability of STPSat-6 will determine the launch date. The Integrated LCRD LEO User Modem and Amplifier Terminal (ILLUMA-T) and Artemis II Optical to Orion (O2O) projects completed their Critical Design Reviews (CDR) on November 15, 2019. ILLUMA-T will implement Laser Communications on NASA spaceflight missions starting with demonstrations of operational utility between the LCRD and an ISS LEO user terminal.

The DSOC optical ground station project completed its Preliminary Design Review (PDR). Promising technologies were advanced in FY 2019, leading to future CubeSat demonstrations in FY 2020 such as the TeraByte InfraRed Delivery (TBIRD) and the Cognitive Application Technology Satellite (CATSAT). TBIRD is an inexpensive, low weight, low power laser communications demonstration that will deliver very high data rates (200 Gigabits per second) to a small ground station. CATSAT will provide an integrated demonstration of advances in cognitive communications for space applications.

In FY 2019, NASA initiated a wideband RF risk reduction initiative. The wideband effort will take two years to design, develop, and conduct benchtop testing of a prototype tunable wideband terminal. The task will integrate NASA, commercial, and Department of Defense waveforms into a common platform to demonstrate technology feasibility and conduct laboratory characterization testing.

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

In June 2019, the U.S. Air Force hosted the DSAC demonstration unit as part of the Space Test Program 2 mission aboard a SpaceX Falcon 9 Heavy. DSAC is a mercury ion clock that is an order of magnitude more stable than the current GPS clocks and will demonstrate its functionality and utility for one-way-based navigation for up to one year of operations.

Through participation in the IOAG and CCSDS, SCaN continued international coordination of space communication and navigation compatibility and interoperability, as well as the development of internationally interoperable space communication and data system standards. NASA missions use internationally interoperable standards to lower the life cycle costs and risks and provide innovative capabilities for current and future missions. Key progress continued for optical and space internetworking standards, which can be used in future space communications and exploration architectures.

At the direction of the Interoperability Plenary, the IOAG is beginning to engage industry in coordination of space communication and navigation cross support and interoperability. CCSDS recently released its first two industry standards for interoperable, free-space optical communications. Commonly known in the space-faring community as blue books, the CCSDS Recommended Standards publications establish comprehensive technology standards for the international space community. These publications include highly detailed specifications for the manufacture and use of interfaces, technical capabilities and protocols, and other controlling standards such as encoding regimes.

As NASA's Spectrum Manager, SCaN continued to participate in domestic and international meetings, ensuring interference-free use of the electromagnetic spectrum supporting requirements for NASA's current and future missions. At the WRC-2019, SCaN focused on planned agenda items, such as renegotiating radio regulations in FY 2020 and working within the U.S. delegation to ensure continued access to the RF spectrum for NASA's mission requirements, the U.S. Government space interests, and the U.S. commercial space community. Additionally, SCaN continued coordinating spectrum use for all domestic and international deep space missions, as well as NASA near-Earth missions. Further, SCaN committed to supporting the National Telecommunications and Information Administration, through the Policy and Plans Steering Group, in developing a National Spectrum Strategy. The strategy is in support of the 2018 Presidential Memorandum on Developing a Sustainable Spectrum Strategy for America's Future and supporting regulatory goals established by the National Space Council.

WORK IN PROGRESS IN FY 2020

SCaN will continue its work with STMD in preparation for the LCRD launch. Final payload to spacecraft integration and testing will be completed with launch estimated to be late FY 2020.

NASA plans to conduct component test and integration for the ILLUMA-T. O2O hardware will also be completed in late FY 2020. Additionally, initial development of CATSAT communication systems with cognitive software and waveforms will be completed, resulting in a PDR. TBIRD final assembly integration test and delivery will take place in FY 2020.

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

In November 2019, SCaN participated in the U.S. delegation, led by the Department of State, to the WRC-2019 in Sharm el-Sheikh, Egypt, to ensure continued access to the RF spectrum supporting NASA's mission requirements, U.S. Government space interests, and the U.S. commercial space community. SCaN will continue to coordinate spectrum use for all domestic and international deep space missions, as well as NASA near-Earth missions.

SCaN continued in its role as Designated Federal Officer and Executive Director of the National Space-Based Positioning, Navigation and Timing Advisory Board (PNTAB), which reports to the National Space-Based Positioning, Navigation and Timing Executive Committee (EXCOM). The PNT EXCOM is co-chaired by the Deputy Secretary of Defense and the Deputy Secretary of Transportation. Additionally, SCaN personnel support the coordination of the National Space Council Users' Advisory Group (UAG). The first meeting organized by SCaN was held on October 21, 2019. Each of the six subcommittees provided briefings on their ongoing activities and plans. The UAG identified synergies and areas of cooperation, and provided Recommendations to the Chair of the Council and its membership concerning Science, Technology, Engineering, and Mathematics (STEM) education, preparing the future U.S. space industry workforce, the need for radio frequemncy protection of space systems, and other areas of potential collaboration with the PNTAB.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

NASA plans to launch the TBIRD CubeSat mission in FY 2021. TBIRD will demonstrate a revolutionary new approach for large volume data delivery of 5-10 terabytes per day from LEO to a single low-cost ground station. In FY 2021, initial development of CATSAT will complete a CDR and continue experiment planning and development.

Through participation in the IOAG and CCSDS, SCaN will continue international coordination of space communication and navigation compatibility and interoperability, as well as the development of internationally interoperable space communication and data system standards. NASA missions use internationally interoperable standards to lower the life cycle costs and risks and provide innovative capabilities for current and future missions. Key progress is planned for optical and space internetworking standards. The IOAG will coordinate with industry, other parts of NASA, and international partners on space communications and navigation requirements.

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

Project Schedule

The table below includes significant Space Communication Support milestones in FY 2020 and FY 2021.

Date	Significant Event
Q2 FY 2020	LCRD Delivery to NGIS for integration onto STPSat-6
Q2 FY 2020	LCRD OGS-2 I&T completed
Q2 FY 2020	DSOC Flight CDR/Ground PDR
Q2 FY 2020	Cognitive Flight Demonstration Mission Concept Review
Q3 FY 2020	O2O and ILLUMA-T Testing and Integration Complete
Q3 FY 2020	O2O WSC Ground Terminal SDR
Q4 FY 2020	LCRD launch
Q1 FY 2021	TBIRD launch
Q3 FY 2021	Ship O2O for Integration on ORION

Project Management & Commitments

The SCaN program office at NASA Headquarters manages Space Communications Support functions.

Element	Description	Provider Details	Change from Formulation Agreement
Space Communications Support	Provides critical communication and navigation architecture planning, systems engineering, technology development, standards development and management, spectrum management, and policy and strategic communications for NASA	Provider: NASA Responsible Center: HQ	N/A

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

Acquisition Strategy

Space Communications Support functions use multiple small contracted efforts, most of which are support services functions.

MAJOR CONTRACTS/AWARDS

None.

HUMAN SPACE FLIGHT OPERATIONS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	133.1	--	89.9	101.1	103.7	104.6	104.8

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

A new class of astronauts, shown here, graduated basic training on January 10, 2020. They will begin careers in exploration that may take them to the ISS, on missions to the Moon under the Artemis program, or someday, to Mars.

The Human Space Flight Operations (HSFO) Program supports the astronaut corps, space flight readiness training, and health of crew members before, during, and after each spaceflight mission to the International Space Station (ISS). All crews on board the ISS have undergone rigorous preparation, which is critical to mission success. Within the HSFO program, the Space Flight Crew Operations (SFCO) element provides astronaut selection and space flight readiness training while the Crew Health and Safety (CHS) element manages all aspects of astronaut crew health.

To pave the way to the Moon and on to Mars, NASA is working with industry to develop the transportation systems that will carry crew to destinations beyond Earth's orbit. NASA must also prepare the human system for living and working for extended periods in the hostile environment of space. As astronauts travel further from Earth, many different issues will arise and need investigating.

- What health risks will astronauts face and how are they resolved?
- What type of training will crews need to prepare for months of travel in the harsh space environment?
- How will they deal with medical emergencies or technical anomalies when Earth is no longer within reach?

CHS, in collaboration with NASA's Office of Chief Health and Medical Officer and the Human Research Program (HRP), answers these and other questions to ensure crew health, safety, and mission success. SFCO and CHS are responsible for astronaut space flight readiness training and health, while HRP funds research of human health and performance countermeasures, the human response to space, and technologies that enable safe, reliable, and productive human space exploration.

HUMAN SPACE FLIGHT OPERATIONS

EXPLANATION OF MAJOR CHANGES IN FY 2021

FY 2021 continues the proposal made in the FY 2020 Budget to consolidate the Aerosciences Evaluation and Test Capabilities budget in a different budget account. In addition, NASA is evaluating different models for more cost-effectively maintaining astronaut readiness and health.

ACHIEVEMENTS IN FY 2019

In FY 2019, SFCO continued to provide qualified astronauts for crewed missions aboard the Russian Soyuz spacecraft launch vehicle and U.S. commercial spacecraft, the SpaceX Dragon and Boeing Starliner. The Starliner test flight will include two NASA astronauts and a Boeing astronaut, and the SpaceX Dragon test flight crew will consist of two NASA astronauts. Five NASA astronauts launched on Soyuz to ISS in FY 2019. SFCO completed training for the 2017 Astronaut Candidate (ASCAN) class and determined a FY 2021 ASCAN class is necessary to meet NASA's future human space flight mission manifest requirements. SFCO continued operation and maintenance of the T-38 high-performance jets in support of space flight readiness training, the Super Guppy aircraft for transporting oversized cargo for NASA's programs, and the Gulfstream aircraft in support of science missions and direct crew return missions from Russia.

In support of ISS, CHS provided preflight training, medical services, behavioral health management, physical conditioning, radiation monitoring, and occupational healthcare for astronauts. Medical, behavioral, physical conditioning and radiation monitoring services for NASA crewed SpaceX Dragon and Boeing Starliner commercial spacecraft added to CHS’s expanding support to new flight programs. CHS began implementation of the To Research, Evaluate, Assess, and Treat Astronauts Act (TREAT Astronauts Act). Full implementation will include expanding the occupational surveillance program for former astronauts to better understand long-term health consequences of space exploration. A charter for the TREAT Astronauts Act Board was developed and its initiation is awaiting Code of Federal Regulations publication. This Board will evaluate the degree to which medical conditions of former astronauts are associated with spaceflight. Data analytics capabilities, including the Integrated Medical Model (IMM), were expanded to support capabilities for NASA's Artemis, Gateway, and Lunar vehicles and supporting Commercial Crew development efforts. New tools for enhancing data mining and data analytics were brought on-line, which will inform future missions and vehicles based on human spaceflight risk assessments and astronaut occupational surveillance.

WORK IN PROGRESS IN FY 2020

SFCO will provide trained astronauts for NASA human space flight efforts, including for Expeditions 61 through 63. SFCO will continue to operate and maintain the T-38 high-performance jets for crew space flight readiness training, the Gulfstream aircraft for support of direct crew return after completion of ISS Expeditions, and the Super Guppy aircraft for transporting oversized cargo for NASA's programs. SFCO will review crew training requirements for Artemis missions to identify efficiencies, particularly the need for, and ways to acquire, the benefits currently provided by high-performance aircraft flight experience. The FY 2017 ASCAN class graduated, and the selection process for the FY 2021 ASCAN class will begin.

CHS maintains the Astronaut Occupational Health program that includes clinical certification for active astronauts and health and fitness through training, flight, and post mission recovery. CHS is implementing requirements of the TREAT Astronauts Act to monitor, diagnose, and treat former astronauts and enhance behavioral health and medical data collection. CHS continues to develop the occupational surveillance program for former astronauts and will include medical data obtained through the TREAT Astronauts Act. CHS is utilizing clinical text extraction software to mine astronaut medical records and efficiently capture data from clinical notes. To support mission increments, CHS will provide preflight training, medical and behavioral health management, physical conditioning, and baseline occupational surveillance, as well as technical expertise to NASA's Artemis mission architecture and vehicles.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

SFCO will direct and manage the astronaut corps and provide trained astronauts for NASA human space flight efforts, including for Expeditions 64 through 68. SFCO will continue to operate and maintain the T-38 high-performance jets in support of space flight readiness training, the Gulfstream aircraft for support of direct crew return after completion of ISS Expeditions, and the Super Guppy aircraft for transporting oversized cargo for NASA's programs. SFCO will complete selection and begin new astronaut training for the FY 2021 ASCAN class.

CHS will maintain the Astronaut Occupational Health program that includes clinical certification for active astronauts and health and fitness through training, flight, and post mission recovery. CHS will fully implement requirements of the TREAT Astronauts Act to monitor, diagnose, and treat former astronauts and enhance behavioral health and medical data collection. This implementation will include full utilization of the TREAT Astronauts Act Board, which will assist in determining whether medical conditions are associated with spaceflight. CHS will continue development of the occupational surveillance program for former astronauts. Processes for inclusion of data obtained under the TREAT Astronauts Act in Information Management Platform for Data Analytics and Aggregation will be implemented. Continued use of clinical text extraction capabilities will generate usable data captured from medical notes in text files. To support ISS mission increments, CHS will provide preflight training, medical and behavioral health management, physical conditioning, and baseline occupational surveillance, as well as technical expertise to NASA's Artemis, Gateway, and Lunar mission architecture and vehicles. CHS will also provide medical and behavioral screening expertise to SFCO in support of the 2021 ASCAN selection.

Program Elements

SPACE FLIGHT CREW OPERATIONS (SFCO)

SFCO directs and manages the astronaut corps activities, assigns flight crew, is responsible for human space flight readiness training, and maintains and operates the Johnson Space Center aircraft fleet, including the T-38 high-performance aircraft, the Gulfstream aircraft, and the Super Guppy transport aircraft.

SFCO also determines the need for and selects astronaut candidates. It takes approximately two years from the decision to select a new astronaut class until the process is completed. Once selected, new astronauts must complete two years of training for eligibility and then 30 months of ISS training before qualifying for an ISS mission. The number of spacecraft seats U.S. astronauts will fill in the next four years of human space flight determines the manifest requirement. The manifest includes projected commercial crewed flights to ISS, Commercial Crew test flights, and Artemis flights. Requirements for future missions, for example to Gateway and the Moon, will be planned as those missions become better defined.

Astronaut space flight readiness training activities, implemented by SFCO, put the crew into operational environments which share some aspects of the fast dynamics, physical stress, and risk found in spaceflight. The training develops the skills and ability to work as a team in an environment that is fast-paced, is stressful, and carries potentially severe penalties for failure. It includes developing the skills necessary to respond in an emergency/high-stress environment and operate a high-performance aircraft.

CREW HEALTH AND SAFETY (CHS)

CHS enables healthy and productive crew during all phases of spaceflight missions, implements a comprehensive astronaut occupational health care program, and works to understand, prevent, and mitigate negative long-term health consequences from exposure to the spaceflight environment. Using HRP research and other findings, CHS implements enhancements to astronaut occupational health protocols to ensure crew health and safety. In this collaboration, HRP concentrates on the research aspects of crew health, whereas CHS focuses on implementing the research results and mitigation plans into occupational health protocols. As research continues on ISS, CHS is actively seeking new approaches to apply research findings to improve NASA health protocols, including collaborative opportunities with other Federal agencies and academia. Further, CHS is implementing the TREAT Astronauts Act for former astronauts. This Act enables NASA to provide monitoring, diagnosis, and treatment to astronauts for spaceflight-related medical issues following retirement from NASA. In addition, NASA will be able to obtain more medical data to supplement the occupational surveillance program for former astronauts and better assess the long-term effects of spaceflight on the human body to enable exploration.

CHS is also responsible for maintaining the health of active astronauts during non-mission periods, focusing on three aspects of health care: preventive care, risk factor management, and long-term health monitoring. CHS integrates and coordinates information relevant to human health before, during, and after spaceflight. CHS documents and assesses all emerging health risks, such as Spaceflight Associated Neuro-ocular Syndrome and the risk of venous flow changes. CHS continues to collaborate with several non-NASA organizations, including the National Academies, to inform the risk decisions associated with long duration and exploration missions.

HUMAN SPACE FLIGHT OPERATIONS

Program Schedule

Date	Significant Event
Early 2020	Begin process to hire a FY 2021 ASCAN class

Program Management & Commitments

Program Element	Provider
SFCO	Provider: SFCO Lead Center: JSC Performing Center(s): JSC Cost Share Partner(s): N/A
CHS	Provider: CHS Lead Center: JSC Performing Center(s): JSC Cost Share Partner(s): N/A

Acquisition Strategy

The section below identifies the current contract(s) that support SFCO and CHS.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Aircraft Logistics, Integration, Configuration and Engineering	Yulista Tactical	Ellington Field, Houston, TX El Paso, TX
Human Health and Performance Contract	KBR Wyle	Houston, TX

HUMAN SPACE FLIGHT OPERATIONS

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	National Council on Radiation Protection (NCRP) and Measurements	Nov 2014	The NCRP reviewed NASA Radiation Protection Standards for crew member exposure to spaceflight radiation.	NCRP Commentary Report 23: Radiation Protection for Space Activities: Supplement to Previous Recommendations	2020
Performance	NCRP	Feb 2016	The NCRP conducted a Phase I review of potential central nervous system (CNS) effects from radiation exposure during space activities.	NCRP Commentary Report 25: Potential Central Nervous System Risks Following Space Radiation Exposure	Phase II in progress

LAUNCH SERVICES

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	88.4	--	91.9	101.9	92.2	92.2	92.2

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

The L-1011 Stargazer aircraft, shown here, with the Pegasus XL rocket attached beneath, takes off from the Skid Strip runway at Cape Canaveral Air Force Station in Florida on October 10, 2019. NASA's Ionospheric Connection Explorer (ICON) is secured inside the rocket's payload fairing. The air-launched Pegasus XL was released from the aircraft at 9:59 p.m. EDT to start ICON's journey to space.

The Launch Services Program (LSP) ensures access to space for the Nation's civil sector satellite and robotic planetary missions.

In addition to NASA's science and discovery missions civil communications, geographic survey, and civil weather missions provide key services for our Nation and the world. The National Space Transportation Policy identifies the NASA Administrator as the launch agent for the Nation's civil sector. LSP enables the Administrator to execute this role by acquiring and managing domestic commercial launch services for assigned missions, certifying new commercial launch vehicles for readiness to fly high-value spacecraft, performing mission design and launch integration activities, and directing launch mission assurance efforts to ensure the greatest probability of launch mission success. While no space mission is routine, LSP has unique launch system expertise involving payloads containing nuclear power sources for launching one-of-a-kind science exploration missions to other planets, the Sun, or other locations in space. NASA relies on LSP to provide robust, reliable, and cost-effective launch services via commercial launch providers. NASA achieves assured access to space through a competitive mixed-fleet approach utilizing the breadth of U.S. industry's capabilities. In addition, LSP provides launch-related expertise to other NASA programs, such as Commercial Resupply Services, Commercial Crew Program (CCP), and programs supporting the Artemis campaign. It also provides launch advisory support to NASA payload missions using launch services contributed by a foreign partner, to other Government agencies, and to the launch industry.

In addition to acquiring the commercial launch service, LSP arranges pre-launch spacecraft processing facility support and communications and telemetry during ascent for its customers. LSP offers insight into the commercial launch vehicle industry, which has been utilized by CCP. LSP also tracks lessons learned to identify and mitigate risks for future managed launches and certifies the readiness of new commercial launch vehicles for NASA and other civil sector uncrewed spacecraft. The program also conducts engineering analyses and other technical tasks to maximize launch success for every assigned payload.

EXPLANATION OF MAJOR CHANGES IN FY 2021

The Human Exploration and Operations Mission Directorate (HEOMD) transferred the management and oversight of the CubeSat Launch Initiative (CSLI) activity from the Advanced Exploration Systems Program to LSP to consolidate HEOMD space launch responsibilities within a single program. LSP is funding the Vandenberg Air Force Base Space Launch Complex-2 closeout and demolition cost, which is necessary because of the retirement of the Delta II launch vehicle. Per agreement with the Air Force, NASA is responsible for the final Delta II close out costs.

ACHIEVEMENTS IN FY 2019

LSP provided expertise and active launch mission management for over 60 NASA scientific spacecraft missions in various stages of development. LSP continuously works with the U.S. commercial launch industry to assess their designs and provide advice, which expands the selection of domestic launch vehicles available to NASA's missions and nurtures a competitive commercial launch service environment.

LSP acquired new launch services for three future NASA missions through competitively awarded launch service task orders for the Science Mission Directorate (SMD):

Launch Date/Location	Launch Vehicle	Payload	Customer	Mission Objectives
Apr 2021 Cape Canaveral Air Force Station	Falcon 9 Full Thrust	Imaging X-Ray Polarimetry Explore (IXPE)	NASA SMD	Exploits the polarization state of light from astrophysical sources to provide insight into our understanding of X-ray production in objects (e.g., neutron stars, pulsar wind nebulae), as well as stellar and supermassive black holes.
Jul 2021 Vandenberg Air Force Base	Falcon 9 Full Thrust	Double Asteroid Redirection Test (DART)	NASA SMD	DART will be the first demonstration of the kinetic impact technique to change the motion of an asteroid in space.
Oct 2021 Cape Canaveral Air Force Station	Atlas V	Lucy	NASA SMD	A planned NASA space probe that will tour five Jupiter trojans, asteroids which share Jupiter's orbit around the Sun, orbiting either ahead of or behind the planet, and one main belt asteroid.

**LSP’s customers own and manage the payload mission objectives described above.*

LSP successfully completed Category 3 certification of the SpaceX Falcon 9 Full Thrust launch vehicle and continued pre-certification activities with Blue Origin's New Glenn, United Launch Services' (ULS) Vulcan, Northrop Grumman's Omega, and SpaceX's Falcon Heavy launch vehicles. Certifying a provider's launch vehicle enhances NASA’s understanding of commercially-built launch vehicles and enables LSP to better identify and manage launch risks. Certification also enhances competition as it results in multiple qualified launch vehicles and launch providers.

LSP continued partnering with several universities and NASA Centers to launch small research satellites through the CSLI, which provides rideshare opportunities for small satellite payloads to fly on upcoming launches when space is available. These partnerships have provided regular educational opportunities for students in Science, Technology, Engineering, and Mathematics (STEM) disciplines, which help strengthen the Nation’s future workforce. To date, CubeSats have been selected from 39 states and Puerto Rico, with 96 missions launched and 40 manifested on NASA, National Reconnaissance Office, United States Air Force, and commercial missions. In FY 2019, 19 CSLI CubeSat missions were launched.

Venture Class Launch Service (VCLS) contracts for CubeSat satellites foster a commercial launch market dedicated to flying small satellite payloads, which provide an alternative to the current rideshare approach where one or more CubeSats or other small payloads take advantage of excess payload capacity on a rocket whose primary mission is to launch a larger satellite. In December 2018, Rocket Lab USA successfully launched 10 NASA CubeSats to low-Earth orbit aboard the Electron launch vehicle on the first ever VCLS mission.

Launch Date/Location	Launch Vehicle	Payload	Customer	Mission Objectives
Dec 2018 New Zealand (North Island)	Electron	CubeSats	NASA, one STEM school, and multiple universities	A demonstration flight to determine if new small launch vehicles can deliver NASA payloads to orbit at a fixed price. VCLS aims to provide a dedicated launch capability for smaller payloads, such as CubeSats, on smaller rockets.

**LSP’s customers own and manage the payload mission objectives described above.*

WORK IN PROGRESS IN FY 2020

LSP will continue mission design and launch integration support to over 60 missions in various stages of development. In addition to launch preparation activities for five missions that will launch in FY 2021 (Sentinel-6A, Landsat-9, IXPE, DART and SWOT), the current manifest shows LSP will manage and conduct the launch activities for three NASA missions and one venture class payload:

Launch Date/Location	Launch Vehicle	Payload	Customer	Mission Objectives
Oct 2019 (Launched) Cape Canaveral Air Force Station	Pegasus XL	Ionospheric Connection Explorer (ICON)	NASA SMD	A suite of instruments designed to explore the mechanisms controlling environmental conditions in space and how they are modified by weather on the planet.

LAUNCH SERVICES

Launch Date/Location	Launch Vehicle	Payload	Customer	Mission Objectives
Feb 2020 Cape Canaveral Air Force Station	Atlas V	Solar Orbiter	NASA SMD	Solar Orbiter is a mission dedicated to solar and heliospheric physics. The program outlines key scientific questions that need to be answered about: the development of planets and emergence of life, how the Solar System works, the origins of the Universe, and the fundamental physics at work in the Universe. Solar Orbiter will be used to examine how the Sun creates and controls the heliosphere.
Feb 2020 Mojave, CA	Launcher One	CubeSats	NASA and multiple universities	A demonstration flight to determine if new small launch vehicles can deliver NASA payloads to orbit at a fixed price. VCLS aims to provide a dedicated launch capability for smaller payloads, such as CubeSats, on smaller rockets.
Jul 2020 Cape Canaveral Air Force Station	Atlas V	Mars 2020	NASA SMD	A rover that will address high-priority science goals for Mars exploration, including key questions about the potential for life on Mars. The mission will seek signs of habitable conditions on Mars in the ancient past and search for signs of past microbial life.

LSP will continue to actively acquire new launch services for future NASA missions. The program is currently in the process of competitively awarding multiple Science Missions including GOES T and Psyche/EscaPADE/Janus.

Along with full end-to-end launch service management of awarded missions, LSP continues to offer advisory support, expertise, and knowledge to NASA programs and projects utilizing launch services not procured and managed by LSP. The program is currently providing these advisory services to several programs and missions, including the:

- ISS Cargo Resupply Service missions;
- Commercial Crew Program;
- James Webb Space Telescope (Webb); and
- NASA-Indian Space Research Organization Synthetic Aperture Radar (NISAR) missions.

LSP will continue work towards certifying new commercial launch vehicles to launch high-value payloads. Certification activities are ongoing with Blue Origin's New Glenn, ULS' Vulcan, Northrop Grumman's Omega, and SpaceX's Falcon Heavy launch vehicles.

LAUNCH SERVICES

KEY ACHIEVEMENTS PLANNED FOR FY 2021

LSP will continue to execute the role of launch agent for the NASA Administrator on behalf of the U.S. civil sector, as described in the National Space Transportation Policy. The Program will provide management of NASA Launch Services contracts, launch mission assurance, mission design, and launch integration support to scientific spacecraft missions in various development phases. LSP will also continue work towards certifying new commercial launch vehicles to launch high-value payloads, as needed, and will continue launch service acquisition activities necessary to support NASA and other approved Government missions.

The program will support commercial logistics acquisition services for Gateway and Human Landing System (HLS) and provide launch advisory services for Webb and NISAR.

**FY 2021 Launch Dates shown in this table correspond to launch dates listed as Management Agreements elsewhere in this document.*

Launch Date/Location*	Launch Vehicle	Payload	Customer	Mission Objectives
Nov 2020 Vandenberg Air Force Base	Falcon 9 Full Thrust	Sentinel 6A	NASA SMD	To measure sea surface topography with high-accuracy and reliability to support ocean forecasting systems, environmental monitoring and climate monitoring. The mission provides continuity of the TOPEX and JASON missions, with improvements in instrument performance and coverage.
Early 2021 Vandenberg Air Force Base	Atlas V	Landsat 9	NASA SMD	A planned U.S. Earth observation satellite designed and operated to repeatedly observe the global land surface at a moderate scale that shows both natural and human-induced change. NASA is in charge of building, launching, and testing the system, while the United States Geological Survey will process, archive, and distribute its data.
Apr 2021 Cape Canaveral Air Force Station	Falcon 9 Full Thrust	Imaging X-Ray Polarimetry Explorer (IXPE)	NASA SMD	Exploits the polarization state of light from astrophysical sources to provide insight into our understanding of X-ray production in objects (e.g., neutron stars, pulsar wind nebulae), as well as stellar and supermassive black holes.
Jul 2021 Vandenberg Air Force Base	Falcon 9 Full Thrust	Double Asteroid Redirection Test (DART)	NASA SMD	Will be the first demonstration of the kinetic impact technique to change the motion of an asteroid in space.

LAUNCH SERVICES

Launch Date/Location*	Launch Vehicle	Payload	Customer	Mission Objectives
Sep 2021 Vandenberg Air Force Base	Falcon 9 Full Thrust	Surface Water Ocean Topography (SWOT)	NASA SMD	A joint mission between U.S. and French oceanographers and hydrologists to make the first global survey of Earth's surface water to provide a better understanding of the world's oceans and its terrestrial surface waters.

Program Management & Commitments

Program Element	Provider
Commercial Launch Vehicle (CLV) Launch Services	Provider: ULS, Northrop Grumman Innovation Systems (NGIS) (formerly Orbital ATK), SpaceX, Rocket Lab USA, Virgin Orbit Lead Center: Kennedy Space Center (KSC) Performing Center(s): KSC Cost Share Partner(s): N/A

ACQUISITION STRATEGY

LSP's acquisition strategy was created for the original NASA Launch Services (NLS) contracts for procuring CLV launch services from domestic commercial launch service suppliers. To meet the needs of science and technology customers who typically spend three to seven years developing a spacecraft mission, NASA created a contractual approach providing multiple competitive launch service options to cover small-, medium-, intermediate-, and heavy-sized missions. The follow-on contract mechanism, known as NLS II, has similar contract features. These features include: not-to-exceed prices, indefinite-delivery-indefinite-quantity contract terms, and competitive firm-fixed-price launch service task order based acquisitions. The NLS II ordering period has been extended to June 30, 2025. To ensure active competition for NASA customers and encourage new launch capability development through these long-term contracts, NASA provides annual opportunities to U.S. industry to add new commercial launch service providers and/or launch vehicles to the contract.

LSP is also able to contract separately from the NLS contract mechanism if such an approach is necessary to meet a mission or customer need. For instance, launch service for the Parker Solar Probe mission funded by NASA SMD was competed outside and separate from the NLS II contract due to the special needs of that mission. In addition, VCLS awards for very small launch vehicles were conducted outside and separate from the NLS II contract to provide more flexibility to the new, small-class launch providers.

NASA has also made efforts to provide a complete launch service, including payload processing at the launch site. LSP uses firm-fixed-price indefinite-delivery-indefinite-quantity contracts for commercial payload processing capabilities on both the East and West coasts. The Payload Processing Facility (PPF) contracts are up for recompete. The East Coast Commercial Payload Processing Contract-4 (ECCPP-4) was awarded in April 2017 and the period of performance ends in April 2022. The West Coast

LAUNCH SERVICES

Commercial Payload Processing Contract-3 (WCCPP-3) solicitation was cancelled. LSP is currently awarding mission specific PPF contracts for those on the West coast.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Venture Class	Virgin Orbit Rocket Lab USA	Long Beach, CA Los Angeles, CA
NASA Launch Services-II-U	ULS, LLC	Centennial, CO
NASA Launch Services-II-S	SpaceX	Hawthorne, CA
NASA Launch Services-II-O	NGIS (formerly Orbital ATK Corporation)	Dulles, VA
East Coast Commercial Payload Processing-4	Astrotech Space Operations	Titusville, FL
West Coast Commercial Payload Processing-Landsat 9	Astrotech Space Operations	Vandenberg Air Force Base, CA
Integrated Processing Facility	Spaceport Systems International	Vandenberg Air Force Base, CA
Expendable Launch Vehicle Integrated Support (ELVIS) 2/3	a.i. Solutions, Inc.	Lanham, MD

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Program Implementation Review (PIR)	Standing Review Board (SRB)	May 2014	Life Cycle Review	The SRB found LSP is a successful program with a strong technical and management team representing NASA’s core competency, demonstrating exceptional performance with a 97.4 percent launch success record. The SRB recommended continuation of LSP operations as currently performed.	FY 2024*

**The FY 2024 milestone for LSP will be assessed by the Human Exploration and Operations Mission Directorate (HEOMD) Associate Administrator, and a determination will be made as to whether a PIR is required or if it can be delayed another two years. The FY 2024 milestone is also subject to change depending on LSP's manifest/launch schedule for that year.*

Historical Performance

LSP managed CLV Missions from inception through FY 2019:

Launch Vehicle Configuration	Provider	Number of Launches	Successful Launches	Unsuccessful Launches
Athena	Lockheed Martin/Alliant Techsystems	1	1	0
Atlas IIA	Lockheed Martin	5	5	0
Atlas IIAS	Lockheed Martin	1	1	0
Atlas V	Lockheed Martin	2	2	0
	ULS	17	17	0
Delta II	Boeing Launch Services	27	27	0
	ULS	16	16	0
Delta IV H	ULS	1	1	0
Falcon 9 v1.1	Space X Launch Services	1	1	0
Falcon 9 FT	Space X Launch Services	1	1	0
Pegasus Hybrid	Northrup Grumman (formerly OSC)	1	1	0
Pegasus XL	Northrup Grumman (formerly OSC)	16	16	0
Taurus XL	Northrup Grumman (formerly OSC)	2	0	2
Titan II	Lockheed Martin	3	3	0

ROCKET PROPULSION TEST

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**60.0**	**--**	**47.6**	**47.8**	**47.8**	**47.8**	**47.8**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

The Pegasus barge is shown here delivering Space Launch System (SLS) Core Stage Pathfinder to the B-1/B-2 test stand for practice lifts and fit checks in 2019 at Stennis Space Center in Mississippi.

Developing and testing rocket propulsion systems is foundational to spaceflight. Whether the payload is a robotic science experiment or a crewed mission, the propulsion system must be safe and reliable. A rigorous engine test program is a critical component of any rocket propulsion development activity.

NASA's Rocket Propulsion Test (RPT) program maintains and manages a wide range of facilities capable of ground testing rocket engines and components under controlled conditions. This test infrastructure includes facilities located across the U.S. and provides a single entry point for any user of NASA rocket test stands. RPT retains a skilled workforce capable of performing tests on all modern-day rockets and supporting complex rocket engine development. RPT evaluates customer test requirements and desired outcomes while minimizing test time and costs. It also streamlines facility usage and eliminates redundant capabilities by closing and consolidating NASA's rocket test facilities, as appropriate.

RPT is NASA's implementing authority for rocket propulsion testing. It approves and provides direction on test assignments, capital improvements, and facility modernization and refurbishment to reduce propulsion test costs. RPT integrates multi-site test activities, identifies and protects core capabilities, and develops advanced testing technologies.

The Agency has designated RPT as the NASA representative for the National Rocket Propulsion Test Alliance (NRPTA), an inter-agency collaboration with the Department of Defense (DoD), to facilitate efficient and effective use of the Federal Government's rocket propulsion test capabilities. The RPT Program Manager serves as a co-chair of the NRPTA Senior Steering Group and appoints NASA's alliance co-chair. The alliance co-chair position is a rotational appointment chosen from primary Center representatives of RPT's management board.

For more information, go to: https://rpt.nasa.gov/

ROCKET PROPULSION TEST

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

ACHIEVEMENTS IN FY 2019

At Stennis Space Center (SSC), RPT continued testing the RS-25 engine in support of the Space Launch System (SLS) program. Development testing continued for Government and commercial companies seeking to test their engine systems on a reimbursable basis. For example, RPT tested Hydrocarbon Boost components designed by the U.S. Air Force for the RD-180 replacement project and tested an Aerojet Rocketdyne hydrocarbon engine for certification. Planned refurbishment and repair activities for critical enabling infrastructure included: continuing repair of SSC’s liquid oxygen and liquid hydrogen barges, upgrading a high-pressure gas facility, replacing the E-Complex data acquisition system, replacing E-Complex high-speed video equipment, and activating the B-2 test stand to prepare for SLS core stage testing. These modernization, refurbishment, and repair activities support the continued efficient and effective support of NASA and partner programs. SSC also completed the construction of the joint Michoud Assembly Facility/SSC Consolidated Fluid Component Processing Facility, which will provide an improved capability to multiple NASA facilities, programs, and customers.

The White Sands Test Facility (WSTF) team conducted propulsion system development and certification testing for the NASA Orion European Space Agency (ESA) Service Module and completed certification testing for the Commercial Crew Program's Boeing CST-100 Service Module. These tests support human spaceflight certification. Other testing included activities for Aerojet Rocketdyne, the Missile Defense Agency, the U.S. Air Force, and the U.S. Navy.

Marshall Space Flight Center (MSFC) continued testing rocket engine technology improvements, including components constructed using select laser melting and other additive manufacturing processes that could lead to significant improvements in construction of these complex machines.

At the Glenn Research Center-Plum Brook Station (GRC-PBS) In-Space Propulsion Facility (ISPF), RPT completed improvements for future space exploration propulsion needs through the Evolvable Cryogenics Project (eCRYO) in partnership with Space Technology Mission Directorate. RPT also supported research to reduce the boil-off rate on large cryogenic upper stages with the Structural Heat Intercept, Insulation and Vibration Evaluation Rig (SHIIVER) in a simulated space environment (vacuum and thermal). The ISPF also supported the Science Mission Directorate Balloon program, and GRC-PBS completed the 30,000 pounds (lb.) of thrust and 300-second run-time refurbishment activity.

In FY 2019, RPT was also able to execute several large facility modernization programs, including the upgrade to Data Acquisition Systems (DAS) at WSTF, MSFC and SSC. These systems will gain efficiencies by utilizing a common NASA-developed software package called the NASA Data Acquisition System (NDAS). Funding was also allocated to modernize the Small Altitude Simulation System (SASS) at the WSTF by replacing the legacy steam boiler system with a more efficient modern steam generation system. The updated SASS allows the facility to continue to create the required environment for testing in-space propulsion systems for NASA and our Government and industry partners.

ROCKET PROPULSION TEST

WORK IN PROGRESS IN FY 2020

Building on test results from previous years, RPT will continue to provide valuable propulsion data to the SLS and Orion programs as they prepare for Artemis I and Artemis II. These tests will provide data to validate baseline designs and increase confidence in technical performance, reducing risks and aiding in achieving launch readiness on schedule. This ongoing effort will allow the program to assess design changes that could affect performance and improve safety. RPT personnel will execute hot fire testing of the SLS RS-25 engine for Artemis Missions on SSC’s A-1 test stand and begin testing the SLS core stage Green Run for Artemis I on the B-2 test stand. The Green Run test will help ensure mission success, and many aspects will be carried out for the first time, such as fueling and pressurizing the stage. The test series culminates with firing up all four RS-25 engines to demonstrate that the engines, tanks, fuel lines, valves, pressurization system, and software can all perform together just as they will on launch day. RPT will also continue engine certification of the Aerojet Rocketdyne RS-68 liquid hydrogen/oxygen engine for the Delta IV launch vehicle on the B-1 test stand.

At PBS, RPT will complete all planned modifications of the ISPF and begin testing of Northrop Grumman's OmegA launch system upper stage.

At the WSTF, RPT will continue testing activities for the Orion ESA Service Module. RPT will also continue providing propulsion test services to the Missile Defense Agency, Aerojet Rocketdyne, and U.S. Air Force.

All RPT facilities and personnel will continue maintaining and modernizing these test facilities that will be used to test future space vehicles in a simulated space environment and ambient conditions.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

RPT will continue to provide propulsion data to validate baseline designs, increase confidence in technical performance, reduce risks, and achieve launch readiness on schedule for the SLS and Orion programs and preparations for Artemis I and Artemis II. RPT personnel will execute hot fire testing the SLS RS-25 engine on SSC’s A-1 test stand and complete SLS core stage Green Run on the B-2 test stand. RPT will also continue engine certification of the Aerojet Rocketdyne RS-68 liquid hydrogen/oxygen engine for the Delta IV launch vehicle on the B-1 test stand. Interstellar liquid oxygen/liquid hydrogen testing will continue on the SSC E1 test stand's Cell 2.

At PBS, RPT will perform hotfire and thermal vacuum testing of Northrop Grumman's OmegA launch system upper stage and thermal vacuum testing for the Sierra Nevada Dream Chaser Cargo System (DCCS) in the ISPF.

At the WSTF, RPT will continue testing activities for the Orion ESA Service Module and continue the Commercial Crew Program Boeing CST-100 SM thruster acceptance test program. These test activities will support new service modules which are not recovered in flight.

RPT facilities will continue maintaining a right-sized propulsion test portfolio to meet current and emerging test requirements and continue evaluating and implementing high-risk/high-priority facility maintenance and modernization projects to assure propulsion test assets are available to meet current and future propulsion test requirements.

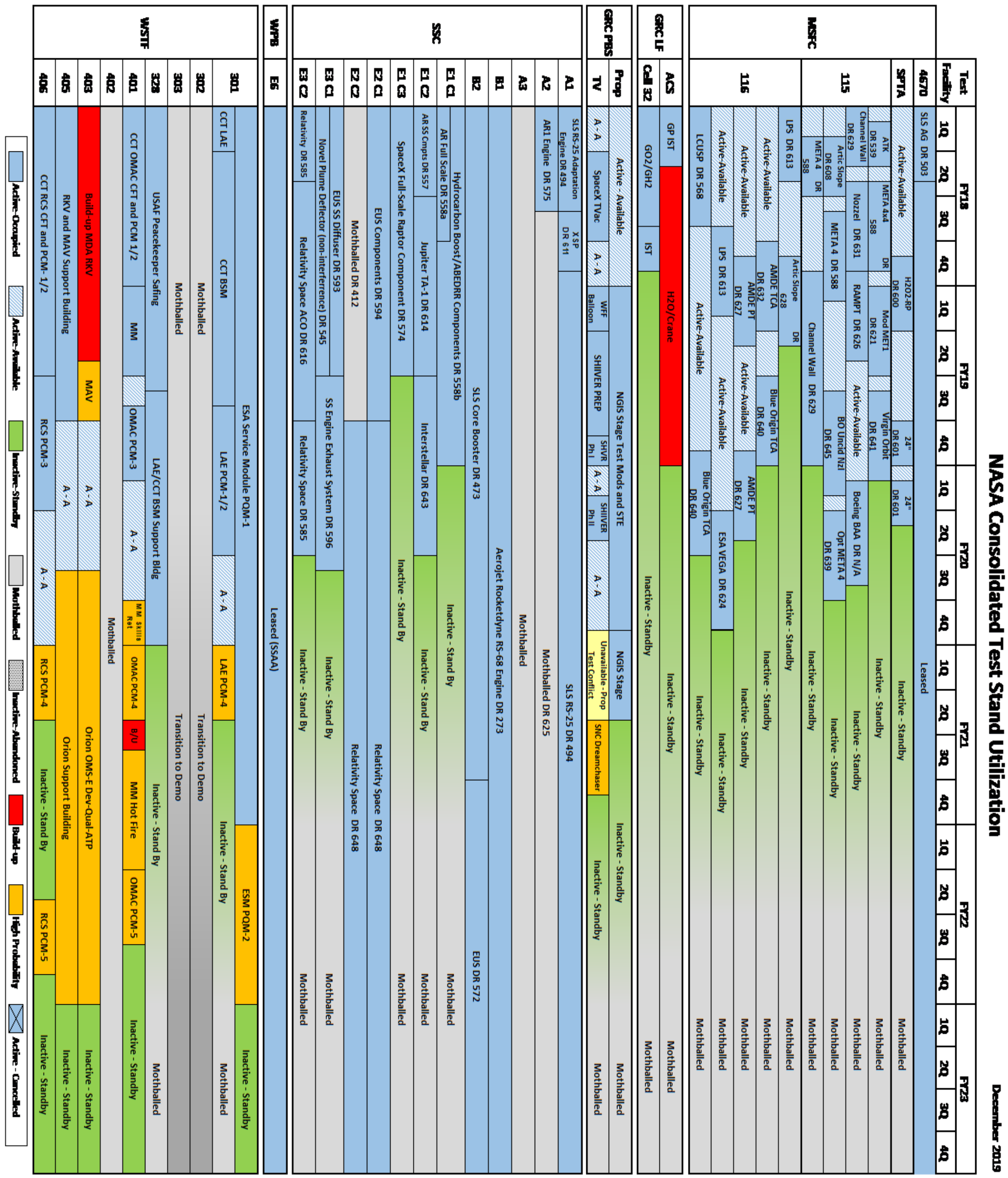
ROCKET PROPULSION TEST

Program Schedule

The following chart shows past, current, and planned test campaigns at SSC, MSFC, GRC, and WSTF rocket propulsion test facilities. The designations at the far left of the chart refer to the facility, the top of the chart shows time by quarter of fiscal and calendar year, and the key to the status of each facility is at the bottom.

Most test stands and facilities are scheduled 18 months in advance. Defining scope of work, selecting test stands and fuel, and estimating labor and total cost to customers is a complex process that can take 18 to 36 months. RPT is working now with internal and external customers to design testing programs for FY 2021 and beyond.

ROCKET PROPULSION TEST



ROCKET PROPULSION TEST

PROGRAM MANAGEMENT & COMMITMENTS

Program Element	Provider
RPT	Provider: RPT Lead Center: N/A Performing Center(s): SSC, JSC/WSTF, GRC-PBS, MSFC, KSC, WFF Cost Share Partner(s): Various other NASA programs, DoD, and commercial partners

ACQUISITION STRATEGY

None.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

None.

COMMUNICATIONS SERVICES PROGRAM

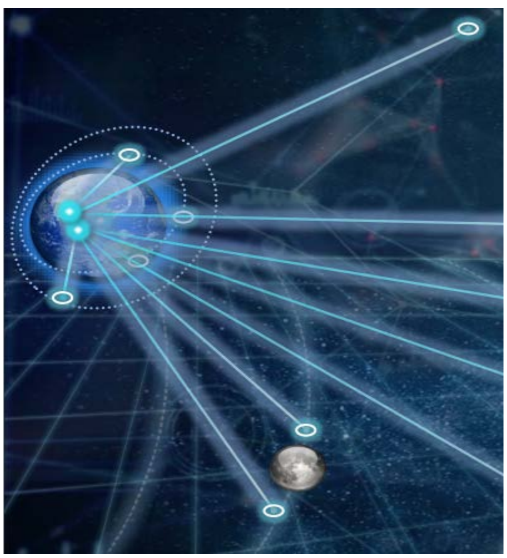
FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**101.9**	**--**	**23.4**	**42.0**	**51.2**	**58.9**	**58.9**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

In FY 2019 the funding displayed in the Communications Services Program (CSP) was included under the Space Communications and Navigation (SCaN) program and executed there under the title "Next Generation Capability" funding. Upon establishment of the CSP in FY 2020, NASA transferred the Next Generation Capability funding line from SCaN to CSP.



The Communications Services Program is being established to support commercially provided data relaying services, depicted above, to more efficiently meet future needs.

The Communications Services Program (CSP) will focus on demonstrating the feasibility of commercially provided satellite communications (satcom) services to NASA missions. As an initial activity, the CSP will pursue opportunities that will allow future NASA missions to deploy flight-qualified capabilities. Ultimately, near Earth users may transition from using NASA-owned networks to commercially-provided services.

CSP will work with the commercial market to identify requirements and explore opportunities that are mutually beneficial to NASA and industry and will develop an acquisition model for incorporating commercial communications services into operations. NASA will define the acquisition strategy for transitioning near Earth NASA users to suitable commercially provided services.

This acquisition strategy could include commercial service contracts, hosted payloads, and/or public-private partnerships to demonstrate the feasibility of commercially provided satellite communications services. NASA expects to partner with multiple commercial entities to explore which services, technologies, and partnership strategies best fulfill NASA's requirements. These partnerships will bolster American industry, significantly reduce the cost of communication services to NASA, and maximize interoperability between Government and commercial service providers while promoting a diverse commercial market.

COMMUNICATIONS SERVICES PROGRAM

The funding being requested in FY 2021 for CSP will support the establishment of multiple partnerships between NASA and commercial satcom companies to develop and demonstrate capabilities that can meet NASA's needs and begins the initial planning for acquisition of commercial satcom services.

Formulation activities will be directed by an existing NASA Headquarters office rather than by a newly-created entity or organization.

COMMERCIAL LEO DEVELOPMENT

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**40.0**	**--**	**150.0**	**175.0**	**200.0**	**200.0**	**200.0**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

NASA will partner with industry to develop and establish new platforms in low-Earth orbit (LEO), culminating in NASA's participation as a customer in a robust space economy.

NASA seeks to maintain access to a space station and continue the U.S. human presence in low-Earth orbit (LEO) – both with Government astronauts and with private citizens – to support the utilization of space by U.S. citizens, companies, academia, and international partners and to expand the American foothold in space. Guided by NASA's Strategic Goals and Objective 2.1 to "Lay the foundation for America to maintain a constant human presence in low Earth orbit enabled by a commercial market," NASA is undertaking the Commercial LEO Development program as a focused effort to develop a robust commercial space economy in LEO. The program is led out of NASA Headquarters with execution of the various program elements at Johnson Space Center. NASA's Commercial LEO Development program is supporting the development of commercially-owned and operated LEO destinations from which NASA, along with other customers, can purchase services and stimulate the growth of commercial activities in LEO. As commercial LEO destinations become available, NASA intends to implement an orderly transition from current International Space Station (ISS) operations to these new commercial destinations as laid out in NASA's ISS Transition Report, dated March 30, 2018. Transition of LEO operations to the private sector will yield efficiencies in the long term, enabling NASA to shift resources towards exploration objectives. With the introduction of commercial LEO destinations, NASA expects to realize efficiencies from the use of smaller, more modern and efficient platforms and a more commercial approach to meeting the Agency's needs in LEO. In the longer term, the gradual emergence of additional customers for commercial LEO destinations will offer the opportunity for additional savings.

To achieve the Commercial LEO Development program's overall goals, NASA developed and is implementing a five-point plan. This plan builds on, uses the capabilities of, and applies the lessons learned from over a decade of work and experience with commercial companies. The plan, entitled NASA's Plan for Commercial LEO Development, addresses how NASA partners with industry to develop commercial LEO destinations, stimulates demand for new and emerging markets in LEO, and takes near-term steps to achieve a robust economy in LEO. The five key parts of the plan are:

COMMERCIAL LEO DEVELOPMENT

(1) NASA established a commercial use and pricing policy for the ISS, enabling companies to reduce uncertainty and build business plans as they seek to perform commercial activities, including marketing. To enable this goal, NASA developed the NASA Interim Directive (NID) on Use of International Space Station (ISS) for Commercial and Marketing Activities (NID 8600.121). This document establishes new NASA ISS Program policies governing commercial and marketing activities using the U.S. Government (USG) modules of the ISS with the intent of catalyzing and nurturing new emerging markets leading to a commercial LEO economy. With this new policy, U.S. entities will have the ability to manufacture, produce, transport, or market commercial resources and goods, including products intended for commercial sale on Earth. The policy also addresses the inclusion of private astronauts on USG or commercial missions to the ISS, conducting coordinated and scheduled activities, and associated on-orbit activities.

For more information on NID 8600.121, go to:
https://www.nasa.gov/sites/default/files/atoms/files/nid_8600_121_tagged.pdf

(2) NASA announced the intent to enable flight of private astronaut missions to the ISS, and released a solicitation to enable the assessment and approval of these missions. As part of NASA's mission to stimulate a LEO economy, NASA is proposing to facilitate up to two short-duration private astronaut missions per year to the ISS beginning as early as FY 2021. Private astronaut missions will be privately funded, dedicated commercial spaceflights on a commercial launch vehicle to conduct approved commercial and marketing activities on the ISS, or in a commercial segment attached to the ISS. These missions must use U.S. transportation vehicles certified by NASA, such as the ones developed by Boeing and SpaceX under NASA's Commercial Crew Program (CCP). NASA expanded the International Space Station Utilization NASA Research Announcement (NRA) to assist U.S. entities pursuing these missions.

For more information on NASA's CCP, go to:
https://www.nasa.gov/exploration/commercial/crew/index.html

For more information on the International Space Station Utilization NRA, go to:
https://nspires.nasaprs.com/external/solicitations/solicitationAmmendments.do?solId=%7B21E0270C-BC1F-EFC4-3D87-30713B5FF373%7D&path=&redirectURL=

(3) NASA initiated a process for developing commercial LEO destinations, including the overall strategy, timeline, and solicitations for developing commercial destinations using the ISS Node 2 Forward Port and free-flyer destinations. An important part of NASA's strategy is stimulating the commercial space industry while leveraging commercial capabilities through partnerships and future contracts delivering mission capabilities. These partnerships provide an opportunity for NASA and industry to develop capabilities meeting NASA human space exploration objectives in support of more extensive human spaceflight missions, while also supporting industry commercialization plans for expanding the frontiers of opportunities in space.

NASA's long-term research and technology development efforts in LEO will be most cost-effective if a robust commercial human spaceflight economy emerges such that NASA is one of many customers of a broad portfolio of commercial products and services. To support the development of this broad portfolio of products and services, NASA is partnering with industry for the development of commercial destinations in LEO, either using the ISS or by going directly to a free-flying platform.

NASA offered commercial use of the ISS Node 2 forward port and associated ISS services to enable development, launch, and demonstrations of one or more commercial destination modules attached to

ISS. In January 2020, NASA announced the selection of Axiom Space under the NextSTEP-2 Broad Area Announcement (BAA), (Appendix I) to enter into a public-private partnership with NASA. The primary objective is to successfully develop commercial markets through demonstration of products and services in one or more habitable commercial elements attached to ISS Node 2 forward port and to transition to an independent long-term, sustainable, commercial, human spaceflight enterprise in LEO. NASA will also fund award(s) made under NextSTEP-2 BAA (Appendix K) to enable additional partnerships for development and space flight demonstrations of free-flying commercial destinations in LEO. NASA seeks commercial destinations that will provide a diverse portfolio of products and services that meet both NASA and non-NASA needs. NASA intends to acquire services from commercial destination through a future competitive solicitation once more information is available about the services that will be offered.

For NextSTEP-2 BAA (Appendix I), go to:
https://beta.sam.gov/opp/ea63938a251ffaf312bc4b3a8e7106b7/view?keywords=nextstep-2&sort=-relevance&index=&is_active=true&page=1

For NextSTEP-2 BAA (Appendix K), go to:
https://beta.sam.gov/opp/4588428134084aa9bdc65d4ba22b7ab2/view?keywords=%22NextSTEP-2%22&sort=-relevance&index=&is_active=true&page=2&date_filter_index=0&inactive_filter_values=false

(4) NASA laid out a plan pursuing opportunities to stimulate scalable and sustainable non-NASA demand for LEO destinations, working to leverage the capabilities of the ISS National Laboratory. This includes solicitations for advanced in-space manufacturing and industrialized biomedicine flight demonstrations, as well as efforts expanding the pipeline of potential users and seeking innovative approaches to broadly stimulate demand. NASA is interested in developing and reducing the cost and technical barriers of access to LEO to strengthen a commercial market in LEO. NASA is working to develop and execute a targeted strategy for enabling the development and growth of a sustainable, scalable, and profitable non-NASA demand for LEO services.

As an initial step, NASA expanded the International Space Station Utilization NASA Research Announcement (NRA) requesting proposals from U.S. industry for commercial concepts with a focus on the areas of in-space manufacturing and regenerative medicine/bioengineering. NASA will also consider other fields that may lead to a scalable, financially self-sustaining demand for LEO capabilities. Successful ventures will include non-NASA funding and further mature concepts with potential for scalability, such as returning high-value items for terrestrial use, capturing sizeable markets or creating new markets, and disrupting existing technologies by taking advantage of the ISS and eventually follow-on human-rated destinations in LEO.

For more information on the International Space Station Utilization NRA, go to:
https://nspires.nasaprs.com/external/solicitations/solicitationAmmendments.do?solId=%7B21E0270C-BC1F-EFC4-3D87-30713B5FF373%7D&path=&redirectURL=

NASA also released NextSTEP-2 BAA (Appendix J) requesting proposals from U.S. entities in support of further developing a LEO economy. This request for proposals seeks innovative approaches to reducing transportation costs to and from LEO destinations, broadening the base of industry, academia, and government researchers seeking to utilize LEO capabilities or other opportunities to foster long-term market growth.

COMMERCIAL LEO DEVELOPMENT

For NextSTEP-2 BAA (Appendix J), go to:
https://beta.sam.gov/opp/46e62589e753679e97ff07ba0410241a/view?keywords=nextstep-2&sort=-relevance&index=&is_active=true&page=1

(5) NASA updated a white paper quantifying the Agency's long-term needs in LEO. The NASA Transition Authorization Act of 2017 directed NASA to develop an ISS Transition Plan, specifically "to transition in a step-wise approach from the current regime that relies heavily on NASA sponsorship to a regime where NASA could be one of many customers of a LEO non-governmental human space flight enterprise." To that end, NASA has examined its potential future needs in LEO, such as space life and physical sciences research derived from the National Academies Decadal Survey, research on the effects of the space environment on humans, technology demonstrations, life cycle testing of systems intended to be deployed in deeper space, and in-flight crew training. In a mature, sustainable LEO market, commercial destinations will have robust business bases that rely on NASA as one of many customers instead of as a primary customer. The white paper entitled "Forecasting Future NASA Demand in Low-Earth Orbit: Revision Two - Quantifying Demand" forecasts the services NASA intends to purchase as a customer in this sustainable LEO marketplace. NASA is providing this forecast to aid industry in planning for future commercial LEO destination capabilities and will periodically update as NASA's forecasts of its future demand evolve.

For the NASA Transition Authorization Act of 2017, go to:
https://www.congress.gov/115/plaws/publ10/PLAW-115publ10.pdf

For the white paper entitled Forecasting Future NASA Demand in Low-Earth Orbit: Revision Two - Quantifying Demand, go to:
https://www.nasa.gov/sites/default/files/atoms/files/forecasting_future_nasa_demand_in_low-earth_orbit_revision_two_-_quantifying_demand.pdf

NASA's Commercial LEO Development budget request for FY 2021 supports and will advance the Nation's goals in LEO and for deep space exploration by furthering the development and maturity of the commercial space market. This development will enable private industry to assume roles that have been traditionally Government-only by creating new opportunities for economic growth through new markets and industries in LEO and potentially yielding long-term cost savings to the Government by leveraging industry innovation and commercial market incentives.

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

ACHIEVEMENTS IN FY 2019

NASA publicly unveiled the Commercial LEO comprehensive plan on June 7, 2019, at NASDAQ in New York. Following the announcement, NASA released the draft port solicitation and the synopsis of solicitation for free-flyer development. In FY 2019, NASA also completed the NASA Interim Directive 8600.121 on Use of ISS for Commercial and Marketing Activities and released multiple solicitations to stimulate demand and catalyze new markets for LEO services. NASA also released an updated white paper entitled "Forecasting Future NASA Demand in Low-Earth Orbit: Revision Two - Quantifying

COMMERCIAL LEO DEVELOPMENT

Demand" that forecasts the services NASA intends to purchase from future commercial space station operators.

WORK IN PROGRESS IN FY 2020

A robust and competitive low-Earth orbit (LEO) economy would greatly accelerate progress in space. NASA is collaborating with industry on the development and demonstration of commercial destinations at ISS or as free-flyers. On January 27, 2020, NASA selected Axiom Space to provide a habitable commercial module, attached to the ISS Node 2 forward port. NASA plans to make award(s) for the development of a commercial free-flying destination by the end of FY 2020.

In FY 2020, NASA will pursue opportunities to stimulate scalable and sustainable demand for LEO destinations through the award of contracts with companies seeking the opportunity to enhance the unique capabilities of the ISS, and utilize the ISS to develop and/or operate systems or facilities that may lead to a sustainable demand for a human-rated LEO platform. In FY 2020, NASA will begin to accommodate new commercial activities on the ISS under the NASA Interim Directive 8600.121 on Use of ISS for Commercial and Marketing Activities. NASA will also enter into agreements to initiate training of private astronauts and planning for private astronaut missions to the ISS. NASA also plans to conduct a Program Status Assessment (PSA) for Commercial LEO Development in the latter part of FY 2020, to assess progress to date and identify opportunities for improvement going forward.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

NASA will continue development of the ISS commercial module and commercial free-flyer destinations that will lead to demonstrations in LEO. NASA will also continue awards and partnerships to mature and demonstrate promising new activities (e.g. advanced materials manufacturing, industrialized biomedicine, etc.) and leverage use of the ISS National Laboratory, facilitating increased demand for products and services in the LEO economy.

COMMERCIAL LEO DEVELOPMENT

Program Schedule

Date	Significant Event
Apr 2019	Request for proposals for demand stimulation using ISS
Jun 2019	Developed and released NASA's Plan for Commercial LEO Development
Jun 2019	Released request for information regarding feedback and areas of improvement on NASA's Plan for Commercial LEO Development
Jun 2019	NASA Interim Directive (NID) on Use of ISS for Commercial and Marketing Activities (NID 8600.121)
Jun 2019	NASA's demand forecast: "Forecasting Future NASA Demand in Low-Earth Orbit: Revision Two – Quantifying Demand"
Jun 2019	Request for proposals for commercial modules at the ISS
Jun 2019	Request for proposals for broadly stimulating demand in the LEO economy
Jun 2019	Request for proposals for private astronaut missions
Oct 2019	Draft request for proposals for commercial free-flying destinations in LEO
Jan 2020	Selection for commercial module at the ISS
2020	Release commercial free-flyer destination solicitation
2020	Award agreements for training private astronauts
2020	Award demand stimulation contracts
2020	Award commercial free-flying destinations in LEO
2021	Initial private astronaut mission to ISS
2021	Ongoing non-research and development commercial activities on the ISS
2021	Mature commercial concepts through research and development on ISS
2021	Agreements for additional private astronaut missions
2021	Additional awards for demand stimulation

Program Management & Commitments

NASA Headquarters manages the Commercial LEO Development program.

Program Element	Provider
Commercial LEO Development Program Management	Lead Center: NASA Headquarters (HQ) Performing Center(s): Johnson Space Center (JSC) Cost Share Partner(s):TBD

COMMERCIAL LEO DEVELOPMENT

Program Element	Provider
Partner(s)	Provider: Axiom Space, Inc. Lead Center: TBD Performing Center(s): TBD Cost Share Partner(s): TBD

Acquisition Strategy

NASA will utilize multiple acquisition tools for Commercial LEO Development. The established NextSTEP-2 Broad Agency Announcement (BAA) contract vehicle is being used to develop commercial destinations in LEO. Through this approach, NASA will award firm-fixed-price contracts for a series of task orders to demonstrate capabilities in LEO, using Appendix I for commercial modules at the ISS and Appendix K for commercial free-flyer destinations. In addition, Appendix J is being used for firm fixed price contracts that will help broadly stimulate demand for products and services in LEO.

In parallel, NASA is employing the existing ISS Utilization NASA Research Announcement (NRA) to select and develop commercial concepts that will stimulate demand in the LEO economy. This NRA will also be used to solicit and evaluate proposals for private astronaut missions, and for non-research and development commercial activities on the ISS.

Major Contracts/Awards

Element	Vendor	Location (of work performance)
Commercial Destination Module for International Space Station	Axiom Space, Inc.	Houston, TX

Independent Reviews

N/A

Historical Performance

N/A

SCIENCE

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Earth Science	1931.0	1971.8	**1768.1**	1878.2	1846.1	1834.5	1984.6
Planetary Science	2746.7	2713.4	**2659.6**	2800.9	2714.9	2904.8	2830.7
Astrophysics	1191.1	1306.2	**831.0**	891.2	1000.9	959.7	975.5
James Webb Space Telescope	305.1	423.0	**414.7**	175.4	172.0	172.0	172.0
Heliophysics	712.7	724.5	**633.1**	807.8	841.8	834.1	804.1
Total Budget	**6886.6**	**7138.9**	**6306.5**	**6553.5**	**6575.7**	**6705.2**	**6766.9**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

SCIENCE

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Earth Science	1931.0	1971.8	**1768.1**	1878.2	1846.1	1834.5	1984.6
Planetary Science	2746.7	2713.4	**2659.6**	2800.9	2714.9	2904.8	2830.7
Astrophysics	1191.1	1306.2	**831.0**	891.2	1000.9	959.7	975.5
James Webb Space Telescope	305.1	423.0	**414.7**	175.4	172.0	172.0	172.0
Heliophysics	712.7	724.5	**633.1**	807.8	841.8	834.1	804.1
Total Budget	**6886.6**	**7138.9**	**6306.5**	**6553.5**	**6575.7**	**6705.2**	**6766.9**
Change from FY 2020			**-832.4**				
Percentage change from FY 2020			**-11.7%**				

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

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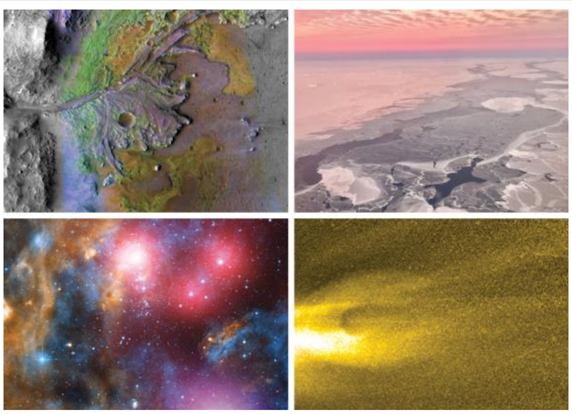


From the vantage point of space, NASA captures breath-taking images of our world and the universe. These images advance our scientific understanding in a multitude of disciplines. They also have the power to influence action and inspire learning.

Since NASA's inception, scientific discovery about our Earth, the Sun, the solar system and the universe beyond has been an enduring purpose of the Agency as part of its three major strategic thrusts: discover, explore, and develop. NASA's Science Mission Directorate (SMD) conducts scientific exploration enabled by observatories that view Earth from space, observe and visit other bodies in the solar system, and gaze out into the galaxy and beyond. NASA's scientific exploration will also inform human exploration of the Moon, Mars, and the solar system, providing valuable scientific data for such human missions. NASA's science programs focus on three interdisciplinary objectives:

- Discovering the secrets of the universe;
- Searching for life in the solar system and beyond; and
- Protecting and improving life on Earth.

NASA science programs address fundamental research about the universe and our place in it. How did the universe begin and evolve? How did our solar system originate? How and why is the Earth changing on all time-scales? This fundamental research covers all areas of science and the intersections thereof when addressing the question, "Are we alone?" NASA's science programs also help protect and improve life on Earth through fundamental research that enables innovative and practical applications for decision-makers, including disaster response, natural resource management, and planetary defense. NASA also focuses on improving its operations and launching its science missions on schedule and on budget. Our discoveries continue to rewrite textbooks, inspire learners of all ages, and demonstrate U.S. leadership worldwide.

NASA uses the recommendations of the National Academies' decadal surveys as important inputs in planning and prioritizing the future of its science programs. For almost 50 years, decadal surveys have proven vital in establishing a broad consensus within the national science community on the state of science, the highest priority science questions we can address, and actions we can take to answer those questions. NASA uses these recommendations to prioritize future flight missions, including space observatories and probes, as well as technology development and proposals for theoretical and suborbital supporting research. In determining the content of the Science portfolio, NASA also considers national priorities and policies, budgets, existing technological capabilities, partnership opportunities, and other programmatic factors.

EXPLANATION OF MAJOR CHANGES IN FY 2021

The FY 2021 Budget provides $6.3 billion for Science and reflects expanded investments in lunar and Mars exploration and terminations of lower-priority programs.

The Budget accelerates the Commercial Lunar Payload Services (CLPS) and other activities in the Lunar Discovery and Exploration program. NASA recently announced the selection of five additional CLPS providers. Early CLPS lunar missions will enable important technology demonstrations that will inform the development of future landers and other exploration systems needed for NASA's Moon-to-Mars campaign. The Budget proposes a collaboration with Canada on a Mars Ice Mapper, a remote sensing mission under study intended to map and profile the near-surface (3-15 meters) water ice, particularly that which lies in the mid-latitude regions, in support of future science and exploration missions, and continues support for a Mars Sample Return mission as early as 2026.

Given the delay to initiating a contract for a commercial launch vehicle, the Budget supports the launch of the Europa Clipper as early as 2024 (one year later than previously proposed) on a commercial launch vehicle, which would save taxpayers over $1.5 billion compared to an SLS rocket. A Europa Lander mission, which was not supported by the science community in the Planetary Science decadal midterm report, is not funded.

Consistent with prior requests, the Budget proposes termination of the Pre-Aerosol, Clouds, and ocean Ecosystem (PACE) and Climate Absolute Radiance and Refractivity Observatory (CLARREO) Pathfinder missions. Given existing ocean and climate monitoring missions and future mission plans from the National Oceanic and Atmospheric Administration (NOAA) and international partners, demonstrating expanded measurement capabilities is a not a priority for NASA funding.

The Budget again proposes to terminate funding for the Wide Field Infrared Survey Telescope (WFIRST) mission and focus on the completion of the James Webb Space Telescope (Webb), now planned for launch in March 2021. The Administration is not ready to proceed with another multi-billion-dollar telescope until Webb has been successfully launched and deployed. The Budget also proposes termination of the SOFIA mission, which costs over $80 million per year and has not proven to be as scientifically productive as other missions.

SCIENCE

ACHIEVEMENTS IN FY 2019

SCIENCE RESULTS

NASA investments continue to generate productive science and interesting results. In Planetary Science, after three years orbiting Jupiter, Juno confirmed minute but distinct changes in Jupiter's internal magnetic field over time. It is the first observation of this phenomenon, called secular variation, outside of Earth. The variation is best explained by Jupiter's deep atmospheric winds shearing the magnetic fields as they pull electrically conductive hydrogen around the planet. Improving the understanding of Jupiter has important implications for studying and anticipating changes in Earth's magnetic field.

In Astrophysics, as of October 2019, the Transiting Exoplanet Survey Satellite (TESS) has completed two thirds of the data collection for its exoplanet survey, identifying over 1,100 candidate planets orbiting other stars. TESS has recently discovered rocky, Earth-size planets, planets within the habitable zones of their host stars where temperatures are just right for liquid water to exist on the planet's surface, planetary systems with multiple planets orbiting the same star, and planets within binary star systems having two suns in their sky.

In Earth Science, a review of snow pack trends found that there is extensive surface and satellite-based evidence of significant declines in the spring snow cover in the Northern Hemisphere starting in the mid 1980's. Scientists attribute the decline in snowpack to a response to recent warming. They also found that limitations in current satellite systems severely hamper our ability to monitor snow cover and trends in mountain regions. Persistent changes to the regional snowpack in a changing climate can have disruptive societal and economic impacts (e.g., water supply disruptions, agriculture challenges, and regional flooding).

In Heliophysics, the Parker Solar Probe spacecraft made three close passes through the Sun's corona and returned a wealth of scientific data. These data are the subject of the papers published in *Nature* magazine on December 4, 2019. Included in these papers are major findings that tie directly to the mission objectives of understanding how the corona is heated to millions of degrees and how the solar wind is accelerated to supersonic speeds. It has long been thought that waves seen in the solar wind are relics of more intense waves back in the corona that heated the plasma. Researchers were hoping to see the waves increase in intensity closer to the Sun. To their surprise, the waves are stronger but also organized into coherent structures that travel at high speeds through the solar wind and can flip the direction of the magnetic field. These structures may be a sign that specific events at the Sun are expelled into space and heat the corona. Researchers also discovered an unexpected large rotational flow of the solar wind around the Sun. This large flow is ten times larger than predicted by models and challenges everything from our simulations of the Sun to predictions of how quickly the Sun loses angular momentum and slows down its spin.

NASA highlights these and many other scientific results in the pages that follow.

COST AND SCHEDULE PERFORMANCE

In June 2018, NASA announced a launch delay and cost growth on the James Webb Space Telescope. In December 2019, NASA submitted a Breach Report to Congress due to cost growth on the Mars 2020 mission, which remains on track for launch in July 2020. Otherwise, most Science missions have continued to demonstrate good cost and schedule performance. Since 2011, when NASA implemented a requirement for missions entering development to budget at the 70 percent confidence level, we have launched 22 Science missions subject to GAO reporting, with a total net budget underrun of three percent. Twelve of those missions launched by NASA's original commitment date.

In the last 12 months, NASA launched the Orbiting Carbon Observatory 3 (OCO-3) and Ionospheric Connection (ICON) missions. OCO-3 launched to the International Space Station four days late and was about one percent under budget. Due to issues with its Pegasus launch vehicle, ICON launched two years late, but was only five percent over budget. Both OCO-3 and ICON are performing well in orbit.

WORK IN PROGRESS IN FY 2020

NASA Science includes about 100 missions, most of which involve collaboration with international partners or other U.S. agencies. Work on over 30 missions in formulation and development continues. Launch of the ESA/NASA Solar Orbiter Collaboration is scheduled for February 2020. Our Mars 2020 rover is on track for launch in July 2020, as is ESA's ExoMars rover, which will carry the NASA-provided Mars Organic Molecule Analyzer Mass Spectrometer. Operations of more than 60 other Science missions continue. Suborbital flights using aircraft, sounding rockets, and balloons are ongoing, as are more than 3,000 competitively selected research awards to scientists located at universities, independent research centers, NASA field Centers, industry, and other government agencies.

By the end of FY 2020, NASA plans to make final selections from the nine candidate Heliophysics Missions of Opportunity, select the first Earth Venture Continuity (EVC-1) mission - focused on Earth's radiation budget, select the third full Earth Venture Mission (EVM-3), complete architecture studies of and start development of Landsat-Next systems, and make initial selections for the next Astrophysics Small Explorer and Astrophysics Mission of Opportunity.

The SMD-wide CubeSat/SmallSat initiative is responsive to recommendations from a 2016 National Academies report that concluded that small satellites are suitable to address specific high-priority science goals. The investment supports technology development in all science themes and provides new partnership opportunities among NASA and commercial partners.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

In FY 2021, NASA plans to launch the James Webb Space Telescope and the Multi-Angle Imager for Aerosols (MAIA) Earth Venture-Class mission. NASA plans to select up to two new Discovery missions, the next Earth Venture - Instrument (EVI-6), and the next Heliophysics Mid-class Explorer (MIDEX). NASA plans to release a new Heliophysics Small Explorer (SMEX) Announcement of Opportunity (AO) and a new Astrophysics MIDEX AO, and it will begin formulation activities on the first Earth Science Designated Observable mission.

Themes

EARTH SCIENCE

From the vantage point of space, NASA satellites can view and study our home planet and its dynamic system of diverse components: the oceans, atmosphere, continents, ice sheets, and life. The Nation's scientific community can thereby observe and track global-scale changes, connecting causes to effects. Scientists can study regional changes in their global context, as well as observe the role that human civilization plays as a force of change. NASA's Earth Science activities are an essential part of national and international efforts to understand change at all time-scales and to use Earth observations and scientific understanding in service to society. Through its partnerships with other agencies that maintain forecasting and decision support systems, NASA helps to advance national capabilities to predict climate, weather, and natural hazards; manage resources; and inform the development of environmental policy.

In January 2018, the National Academies released the second Decadal Survey for Earth Science and Applications from Space, which provided recommendations for the next decade (2018 - 2027). The primary recommendations were:

- Complete the program of record, including maintaining the Venture Class program and completing missions currently in formulation and development. This budget supports the recommendation, except for proposals to terminate funding for PACE and CLARREO Pathfinder.
- Establish a "Continuity Measurement" strand as an addition to the existing Venture-class program to provide opportunity for the demonstration of low-cost sustained observations. This budget supports the recommendation.
- Implement cost-capped medium- and large-size missions/observing systems to address the five "Designated" observables (Aerosols; Clouds, Convection, & Precipitation; Mass Change; Surface Biology & Geology; Surface Deformation & Change). This budget supports the recommendation, enabling the start of one Designated Observable mission in FY 2021.
- Establish a new competed "Explorer" flight line to provide opportunities for cost-capped medium-size instruments and missions. Due to budget limitations and other priorities, this budget does not establish an Earth Explorer program.
- Establish an "Incubator Program" to mature specific technologies for important – but presently immature – measurements. This budget supports the recommendation.

NASA asks the Earth Science Advisory Committee for input to ensure that our proposed programs maximize scientific productivity within the general framework established by the National Academies.

PLANETARY SCIENCE

To answer questions about the solar system and the origins of life, NASA sends robotic space probes to the Moon, other planets and their moons, asteroids and comets, and the icy bodies beyond Neptune. In FY 2019, NASA began a new Lunar Discovery and Exploration program that is part of the Agency's exploration initiative. The program develops instruments and other payloads for missions to the lunar surface. In partnership with industry and with other NASA organizations, the new program will address exploration, science, and technology demonstration objectives as the agency prepares for a sustained program of lunar exploration. NASA is also building the next Mars rover, which will launch in July 2020. The Mars 2020 rover will address key questions about the potential for life on Mars and will cache samples for a future Mars Sample Return mission. In January 2019, the New Horizons spacecraft completed the first fly-by of a Kuiper Belt object. NASA is operating spacecraft at Mars, Jupiter, and the Moon, and the OSIRIS-REx spacecraft is orbiting and studying the potentially hazardous asteroid Bennu, with the intention of capturing and returning a sample to Earth.

SCIENCE

The primary recommendations of the National Academies' 2012 Decadal Survey for Planetary Science were:

- Continue Discovery solicitations, with the cost cap adjusted for inflation and a 24-month cadence. In the upcoming AOs, NASA will impose a cost cap of $500 million FY 2019 constant dollars for phases A through D, not including the cost of the launch vehicle or the value of any non-NASA contributions, per the Decadal recommendation. This cost cap is equivalent to the $450 million FY 2015 in the previous AO, which led to the selection of the Lucy and Psyche missions. The out-year budget supports an approximate 30-month cadence for future launches. In addition, the Lunar Discovery and Exploration program includes the Lunar Reconnaissance Orbiter, VIPER lunar rover, and payloads for delivery to the lunar surface and orbit.
- Continue New Frontiers with a $1 billion cost cap, and select two new missions by 2022. This budget supports the recommended cost cap for the AO released in February 2017, which resulted in the 2019 selection of the Dragonfly mission to Saturn's moon Titan.
- Begin the two highest priority flagships: a Mars Astrobiology Explorer-Cacher and a Europa mission. This budget supports both the Mars 2020 rover mission that will address the highest priority Mars science objectives recommended by the Planetary Decadal Survey and the Europa Clipper project. The budget includes $233 million in FY 2021 for studies and technology development (along with international partners) towards a Mars sample return mission, launching as early as 2026.
- Continue missions in development and flight, subject to senior review. This budget supports all missions selected for development, all missions in prime operations, and all extended missions.
- Increase research and analysis (R&A) spending by 5 percent above the FY 2011 budget level, and then 1.5 percent above inflation thereafter. This budget meets the recommendation.
- Increase Planetary Technology spending to six to eight percent of the total division budget, including completion of the advanced Stirling radioisotope generators. This budget meets the recommended goal for technology spending and includes funding for dynamic radioisotope power system development.
- Achieve a balanced program through a mix of Discovery, New Frontiers, and flagship missions and an appropriate balance among the many potential targets in the solar system. This budget achieves a balanced program by supporting the competed, Principal Investigator (PI)-led programs and two flagship missions (Mars 2020 rover and Europa Clipper). It also continues formulation of a Mars Sample Return mission for launch in 2026. To preserve the balance of NASA's science portfolio and maintain flexibility to conduct missions that were determined to be more important by the science community, this budget provides no funding for a multi-billion-dollar mission to land on Europa.

NASA asks the Planetary Science Advisory Committee for input to ensure that our proposed programs maximize scientific productivity within the general framework established by the National Academies.

ASTROPHYSICS

Space is the proving ground for many theories with breathtaking implications for our understanding of the physical universe, including the origin of the universe, black holes, dark matter and dark energy, and planets throughout the universe where life might exist. Having measured the age of the universe, the scientific community now seeks to explore further extremes: its birth, the edges of space and time near black holes, gravitational waves, and the mysterious dark energy filling the entire universe. Scientists have recently developed astronomical instrumentation and analysis methodologies sensitive enough to detect planets around other stars. With thousands of extrasolar planets now known, scientists are using current NASA missions in conjunction with ground-based telescopes to seek Earth-like planets in other solar systems.

The 2010 Decadal Survey in Astronomy and Astrophysics recommended a coordinated program of research, technology development, ground-based facilities, and space-based missions for implementation during 2012–2021. The primary recommendations were:

- Complete the ongoing program. The Astro 2010 Decadal Survey assumed continuation of the current program, which at that time assumed the launch of Webb in 2014; full operations of the Stratospheric Observatory for Infrared Astronomy (SOFIA) airborne observatory in 2012; and completion of three Explorer missions: the Nuclear Spectroscopic Telescope Array (NuSTAR) in 2012, the Gravity and Extreme Magnetism (GEMS) Explorer in 2014, and the U.S. contribution to the Japanese ASTRO-H mission in 2014. This budget fully supports launch of Webb in March 2021 and continued operations of NuSTAR (launched in 2012). NASA halted development of GEMS in 2012 due to cost overruns. NASA delivered the ASTRO-H instrument to Japan for launch in 2016; in response to the ASTRO-H spacecraft failure, this budget supports NASA's participation in the X-ray Imaging and Spectroscopy Mission (XRISM), Japan's planned recovery mission. This budget proposes termination of SOFIA given its high operating costs and low scientific productivity.
- Support the ongoing core research program to ensure a balanced program that optimizes overall scientific return. This budget fully supports the ongoing core research program and funds a balanced program of strategic and PI-led missions, research and analysis, suborbital projects, and technology development addressing the highest priorities in cosmic origins, exoplanet exploration, and physics of the cosmos.
- Launch WFIRST by 2020. The Astro 2010 Decadal Survey did not account for the delay and cost growth of Webb. The budget provides no funding for WFIRST, as the Administration is not ready to proceed with another multi-billion-dollar space telescope until Webb has been successfully launched and deployed. Additionally, WFIRST was originally proposed as a less-than-$2 billion space telescope in the Decadal Survey. The current WFIRST architecture, which was supported by two National Academy studies, differs from that discussed in the 2010 Decadal Survey and is estimated to cost $3.3-$3.9 billion.
- Augment the Astrophysics Explorers Program to support the selection of four missions and four smaller missions of opportunity each decade. This budget fully supports the recommended cadence of new Astrophysics Explorers missions, with AOs in 2011, 2014, 2016, 2019, and 2021, and a new class of small Pioneer-class Explorers.
- Launch the Laser Interferometer Space Antenna (LISA) by 2025. This budget supports studies and technology development leading toward a potential contribution to an ESA-led gravitational wave observatory for launch in 2034.
- Invest in Technology leading toward an international X-ray observatory in the 2020s. This budget supports a U.S. contribution to the ESA-led Athena advanced X-ray observatory for launch in 2031.
- Invest in a New Worlds technology development and precursor science program for a 2020s mission to image habitable rocky planets. This budget supports studies of two potential missions to image and characterize habitable rocky exoplanets as well as the technologies required to realize them, including coronagraphs, starshades, and advanced mirrors.

- Invest in technology development and precursor science for a 2020s mission to probe the epoch of inflation. This budget supports the development of technology and conduct of precursor science required for a potential future mission to probe the epoch of inflation at the immediate beginning of the universe.
- Increase funding for several targeted areas of supporting research and technology. This budget focuses investments on the science opportunities of CubeSats/SmallSats, taking advantage of the technological progress in the public and private sector toward meeting high-priority science goals. This budget also supports increased funding for research and analysis, including recommended investments in advanced technology development, theoretical and computational networks, suborbital programs, laboratory astrophysics, and technology for future ultraviolet/visible space telescopes.

NASA is continuing to address many of the Decadal Survey recommendations, though in some cases at a slower pace than anticipated. Adjustments to the Decadal Survey recommendations are primarily due to overly optimistic Decadal assumptions regarding future budgets, and challenges and delays to programs such as Webb. Other factors that could not be anticipated by the Decadal Survey include changing international partnership opportunities, emerging technologies that have changed what can be accomplished, and advances in our scientific understanding of the universe. The 2016 Midterm Assessment of decadal survey progress found that "NASA has maintained a balanced portfolio through the first half of the decade and, with the assumption of successful completion of an ambitious Explorer schedule, will do so during the second half of the decade as well." In 2019, NASA received the recommendations from the Senior Review of operating Astrophysics missions, which has informed the FY 2021 budget request.

NASA asks the Astrophysics Advisory Committee for input to ensure that our proposed programs maximize scientific productivity within the general framework established by the National Academies.

HELIOPHYSICS

The Sun, a typical small star midway through its life, governs our solar system. The Sun wields its influence through its gravity, radiation, solar wind, and magnetic fields, all of which interact with the Earth and its space environment. These processes are crucial for our understanding of the universe, and they relate directly to our ability to live in space as they produce space weather, which can affect human technological infrastructure and activities in space. Using a fleet of sensors on various spacecraft in Earth orbit and throughout the heliosphere, NASA seeks to understand the fundamental processes of how and why the Sun varies, how Earth and our solar system respond to the Sun, how the Sun and the solar system interact with the interstellar medium, and how human activities are affected by these processes. The science of heliophysics, including space weather, enables the predictions necessary to safeguard life and society on Earth and the outward journeys of human and robotic explorers.

The primary recommendations of the National Academies' 2013 Decadal Survey for Heliophysics were:

- Maintain and complete the current program. The Decadal Survey assumed launch of Van Allen Probes by 2012, Interface Region Imaging Spectrograph (IRIS) by 2013, Magnetospheric Multiscale (MMS) by 2014, Solar Orbiter Collaboration (SOC) by 2017, Parker Solar Probe by 2018, and continued current funding of the research program. Van Allen, IRIS, MMS, and Parker Solar Probe have launched. NASA plans to launch the ESA-led SOC mission in February 2020.

- Implement the DRIVE (Diversify, Realize, Integrate, Venture, Educate) initiative, including the incorporation of smaller spacecraft and an increase in the competed research program from 10 percent to about 15 percent of the budget request. This budget request meets these objectives and invests in the SMD-wide CubeSat/SmallSat initiative.
- Accelerate and expand the Heliophysics Explorer Program, resulting in an increase to the cadence of competed missions to one launch every two to three years. NASA launched IRIS in 2013, Global-Scale Observations of the Limb and Disk (GOLD) in 2018, and ICON in October 2019. The proposed out-year budgets, if realized, would enable launch of the 2019 selections Atmospheric Waves Experiment (AWE), Polarimeter to Unify the Corona and Heliosphere (PUNCH) and Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (TRACERS) by August 2022. The budget also supports the launch by 2025 of one mission that will be selected through the 2019 MIDEX solicitation. NASA plans additional launches approximately every two years thereafter.
- Restructure Solar Terrestrial Probes (STP) as a moderate-scale, principal investigator-led flight program, and implement three mid-scale missions with an eventual recommended four-year cadence. This budget supports launch of the Interstellar Mapping and Acceleration Probe (IMAP) mission, which is PI-led, in 2024. NASA intends to competitively select future STP strategic missions as recommended by the Decadal Survey.
- Implement a large Living with a Star (LWS) mission to study Global Dynamic Coupling with a launch in 2024. NASA chartered a Science and Technology Definition Team (STDT) for the Geospace Dynamics Constellation (GDC) mission to leverage technical advancements and enable cost-effective solutions in anticipation of launch as early as 2026. The results of the STDT study provided the basis for pre-formulation planning activities to further develop the mission concept.

The Decadal Survey also made recommendations related to space weather applications, addressed collectively to the relevant government agencies. NASA will continue collaborating with other agencies to improve space weather observation and forecasting capabilities.

NASA asks the Heliophysics Advisory Committee for input to ensure that our proposed programs maximize scientific productivity within the general framework established by the National Academies.

EARTH SCIENCE

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Earth Science Research	454.1	--	**447.3**	471.9	494.1	528.5	530.3
Earth Systematic Missions	932.7	--	**608.3**	706.1	695.6	640.7	797.3
Earth System Science Pathfinder	223.8	--	**338.9**	301.2	251.6	241.8	234.4
Earth Science Data Systems	202.0	--	**245.4**	259.9	263.2	278.7	277.7
Earth Science Technology	63.4	--	**74.2**	82.8	84.6	86.4	86.4
Applied Sciences	55.1	--	**53.9**	56.3	57.0	58.5	58.5
Total Budget	**1931.0**	**1971.8**	**1768.1**	**1878.2**	**1846.1**	**1834.5**	**1984.6**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Earth Science

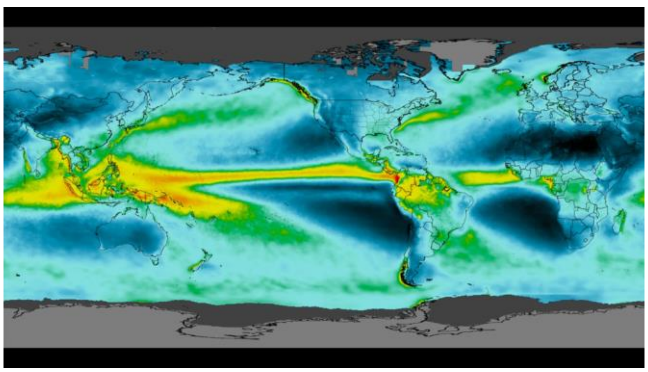
EARTH SCIENCE RESEARCH

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Earth Science Research and Analysis	316.5	--	**309.9**	321.7	324.0	327.4	327.2
Computing and Management	137.6	--	**137.4**	150.2	170.1	201.1	203.1
Total Budget	**454.1**	**--**	**447.3**	**471.9**	**494.1**	**528.5**	**530.3**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.



This image, constructed from IMERG data, shows the "grand average climatology" of global precipitation from June 2000 to May 2019. NASA's Precipitation Measurement Missions (PMM) have collected rain and snowfall from space for nearly 20 years and, for the first time in 2019, scientists can access PMM's entire record as one data set.

NASA's Earth Science Research program develops a scientific understanding of Earth and its response to natural or human-induced changes. Earth is a system, like the human body, comprised of diverse components interacting in complex ways. Understanding Earth's atmosphere, crust, water, ice, and life as a single, connected system is necessary to improve our predictions of climate, weather, and natural hazards. The Earth Science Research program addresses complex, interdisciplinary Earth science problems in pursuit of a comprehensive understanding of the Earth system. This strategy involves six interdisciplinary and interrelated science focus areas, including:

- Water and Energy Cycle: quantifying the key reservoirs and fluxes in the global water cycle, assessing water cycle change, and assessing water quality.
- Weather: enabling improved predictive capability for weather and extreme weather events.
- Earth Surface and Interior: characterizing the dynamics of the Earth's surface and interior and forming the scientific basis for the assessment and mitigation of natural hazards and response to rare and extreme events.
- Climate Variability and Change: understanding the roles of ocean, atmosphere, land, and ice in the climate system and improving our ability to predict future changes.
- Atmospheric Composition: understanding and improving our predictive capability for changes in the ozone layer, Earth's radiation budget, and air quality associated with changes in atmospheric composition.

EARTH SCIENCE RESEARCH

- Carbon Cycle and Ecosystems: quantifying, understanding, and predicting changes in Earth's ecosystems and biogeochemical cycles, including the global carbon cycle, land cover, and biodiversity.

NASA's Earth Science Research program pioneers the use of both space-borne and aircraft measurements in all of these areas. The Earth Science Research program is critical to the advancement of the interagency U.S. Global Change Research Program (USGCRP), established in 1989 and mandated in the Global Change Research Act of 1990 to develop and coordinate "a comprehensive and integrated United States research program which will assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change." The Earth Science Research program also makes extensive contributions to international science programs, such as the World Climate Research Program.

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

ACHIEVEMENTS IN FY 2019

A recent study assessed the impact of assimilating Global Precipitation Measurement (GPM) Microwave Imager (GMI) clear-sky radiance on the track and intensity forecasts of two Atlantic hurricanes during the 2015 and 2016 hurricane seasons using the Hurricane Weather Research and Forecasting Model. Forecast verifications against dropsonde soundings and reanalysis data show that assimilating GMI clear-sky radiance, when it does not overlap with overpasses of other microwave sounders, can improve forecasts of both thermodynamic (e.g., temperature and specific humidity) and dynamic variables (e.g., geopotential height and wind field), which leads to better track forecasts and a more realistic hurricane inner-core structure.

Persistent changes to the regional snowpack in a changing climate can have disruptive societal and economic impacts (e.g., water supply, agriculture, and regional flooding). In a review of snow pack trends, scientists found that there is extensive surface and satellite-based evidence of significant declines in the spring snow cover in the Northern Hemisphere starting in the mid 1980's. They attribute the decline in snowpack as a response to recent warming. They also found that limitations in current satellite systems severely hamper our ability to monitor snow cover and trends in mountain regions.

Research supported by the NASA Glenn Research Center has advanced the understanding of algal blooms in the Great Lakes, and their consequences and impacts on human health. For example, it was determined through airborne hyperspectral imagery collected over Lake Erie that in order to successfully differentiate algal bloom types based on their spectral reflectance, a spatial resolution of no more than 50m is needed. This resolution provides the best sensitivity to high concentration areas that are of significant importance for human health and subject to potential ecological damage.

Analysis of gravity field measurements from GRACE have provided new insights into seismic cycle processes at subduction zones. Following the magnitude 8.1 Samoa-Tonga earthquake in September 2009, investigators used GRACE and GPS data to detect largescale gravity increases (roughly equivalent to a centimeter in equivalent water height change) and ongoing subsidence. Given this intensified subsidence, postseismic rates of relative sea level rise in the surrounding islands increased. American

EARTH SCIENCE RESEARCH

Samoa saw the greatest postseismic subsidence, resulting in a relative sea level rise rate approximately five times faster than the global average sea level rise rate (3.4 millimeters/year).

A study in the Journal of Volcanology integrated satellite-detections of ground deformation, sulfur dioxide emissions based on detections from the Total Ozone Mapping Spectrometer (TOMS) and Ozone Monitoring Instrument (OMI), and thermal features using data from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and Moderate Resolution Imaging Spectroradiometer (MODIS), each of which contributed unique detections, validating a multi-sensor approach. The study found that most volcanic eruptions in the past few decades were measurable from satellites, and those not detected were associated with low volcano explosivity index eruptions and occurred in the earlier decades of remote sensing (pre-2000) when detection thresholds were high. The upcoming NASA-ISRO Synthetic Aperture Radar (NISAR) mission will add new capabilities for observing volcano deformation.

Researchers used Interferometric Synthetic Aperture Radar (InSAR) and a simple hydrological model to characterize 8 years of stable sliding of the Mud Creek landslide in California prior to its rapid acceleration and catastrophic failure on May 20, 2017. Their results suggest a large increase in pore-fluid pressure occurred during a shift from historic drought to record rainfall that triggered a large increase in velocity and drove slip localization, overcoming the stabilizing mechanisms that had previously inhibited landslide acceleration. Such increased precipitation extremes may make it more common for landslides to transition from stable to unstable motion.

A recent study examines the relationship between economic growth and air quality (nitrogen oxides, NOx, as an indicator) in the 100 most populated global cities, based on satellite nitrogen dioxide (NO2) data from the Ozone Monitoring Instrument (OMI) on the Aura satellite and gross urban product (GUP). For the period of 2005-2011, those cities denoted as high-income cities had decreasing NO2 levels compared to cities considered low-income. This is likely due to air pollution controls despite economic growth. The lower income cities showed increasing NO2 with industrialization, urbanization, and increasing energy consumption indicative of rapid economic growth.

Researchers published a comprehensive analysis of CO2 emissions in the urban domain of Boston and surrounding regions. The work establishes the template for monitoring and measuring fossil fuel emission from large urbanized areas, combining inverse modeling with extensive data from sensors on the ground, in aircraft, and from satellites. It introduced and validated new "big-data" approaches to determine actual emissions in an urban area, including spatial and temporal distributions. It lays the groundwork for Orbiting Carbon Observatory-3 (OCO-3) measurements of urban emissions, which have the Boston urban domain as a principal early target.

Scientists analyzed a “marine heatwave” between 2013 and 2015 over the northeast Pacific Ocean, characterized by the highest surface temperatures ever recorded in a swath from near the Gulf of Alaska to off the coast of Baja California, Mexico. Satellite data showed that the heatwave was associated with a record decrease in the typically high cloudiness over an area of the Pacific off Baja California that is roughly half the size of the contiguous United States. Such a deficit in cloud cover coincided with a large increase in the amount of sunlight absorbed by the ocean surface, resulting in extremely warm temperatures. Their findings suggest that a positive feedback between clouds and ocean surface temperature can strongly contribute to significant and difficult-to-predict changes in marine climate.

Two papers came out that put the long-term changes in Arctic and Antarctic sea ice into perspective. The first extended the Arctic sea ice thickness, volume, and multiyear ice records by comparing the presatellite submarine data from 1958 – 1976 to the recent Cryosat-2 measurements from 2011 – 2018. They find that sea ice thickness at the end of the melt season decreased by 66 percent over the six-decade period. Between 1999 and 2017, multiyear ice cover has decreased by 50 percent and now covers less than one third of the Arctic Ocean. The study concludes that as much of the multiyear ice is lost, variations in sea ice thickness and volume will be controlled by the changes in seasonal ice, will be more moderate, and will be more sensitive to climate forcing. The second paper highlights the dramatic reversal in Antarctic sea ice extent trends seen from 2014 to 2017. Previous to 2014, Antarctic sea ice extent had substantial interannual variability but an overall small positive trend. From 2014 to 2017, Antarctic sea ice extent decreased to record low values with 2017 being a minimum. The rate of change during the four-year period exceeded the rate of change in any other four-year period from 1978 to 2018 in either the Arctic or the Southern Ocean.

An increasing amount of evidence from NASA Ocean's Melting Greenland (OMG) campaign and NASA data synthesis and modeling efforts (ECCO) suggests a leading role of oceans in controlling the fate of major land ice complexes of Greenland and Antarctica. NASA scientists show a direct link between warming ocean waters and accelerated mass loss, thinning, and glacier retreats. Similarly, new data also suggest that episodic cooling of ocean waters can slow down glacier melt and cause glacier thickening. This direct ocean-ice link has important implications for projecting future changes of sea level that need to account for ocean-induced melting and dynamic coupling between the ocean and cryosphere.

Researchers demonstrated the utility of satellite salinity data to improve our understanding of El Nino-Southern Oscillation (ENSO) and ENSO-related precipitation. By analyzing NASA and ESA satellite salinity data, they established a relationship between the large-scale fresh pools in the tropical Pacific with ENSO-induced precipitation and oceanic transport associated with mesoscale eddies. The examples of the linkages of satellite salinity with climate modes of variability, such as ENSO and Madden-Julian Oscillation (MJO), demonstrate the potential of satellite salinity measurements to improve the representation of climate variability in ocean models and related forecasts (e.g., through assimilation of satellite salinity data into general circulation and coupled models).

The Global Learning and Observations to Benefit the Environment (GLOBE) project continued a strong record of supporting student research. In 2019, NASA held six in-person research symposia across the United States. In all, 261 students from 26 states presented 114 projects. Students represented a diversity of racial and ethnic groups, and nearly a quarter came from households where languages other than English were spoken. GLOBE Observer added a tree height measurement to the mobile platform, supporting the “Trees Around the GLOBE Student Research Campaign.”

The Scientific Computing project expanded the Discover supercomputing cluster by 46,400 computing cores to support increasing scientific and engineering workloads. The project continued progress towards a centralized storage architecture with a clear data management policy. The project also installed and operationalized a small number of graphics processing units designed for machine learning and artificial intelligence. The High End Computing Capability (HECC) project completed the construction of a modular computing facility. The project also installed the initial units of the Aitken supercomputer with four E-Cells (1,152 nodes or 46,080 cores) to support increasing scientific and engineering workloads.

The Space Geodesy project continued the development and deployment of a modern network that includes co-located next-generation Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging, Global Navigation Satellite System (GNSS), and Doppler Orbitography and Radiopositioning Integrated by Satellite stations. NASA completed the deployment of the new VLBI Global Observing System

(VGOS) antenna at the McDonald Geodetic Observatory in Texas. This instrument will join NASA's VGOS antennas at Kōke'e Park Geophysical Observatory in Hawaii and Goddard Geophysical and Astronomical Observatory in Maryland in contributing measurements towards updates to the terrestrial reference frame.

WORK IN PROGRESS IN FY 2020

NASA will continue to fund projects competitively selected from Research Opportunities in Space and Earth Science (ROSES) 2018 and 2019. Notable new research solicitations include: a) the implementation of a new interdisciplinary science (IDS) solicitation with seven interdisciplinary themes of emerging high priority research, and b) a repurposed Satellite Calibration Interconsistency Study solicitation, refocused on the development of additional and/or enhanced products from operational geostationary satellites and the use of those products for scientific research, which is being implemented together with NOAA.

NASA's Land Cover/Land Use Change (LCLUC) activity will continue to study changes in both human-induced changes in land use and naturally-occurring changes in land cover. The recently-initiated South/Southeast Asia Regional Initiative (SARI) brings together numerous NASA-funded investigators to study this rapidly growing and changing region as a near-term area of emphasis within the ongoing, global LCLUC activity. The SARI program involves close coordination with scientists and managers in this region, holding meetings to facilitate scientific interaction and support training of local investigators in using NASA data. In 2020, such SARI trainings are planned for the Philippines and Sri Lanka. This year, the LCLUC program has also initiated an area of emphasis in the less studied region of Central Asia.

NASA will complete the data validation, provision of data to public archives, and initial analysis and interpretation of data obtained during major field campaigns during FY 2019. Most notably, this includes (a) the joint NASA-NOAA Fire Influence on Regional to Global Environments – Air Quality (FIREX-AQ) campaign carried out in the summer of 2019 using NASA's DC-8 and ER-2 aircraft to study the atmospheric impacts of wildfires and agricultural burning in the US, and (b) the joint NASA/US Navy Cloud, Aerosol, and Monsoon Processes Philippines Experiment (CAMP2Ex) carried out using NASA's P-3 aircraft in the summer of 2019 based in the Philippines to study tropical meteorology and aerosol science, especially the influence of aerosol particles on clouds, precipitation, and atmospheric radiation in the poorly sampled Maritime Continent/Western Pacific/South China Sea area.

The fall of 2019 marks the final deployment for Operation Ice Bridge, which has been carried out since 2009 to bridge the gap in measurements of ice sheet thickness between the end of operations of NASA's Ice, Cloud, and Elevation Satellite (ICESat) in 2009 and the launch of NASA's ICESat-2 satellite in September 2018. In 2020, NASA's G-V aircraft, instrumented with two laser altimeters that measure ice elevation, together with radar sounders, temperature sensors, a gravimeter, and multiple cameras, will fly out of Hobart, Australia, to survey a range of snow and ice properties of Antarctic and the Southern Ocean. This campaign will also have coordinated flights underneath ICESat-2 tracks as well as in-situ measurements in collaboration with the Australian Antarctic Division.

The SnowEx2020 campaign, with both airborne and surface-based observations, is a snow remote sensing effort that makes use of multiple approaches (both active and passive) to improve our knowledge of measuring snow distribution and properties (especially snow water equivalent). The Arctic Boreal Vulnerability Experiment (ABoVE) will continue extensive data collection in northwest Canada and Alaska (highlighted by a recent second major coordinated airborne campaign) as a follow up to the 2017 campaign and to complement on-going ground-based measurements. NASA and the Indian Space Research Organization (ISRO) have initiated a combined L/S-Band radar campaign using an ISRO-provided instrument and a NASA-provided airborne platform. The scientific foci of this effort include terrestrial ecology, cryospheric science, terrestrial hydrology, Earth Surface/Interior, and disaster-related observations.

The Export Processes in the Ocean from Remote Sensing (EXPORTS) activity will conduct its second and final field campaign in the North Atlantic in the spring of 2020. EXPORTS will develop a predictive understanding of the export and fate of global ocean net primary production and its implications for the Earth's carbon cycle in present and future climates. It will employ the same observational approaches for the North Atlantic as it did for the Northeast Pacific 2018 field campaign, which include ships, autonomous observations (via floats and gliders), and satellite remote sensing.

NASA continues its close relationship with the European Space Agency (ESA) as part of their Joint Program Planning Group (JPPG). The calibration/validation subgroup continues to facilitate cooperation in field campaigns that address the research and/or calibration/validation objectives of both agencies. NASA and ESA are also looking to continue their successful cooperation in integrating scientific efforts, initiating a new joint study on emissions of methane from permafrost. NASA and ESA will enhance scientific coordination on surface-based measurements of ozone and nitrogen dioxide distributions through the Pandonia Global Network (PGN). PGN provides calibration/validation support for several United States and European satellite instruments and provides data sets useful for refinement of algorithms to be used for future geostationary air quality measuring satellites launched by the United States, Europe, and Korea.

The GLOBE project celebrates its 25th anniversary in April 2020. Initiatives, spread across the year, include commemorative activities at the Annual Meeting (held in July 2020 in Washington, DC), the release of an updated trainer and mentor-trainer certification process, and a review of existing scientific protocols.

The Space Geodesy Project (SGP) will continue building the next-generation Space Geodesy Satellite Laser Ranging (SGSLR) systems for deployment to McDonald Geodetic Observatory in Texas; Goddard Geophysical and Astronomical Observatory in Maryland (GGAO); and Ny-Ålesund, Svalbard, in collaboration with the Norwegian Mapping Authority. Testing of the first gimbal and telescope assembly for these systems will begin at GGAO. The new SGSLR stations will ultimately allow for automated operations that will facilitate larger numbers of measurements for improved satellite tracking and geodetic science. The SGP also will continue to work with the French National Centre for Space Studies (CNES) on the implementation plan for a new joint NASA-CNES geodetic site in Tahiti.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

In 2021, NASA will select new awards solicited in ROSES 2020. While most of the solicitations represent the periodic solicitations of ongoing R&A elements, there are some efforts that are sufficiently different from previous years that merit particular attention.

Three Atmospheric Composition research programs will initiate proposals for data analysis and modeling of NASA-supported airborne campaign and surface-based network data selected in response to a unified solicitation in ROSES 2020, covering the Atmospheric Composition Modeling and Analysis Program, the

EARTH SCIENCE RESEARCH

Radiation Science Program, and the Tropospheric Composition Programs. These tasks will begin in FY 2021 and will support analysis and modeling of combined satellite remote sensing data, airborne remote sensing and in-situ data and surface-based remote sensing and in-situ data.

NASA's Carbon Cycle and Ecosystems focus area will initiate a focused activity that involves synergistic utilization from several newly launched sensors, most notably the ECOSTRESS, GEDI, and OCO-3 sensors all flying aboard the International Space Station (ISS). This activity will provide new insights into the linkages among processes associated with evapotranspiration, solar-induced fluorescence, and growth of aboveground biomass, and the role these processes play in the global carbon cycle and the coupling between the terrestrial carbon and terrestrial hydrologic cycle.

The Modeling, Analysis, and Prediction (MAP) activity will initiate tasks focused on the characterization and evaluation of precipitation in earth system models, especially those associated with intermediate-term (subseasonal-to-seasonal) global models.

An Ocean Biology and Biogeochemistry (OBB) activity will enter a focused analysis phase for data obtained in the two field phases of its EXPORTS program (2018 in Northeast Pacific, 2020 in North Atlantic). The data synthesis activity will allow for comparison and contrasting of data from the two oceanic regions, as well as assessment of the results relative to the representation of carbon export processes in global biogeochemical models.

The New Investigator Program (NIP) will initiate a new round of tasks to support early career investigators.

Program Elements

GLOBAL MODELING AND ASSIMILATION OFFICE

The Global Modeling and Assimilation Office creates global climate and Earth system component models using data from Earth science satellites and aircraft. Investigators can then use these products worldwide to further their research.

AIRBORNE SCIENCE

The Airborne Science project is responsible for providing aircraft systems to further science and advance the use of satellite data. NASA uses these assets worldwide in campaigns to investigate extreme weather events, observe Earth system processes, obtain data for earth science modeling activities, and calibrate instruments flying aboard earth science spacecraft. NASA Airborne Science platforms support mission definition and development activities. These activities include:

- Conducting instrument development flights;
- Gathering ice sheet observations as gap fillers between missions (e.g., Operation IceBridge);
- Serving as technology test beds for Instrument Incubator Program missions;
- Serving as the observation platforms for research campaigns, such as those competitively selected under the suborbital portion of Earth Venture; and

- Calibrating and validating space-based measurements and retrieval algorithms.

OZONE TRENDS SCIENCE

The Ozone Trends Science project produces a consistent, calibrated ozone record used for trend analyses and other studies.

INTERDISCIPLINARY SCIENCE

Interdisciplinary Science includes science investigations, as well as calibration and validation activities, that ensure the utility of space-based measurements. In addition, this project supports focused fieldwork (e.g., airborne campaigns) and specific facility instruments upon which fieldwork depends.

EARTH SCIENCE RESEARCH AND ANALYSIS

Earth Science Research and Analysis is the core of the research program and funds the analysis and interpretation of data from NASA's satellites. This project funds the scientific activity needed to establish a rigorous foundation for the satellites' data and their use in computational models.

FELLOWSHIPS AND NEW INVESTIGATORS

The Fellowships and New Investigators project supports graduate and early career research in the areas of Earth system research and applied science.

SPACE GEODESY

Geodesy is the science of measuring Earth's shape, gravity, orientation, and rotation and how these properties change over time. The Space Geodesy Project (SGP) encompasses the development, operation, and maintenance of a global network of space geodetic technique instruments, a data transport and collection system, data analysis, and the public dissemination of data products required to maintain a stable terrestrial reference system. SGP provides the data and analysis essential for fully realizing the measurement potential of the current and coming generation of Earth Observing spacecraft.

EARTH SCIENCE DIRECTED RESEARCH AND TECHNOLOGY

The Earth Science Directed Research and Technology project funds the civil service staff who work on emerging Earth Science flight projects, instruments, and research.

GLOBAL LEARNING AND OBSERVATIONS TO BENEFIT THE ENVIRONMENT

GLOBE is a worldwide hands-on primary and secondary school-based project that promotes collaboration among students, teachers, and scientists to conduct inquiry-based investigations about our environment. NASA works in close partnership with NOAA and the National Science Foundation to study the dynamics of Earth's environment, focused on atmosphere, hydrosphere, pedosphere (soil), and biosphere.

EARTH SCIENCE RESEARCH

Students take measurements, analyze data, and participate in research in collaboration with scientists. NASA initiated a citizen science component, called GLOBE Observer, in 2016 that makes four protocols available for use by anyone in a GLOBE country.

For more information, go to: http://www.globe.gov

SCIENTIFIC COMPUTING

The Scientific Computing project funds NASA's Earth Science Discover supercomputing system, high-end storage and network, software engineering, and user interface projects at NASA Goddard Space Flight Center (GSFC), including climate assessment modeling and data analysis. Scientific Computing supports Earth system science modeling activities based on data collected by Earth science spacecraft. The system is separate from the High-End Computing Capability program at NASA Ames Research Center, so it can be close to the satellite data archives at GSFC. The proximity to the data and the focus on satellite data assimilation makes the Discover cluster unique in its ability to analyze large volumes of satellite data quickly. The system currently has approximately 100,000 computer processor cores.

HIGH END COMPUTING CAPABILITY (HECC)

HECC focuses on the Endeavour, Merope, Pleiades, Electra, and Aitken supercomputer systems and the associated network connectivity, data storage, data analysis, visualization, and application software support. It serves the supercomputing needs of all NASA mission directorates and NASA-supported principal investigators at universities. The funding supports the operation, maintenance, upgrade, and expansion of NASA's supercomputing capability. These four supercomputer systems, with approximately 865,000 computer processor cores, support NASA's aeronautics, human exploration, and science missions. For example, the systems are being used to perform first-of-a-kind simulations helping engineers reduce risk from acoustic vibrations generated by Orion's Launch Abort System motor. The systems also run simulations created with unprecedented resolution helping scientists understand how galaxies co-evolve with extensive reservoirs of gas around them.

DIRECTORATE SUPPORT

The Directorate Support project funds the NASA Science Mission Directorate's institutional and crosscutting activities including: National Academies studies, proposal peer review processes, printing and graphics, information technology, the NASA Postdoctoral Fellowship program, working group support, independent assessment studies, procurement support for the award and administration of all grants, and other administrative tasks.

Program Schedule

Date	Significant Event
Q1 FY 2020	ROSES-2019 selection within six to nine months of receipt of proposals
Q2 FY 2020	ROSES-2020 solicitation release

EARTH SCIENCE RESEARCH

Date	Significant Event
Q1 FY 2021	ROSES-2020 selection within six to nine months of receipt of proposals
Q2 FY 2021	ROSES-2021 solicitation release
Q1 FY 2022	ROSES-2021 selection within six to nine months of receipt of proposals
Q2 FY 2022	ROSES-2022 solicitation release
Q1 FY 2023	ROSES-2022 selection within six to nine months of receipt of proposals
Q2 FY 2023	ROSES-2023 solicitation release
Q1 FY 2024	ROSES-2023 selection within six to nine months of receipt of proposals
Q2 FY 2024	ROSES-2024 solicitation release
Q1 FY 2025	ROSES-2024 selection within six to nine months of receipt of proposals
Q2 FY 2025	ROSES-2025 solicitation release

Program Management & Commitments

Program Element	Provider
Global Modeling and Assimilation Office	Provider: Various Lead Center: HQ Performing Center(s): GSFC Cost Share Partner(s): N/A
Airborne Science	Provider: Various Lead Center: HQ Performing Center(s): AFRC, ARC, WFF, JSC, LaRC Cost Share Partner(s): N/A
Scientific Computing	Provider: GSFC Lead Center: HQ Performing Center(s): GSFC Cost Share Partner(s): N/A
Ozone Trends Science	Provider: Various Lead Center: HQ Performing Center(s): LaRC, GSFC Cost Share Partner(s): USGCRP and SOST agencies
Interdisciplinary Science	Provider: Various Lead Center: HQ Performing Center(s): HQ, JPL, GSFC, ARC, AFRC, GRC, LaRC, MSFC, JSC Cost Share Partner(s): USGCRP and SOST agencies

EARTH SCIENCE RESEARCH

Program Element	Provider
Earth Science Research and Analysis	Provider: Various Lead Center: HQ Performing Center(s): All NASA Centers Cost Share Partner(s): USGCRP and SOST agencies
High-End Computing Capability	Provider: ARC Lead Center: HQ Performing Center(s): ARC Cost Share Partner(s): N/A
Directorate Support	Provider: Various Lead Center: HQ Performing Center(s): All NASA Centers Cost Share Partner(s): N/A
Fellowships and New Investigators	Provider: Various Lead Center: HQ Performing Center(s): All NASA Centers Cost Share Partner(s): N/A
Space Geodesy	Provider: Various Lead Center: GSFC Performing Center(s): GSFC, JPL Cost Share Partners: N/A
Global Learning and Observations to Benefit the Environment	Provider: University Corporation for Atmospheric Research Lead Center: HQ Performing Center(s): HQ, GSFC Cost Share Partner(s): N/A

EARTH SCIENCE RESEARCH

Acquisition Strategy

NASA implements the Earth Science Research program via competitively selected research awards. NASA releases research solicitations each year in the ROSES NASA Research Announcements. All proposals in response to NASA ROSES are peer reviewed and selected based on defined criteria. The program competitively awards funds to investigators from academia, the private sector, NASA Centers, and other Government agencies.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Relevance	Earth Science Advisory Committee	2019	To review progress towards Earth Science objectives in the NASA Strategic Plan	All six science focus areas remained on track in their annual performance towards the achievement of research goals	2020; annually

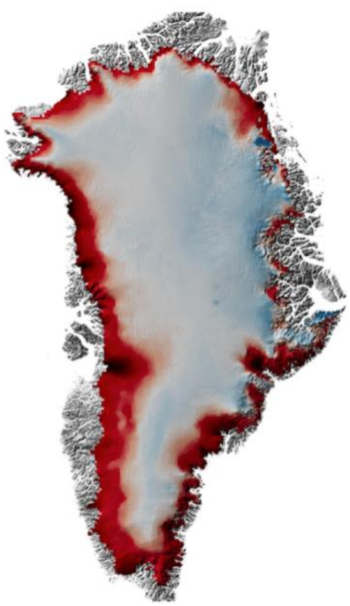
EARTH SYSTEMATIC MISSIONS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Surface Water and Ocean Topography Mission (SWOT)	109.1	82.2	**63.9**	32.8	11.5	9.5	9.5
NASA-ISRO Synthetic Aperture Radar (NISAR)	134.6	136.0	**59.7**	73.5	34.4	24.3	19.7
Landsat 9	137.4	108.9	**86.5**	2.8	2.9	3.0	3.0
Sentinel-6	70.4	59.5	**20.4**	14.9	35.3	52.9	68.0
Other Missions and Data Analysis	481.2	--	**377.8**	582.2	611.5	551.1	697.1
Total Budget	**932.7**	**--**	**608.3**	**706.1**	**695.6**	**640.7**	**797.3**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.



One of the major goals of the ICESat-2 mission is to measure the elevation change of the ice sheets. By comparing elevation measurements from ICESat-2 (2018-19) with those of ICESat (2003-09), scientists can measure decade-long trends in ice sheet elevation. These results indicate that both the Antarctic and Greenland (pictured) ice sheets continue to lose ice along their margins.

The Earth Systematic Missions (ESM) program includes a broad range of multi-disciplinary science investigations aimed at understanding the Earth system and its response to natural and human-induced forces and changes. Understanding these forces will help determine how to predict future changes and mitigate or adapt to these changes.

The ESM program develops Earth-observing satellite missions, manages the operation of these missions once on-orbit, and produces mission data products to support the research and applications communities.

Interagency and international partnerships are central elements of the ESM program. More than half of the projects in development under ESM have an international or interagency contribution, and several on-orbit missions provide data products in near real-time for use by the United States and international meteorological agencies and disaster responders.

EXPLANATION OF MAJOR PROGRAMMATIC CHANGES IN FY 2021

The request for Other Missions and Data Analysis includes funds to begin the implementation of the first Designated Observable mission in FY 2021 and start other

EARTH SYSTEMATIC MISSIONS

Designated Observable missions as out-year budgets permit per the 2017 Decadal survey recommendation.

Consistent with prior Budget requests, this budget provides no funding for the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) and the Climate Absolute Radiance and Refractivity Observatory Pathfinder (CLARREO Pathfinder) missions. PACE would have incorporated ocean color and atmospheric aerosol measurement capabilities that are an enhancement over current capabilities. The CLARREO Pathfinder mission would have demonstrated measurement technologies for a larger, more expensive future mission recommended in the 2007 decadal survey focused on improving detection of climate trends. Existing and planned missions from other NASA, National Oceanic and Atmospheric Administration (NOAA), and international partner satellite fleets are providing or will provide measurements to enable similar science. The PACE and CLARREO Pathfinder missions are in early mission development and are eliminated to achieve cost savings.

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

FY 2021 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	BTC	Total
Formulation	136.8	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	136.8
Development/Implementation	305.3	109.1	82.2	**57.0**	17.9	0.0	0.0	0.0	0.0	571.5
Operations/Close-out	0.0	0.0	0.0	**6.9**	14.9	11.5	9.5	9.5	0.0	52.2
2020 MPAR LCC Estimate	**442.1**	**109.1**	**82.2**	**63.9**	**32.8**	**11.5**	**9.5**	**9.5**	**0.0**	**760.4**
Total Budget	**442.1**	**109.1**	**82.2**	**63.9**	**32.8**	**11.5**	**9.5**	**9.5**	**0.0**	**760.4**
Change from FY 2020				**-18.3**						
Percentage change from FY 2020				**-22.3%**						

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

An artist's conception shows the Surface Water Ocean Topography (SWOT) satellite, which entered the implementation phase in May 2016. SWOT will make high-resolution, wide-swath altimetric measurements of the world's oceans and fresh water bodies to understand their circulation, surface topography, and storage. This multi-disciplinary, cooperative international mission will produce science and data products that will allow for fundamental advances in understanding the global water cycle.

PROJECT PURPOSE

The Surface Water and Ocean Topography (SWOT) mission will improve our understanding of the world's oceans and terrestrial surface waters. The mission will make high-resolution measurements of ocean circulation, its kinetic energy, and its dissipation, through broad swath altimetry. These measurements will improve ocean circulation models, leading to better prediction of weather and climate. The mission will also revolutionize knowledge of the surface water inventory on the continents by making precise measurements of water levels in millions of lakes and water bodies and the discharge of all major rivers. This will allow for deeper understanding of the natural water cycle and potentially better water management.

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

The 2007 and 2017 National Academies decadal surveys endorsed SWOT. The mission will complement the Jason oceanography missions, as well as other NASA missions currently in operation and development to measure the global water cycle: Sentinel-6, Global Precipitation Measurement, Soil Moisture Active Passive, and Gravity Recovery and Climate Experiment Follow-On.

SWOT is a collaborative mission with the Centre National d'Études Spatiales (CNES), Canadian Space Agency (CSA), and United Kingdom Space Agency (UKSA).

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

PROJECT PARAMETERS

SWOT will provide broad-swath sea surface heights and terrestrial water heights for at least 90 percent of the globe using a dual-antenna Ka-band Radar Interferometer (KaRIn). The SWOT payload will also include a precision orbit determination system consisting of Global Positioning System-Payload (GPSP), Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) receivers, and a Laser Retro-reflector Assembly (LRA). In addition, SWOT carries a Nadir Altimeter and a radiometer for tropospheric path delay corrections. NASA will provide a radiometer designed to determine tropospheric water vapor content, the GPSP system to complement DORIS for precise positioning of the satellite, and a backscattering laser for precise calibration of the other instruments. The CSA will provide a key component of the radar instrument – a set of Extended Interaction Klystrons (EIKs). The CNES will provide radar Radio-Frequency Unit (RFU), the Poseidon-3C Ku-/C-band altimeter, and a DORIS precise orbit determination system. The UKSA will provide commercial applications that will strengthen the international collaborations of the mission. SWOT's prime mission is three years.

ACHIEVEMENTS IN FY 2019

The SWOT project completed development of the GPSP instrument and placed it in storage for delivery to CNES, initiated integration and testing of the KaRIn instrument including the CNES-supplied RFU and CSA-supplied EIKs, and initiated integration and testing of the nadir payload module including the Advanced Microwave Radiometer-C (AMR-C) and LRA.

WORK IN PROGRESS IN FY 2020

The SWOT project will complete the System Integration Review (SIR), the KaRIn instrument integration and testing, the nadir payload module integration and testing, and begin the integrated payload module integration and testing.

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

KEY ACHIEVEMENTS PLANNED FOR FY 2021

The SWOT project will complete the integrated payload module integration and testing and ship it to Thales (the CNES spacecraft contractor) for observatory integration and testing.

SCHEDULE COMMITMENTS/KEY MILESTONES

The milestones remain consistent with the confirmation baseline date, except for the Critical Design Review (CDR) and Key Decision Point-D (KDP-D). This is mainly due to delays in the development and delivery of the components related to the KaRIn instrument. The Launch Date remains unchanged.

Milestone	Confirmation Baseline Date	FY 2021 PB Request
KDP-C	May 2016	May 2016
CDR	Feb 2018	May 2018
KDP-D	Oct 2019	Mar 2021
Launch	Apr 2022	Apr 2022
Start Phase E	Oct 2022	Oct 2022
End of Prime Mission	Oct 2025	Oct 2025

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

Development Cost and Schedule

NASA and CNES will strive to launch SWOT in September 2021. Consistent with NASA policies regarding commitments to time and schedule, the SWOT launch will occur no later than April 2022.

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2017	571.5	>70%	2020	571.5	0%	Launch Readiness Date (LRD)	Apr 2022	Apr 2022	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**571.5**	**571.5**	**0**
Aircraft/Spacecraft	0	0	0
Payloads	181.6	288.9	+107.3
Systems I&T	4.9	4.7	-0.2
Launch Vehicle	131.3	107.8	-23.5
Ground Systems	34.7	31.0	-3.7
Science/Technology	46.7	37.6	-9.1
Other Direct Project Costs	172.3	101.5	-70.8

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

Project Management & Commitments

The Earth Systematic Missions program at NASA Goddard Space Flight Center (GSFC) has program management responsibility for SWOT. NASA assigned project management responsibility to the Jet Propulsion Laboratory (JPL). SWOT is a partnership mission between NASA, CNES, CSA, and UKSA.

Element	Description	Provider Details	Change from Baseline
KaRIn	Makes swath measurements of sea surface topography and lake and river heights	Provider: NASA, CNES, CSA, UKSA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): CNES (RFU), CSA (EIK), UKSA (Duplexer)	N/A
AMR	Provides wet tropospheric delay correction of KaRIn	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
GPSP	Provides orbit determination	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
LRA	Provides orbit determination	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
X-band Telecom	Provides downlink of science data	Provider: L-3, Tesat Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
Nadir Altimeter	Measures Jason-heritage ocean surface topography at nadir	Provider: CNES Lead Center: None Performing Center(s): None Cost Share Partner(s): CNES	N/A

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
DORIS	Provides orbit determination	Provider: CNES Lead Center: None Performing Center(s): None Cost Share Partner(s): CNES	N/A
Spacecraft Bus	Provides instrument platform	Provider: CNES Lead Center: None Performing Center(s): None Cost Share Partner(s): CNES	N/A
Launch Vehicle	Delivers spacecraft to orbit	Provider: SpaceX Lead Center: KSC Performing Center(s): None Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: The AirSWOT airborne instrument is insufficient to meet ocean calibration/validation needs, Then: New, more complex approaches (in-situ moorings, airborne LIDAR, GPS floaters) may be required, resulting in impacts to cost reserves.	The project is evaluating alternate ocean calibration/validation approaches using LIDAR and in-situ measurements in pre-launch field campaigns to confirm the approach and associated cost impact. The project is leveraging partnerships with academia, industry, other U.S. Government agencies, and CNES to address the cost reserve risk.

Acquisition Strategy

The acquisition strategy for SWOT leveraged Jason heritage by using JPL legacy instrument designs (AMR, GPSP, and LRA) and in-house build with a combination of sole source and competitive procurements. The KaRIn leverages Earth Science Technology Office investments and is an in-house development. The X-band Telecom was a competitive procurement. NASA selected SpaceX to provide a Falcon 9 launch vehicle through a competitive Launch Service Task Order evaluation under the NASA Launch Services II contract.

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
X-band Telecom	L3 for modulator, Tesat for traveling wave tube amplifiers	San Diego, CA Backnang, Germany
Launch Vehicle	SpaceX	Los Angeles, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Strategic Review Board (SRB)	May 2014	Systems Requirement Review (SRR)/Mission Definition Review (MDR)	Successful	Apr 2016
Performance	SRB	Apr 2016	Preliminary Design Review (PDR)	Successful	Feb 2018
Performance	SRB	May 2018	Critical Design Reviews (CDR)	Successful	Sep 2020
Performance	SRB	Sep 2020	System Integration Review (SIR)	TBD	Feb 2022
Performance	SRB	Feb 2022	Operational Readiness Review (ORR)	TBD	N/A

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

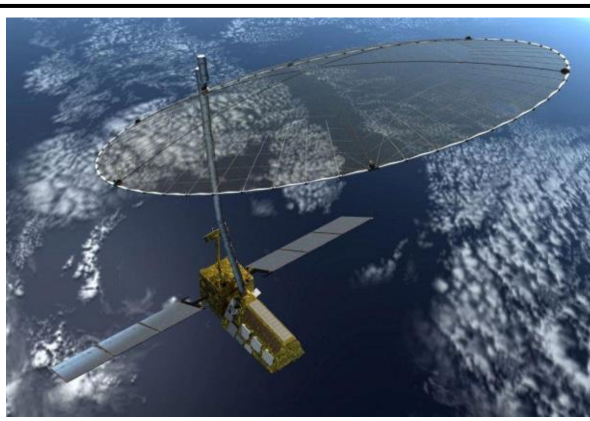
Formulation	Development	Operations

FY 2021 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	BTC	Total
Formulation	117.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	117.0
Development/Implementation	290.4	124.6	125.0	**55.2**	45.1	0.0	0.0	0.0	0.0	640.4
Operations/Close-out	0.0	0.0	0.0	**0.0**	19.9	25.4	21.2	15.8	6.7	88.9
2020 MPAR LCC Estimate	**407.4**	**124.6**	**125.0**	**55.2**	**65.0**	**25.4**	**21.2**	**15.8**	**6.7**	**846.3**
Total Budget	**407.4**	**134.6**	**136.0**	**59.7**	**73.5**	**34.4**	**24.3**	**19.7**	**6.7**	**896.3**
Change from FY 2020				**-76.3**						
Percentage change from FY 2020				**-56.1%**						

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.



The NISAR satellite, shown here, is a joint mission between NASA and the Indian Space Research Organization (ISRO), will be the first radar imaging satellite to use dual frequencies. NISAR will observe and take measurements of some of the planet's most complex processes, including ecosystem disturbances, ice-sheet collapse, and natural hazards.

PROJECT PURPOSE

The NASA-ISRO Synthetic Aperture Radar (NISAR) mission will provide an unprecedented, detailed view of the Earth using advanced radar imaging and a dual frequency (L-band and S-band) Synthetic Aperture Radar (SAR). NISAR will be NASA's first dual frequency radar imaging satellite and will observe and measure some of the planet's most complex processes, including ecosystem disturbances, ice sheet collapse, and natural hazards (e.g., earthquakes, tsunamis, volcanoes, and landslides). The mission will reveal information about the evolution and state of Earth's crust, broaden scientific understanding of our planet's changing processes and their effect on Earth's changing climate, and aid future resource and hazard management.

Both the 2007 and 2017 Earth Science Decadal

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

Surveys endorsed the NISAR science objectives. NISAR is a collaborative mission with the Indian Space Research Organization (ISRO).

EXPLANATION OF MAJOR CHANGES IN FY 2021

The Budget provides an additional $10 million over a five-year period to support the production of a global soil moisture product. This satellite data product, which was recommended by the interagency Satellite Needs Working Group (part of the US Group on Earth Observations), would provide high-resolution, calibrated soil moisture data that more closely aligns with the size of agriculture fields, forests, and other phenomena that is of interest to multiple agencies.

PROJECT PARAMETERS

NISAR consists of a dual frequency (L-band and S-band) Synthetic Aperture Radar (SAR). NASA will provide the L-band SAR, the engineering payload, the payload integration, and payload operations. ISRO will provide the S-band SAR, the spacecraft bus, the launch vehicle, observatory integration and testing, and spacecraft operations. NISAR has a prime mission of three years.

NISAR will implement enhanced data acquisition and data downlink capability as well as a global soil moisture product for agricultural, forest, and modeling efforts, as recommended by the interagency Satellite Needs Working Group (SNWG) process (a function of the US Group on Earth Observations). The SNWG identified multiple other agencies that would benefit from NISAR systematically collecting data over all of North America in Quad-pol 40 MHz mode, thus requiring additional data acquisition and downlink capability. The cost of these additional capabilities will be tracked outside of the Agency Baseline Commitment for cost, as the scope enhancements were approved after mission confirmation.

ACHIEVEMENTS IN FY 2019

The project successfully completed the CDR in October 2018. The project supported the S-band SAR Detailed Design Review (DDR) January 2019 and the Interface DDR conducted by ISRO in May 2019. The project continued building and testing flight hardware. System integration and testing of the L-band SAR started in FY 2019. The project started planning and development of the SNWG's recommended data acquisition and data downlink capability enhancements. The project delivered the Clamshell Radar Instrument Structure (RIS) to ISRO in August 2019 for integration of S-SAR electronics.

WORK IN PROGRESS IN FY 2020

The project is making progress in building, integration, and testing of the L-band SAR. The project will receive the S-band SAR from ISRO in FY 2020 and will start system integration and testing of the combined L- and S-band SAR. The antenna reflector will also be delivered in FY 2020. The project will complete System Integration Review (SIR) followed by KDP-D.

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

KEY ACHIEVEMENTS PLANNED FOR FY 2021

The project will continue system integration and testing of the entire payload along with the reflector and boom assembly in FY 2021. The project will deliver the payload with reflector and boom assembly to ISRO for integration with the ISRO-provided spacecraft bus.

SCHEDULE COMMITMENTS/KEY MILESTONES

NASA has delayed the Key Decision Point D and payload delivery to ISRO by six months as a result of late subsystem deliveries.

Milestone	Confirmation Baseline Date	FY 2021 PB Request
Key Decision Point (KDP-C)	Aug 2016	Aug 2016
Critical Design Reviews (CDR)	Oct 2018	Oct 2018
Key Decision Point (KDP-D)	Dec 2019	June 2020
Payload delivery to ISRO	Feb 2021	Aug 2021
Launch Readiness Date (LRD)	Sep 2022	Sep 2022

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2017	661	>70%	2020	640.4	-3%	LRD	Sep 2022	Sep 2022	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**661.0**	**640.4**	**-20.6**
Aircraft/Spacecraft	77.1	108.2	+31.1
Payloads	211.1	294.1	+83.0
Systems I&T	23.0	21.2	-1.8
Launch Vehicle	0.6	0.3	-0.3
Ground Systems	72.6	60.4	-12.2
Science/Technology	28.2	28.7	+0.5
Other Direct Project Costs	248.4	127.5	-120.9

Project Management & Commitments

The Earth Systematic Missions program at NASA Goddard Space Flight Center (GSFC) has program management responsibility for NISAR. NASA assigned project management responsibility to the Jet Propulsion Laboratory (JPL). NISAR is a partnership between NASA and ISRO.

Element	Description	Provider Details	Change from Baseline
L-band SAR	Radar imaging payload	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
S-band SAR	Radar imaging payload	Provider: ISRO Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ISRO	N/A

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Spacecraft	Provides platform for the payload	Provider: ISRO Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ISRO	N/A
Launch Vehicle	Geosynchronous Satellite Launch Vehicle (GSLV); delivers observatory to orbit	Provider: ISRO Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ISRO	N/A

Project Risks

Risk Statement	Mitigation
If: The ISRO-provided Geosynchronous Satellite Launch Vehicle (GSLV) Mark II reliability does not meet the NASA-ISRO joint requirements, Then: There may be a significant delay in the launch date.	The project documented five success criteria to be met by the GSLV Mark II prior to the NISAR launch. Since ISRO has completed four successful GSLV launches in 2015, 2016, 2017, and 2018, two of the five criteria have been met, reducing this risk substantially. The remaining criteria can only be met closer to the NISAR launch date and NASA expects that ISRO will meet those criteria in due time. If there is a launch delay, the project carries reserve to mitigate the potential schedule risk.

Acquisition Strategy

The design and build of the L-band SAR radar will be an in-house build at JPL, with competed subcontracts.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Solid State Recorder	Airbus	Germany
Reflector Antenna	Astro Aerospace	California

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Strategic Review Board (SRB)	Dec 2014	Systems Requirement Review (SRR)/Mission Design Review (MDR)	Successful	Jun 2016
Performance	SRB	Jun 2016	Preliminary Design Review (PDR)	Successful	Oct 2018
Performance	SRB	Oct 2018	Critical Design Reviews (CDR)	Successful	May 2020
Performance	SRB	May 2020	System Integration Review (SIR)	TBD	Mar 2022
Performance	SRB	Mar 2022	Operational Readiness Review (ORR)	TBD	N/A

LANDSAT 9

Formulation	Development	Operations

FY 2021 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	BTC	Total
Formulation	234.8	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	234.8
Development/Implementation	256.1	137.4	108.9	**85.3**	0.0	0.0	0.0	0.0	0.0	587.7
Operations/Close-out	0.0	0.0	0.0	**1.3**	2.8	2.9	3.0	3.0	3.1	16.1
2020 MPAR LCC Estimate	**490.9**	**137.4**	**108.9**	**86.6**	**2.8**	**2.9**	**3.0**	**3.0**	**3.1**	**838.5**
Total Budget	**490.9**	**137.4**	**108.9**	**86.5**	**2.8**	**2.9**	**3.0**	**3.0**	**3.1**	**838.5**
Change from FY 2020				**-22.4**						
Percentage change from FY 2020				**-20.6%**						

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

The Landsat 9 mission is a partnership between NASA and the U.S. Geological Survey. Landsat 9, shown in this artist's rendition, will continue the Landsat program's critical role in monitoring, understanding and managing the land resources needed to sustain human life.

PROJECT PURPOSE

The Landsat 9 mission will extend the record of multi-spectral, moderate resolution Landsat quality data and meet operational and scientific requirements for observing land use and land change.

Landsat 9 is a collaboration between NASA and the U.S. Geological Survey (USGS) and is a cornerstone of our nation's multi-satellite, multi-decadal, Sustainable Land Imaging (SLI) program. SLI is a NASA-Department of the Interior (DOI)/USGS partnership to develop, launch, and operate a spaceborne system and provide researchers and users with high quality, global, continuous land imaging measurements that are compatible with the existing 47-year Landsat record and will evolve through investing in and introducing new sensor and system technologies.

LANDSAT 9

Formulation	Development	Operations

The Landsat data series, initiated in 1972, is the longest continuous record of changes in Earth's surface as seen from space and the only U.S. satellite system designed and operated to make repeated observations of the global land surface at moderate resolution. Landsat data is available at no cost to users, providing a unique resource for people who work in agriculture, geology, forestry, regional planning, education, mapping, and climate research.

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

PROJECT PARAMETERS

Landsat 9 has two science instruments: the Operational Land Imager 2 (OLI-2) and the Thermal Infrared Sensor 2 (TIRS-2). Landsat 9 is designed to provide 16-day continuous coverage of the global land mass with spatial resolutions of 15 meters for panchromatic light, 30 meters for visible and near-infrared and shortwave infrared light, and 120 meters for infrared light. In concert with other land-imaging satellites, including the currently operating Landsat 8 and Sentinel-2 satellites, Landsat 9 will contribute to improved coverage for users. NASA will build, launch, and perform the initial checkout and commissioning of the satellite. USGS will develop the ground system, operate the Landsat 9 observatory, and process, archive, and freely distribute the mission's data.

ACHIEVEMENTS IN FY 2019

The OLI-2 and the TIRS-2 instruments were delivered to the Northrop Grumman Innovation Systems (NGIS) facility in Gilbert, Arizona and spacecraft integration began in FY 2019.

WORK IN PROGRESS IN FY 2020

The Landsat 9 project will complete its System Integration Review (SIR), Key Decision Point-D (KDP-D) review, and spacecraft assembly in FY 2020 and will begin its observatory integration and testing phase of development.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

The Landsat 9 project will complete observatory integration and testing, its Operational Readiness Review (ORR), its KDP-E review, and deliver the observatory to the launch site. Launch and early operations will be completed in FY 2021.

LANDSAT 9

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

The November 2021 launch estimate reflects the agency baseline commitment made at the KDP-C review in December 2017. Currently, NASA is on-track to launch Landsat 9 in early calendar year 2021.

Milestone	Confirmation Baseline Date	FY 2021 PB Request
KDP-C	Dec 2017	Dec 2017
Critical Design Review	Apr 2018	Apr 2018
System Integration Review	Aug 2019	Jan 2020
KDP-D	Dec 2019	Apr 2020
Operational Readiness Review	Sep 2020	Jan 2021
Launch	Nov 2021	Nov 2021
Handover to USGS	Mar 2022	Mar 2022

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2018	634.2	>70%	2020	587.7	-7%	LRD	Nov 2021	Nov 2021	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

LANDSAT 9

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**634.2**	**587.7**	**-46.5**
Aircraft/Spacecraft	98.1	117.5	+19.4
Payloads	107.6	109.3	+1.7
Systems I&T	0	0.8	+0.8
Launch Vehicle	154.4	154.4	0
Ground Systems	17.2	20.0	+2.8
Science/Technology	9.2	8.8	-0.4
Other Direct Project Costs	247.7	176.9	-70.8

Project Management & Commitments

The Earth Systematic Missions (ESM) program at Goddard Space Flight Center (GSFC) has program management responsibility for Landsat 9. NASA assigned project management responsibility to GSFC. The Landsat 9 mission is a partnership between NASA and USGS.

Element	Description	Provider Details	Change from Formulation Agreement
Operational Land Imager 2	Provide moderate resolution, multi-channel, wide swath visible imaging of the Earth's surface, consistent with previous Landsat missions.	Provider: Ball Aerospace Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Thermal Infrared Sensor 2	Provide moderate resolution thermal infrared imaging of the Earth’s surface, consistent with previous Landsat missions.	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A

LANDSAT 9

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
Spacecraft	Provide a platform with performance commensurate with OLI-2 and TIRS-2 requirements	Provider: Northrop Grumman Innovation Systems (NGIS) Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Launch Vehicle	Provide launch services for the Landsat 9 Observatory	Provider: United Launch Services LLC Lead Center: GSFC Performing Center: Kennedy Space Center (KSC) Cost Share Partner(s): N/A	N/A
Ground System	Collect, process, archive, and freely distribute Landsat data	Provider: General Dynamics Mission Systems (GDMS) Lead Center: USGS Earth Resources Observation and Science (EROS) Center Performing Center(s): USGS EROS Cost Share Partner(s): USGS	N/A
Mission Operations Element	Provide software and system with capabilities for command and control, mission scheduling, long-term trending and flight dynamics analysis	Provider: General Dynamics Mission Systems (GDMS) Lead Center: USGS EROS Performing Center(s): USGS EROS Cost Share Partner(s): USGS	N/A

Project Risks

Risk Statement	Mitigation
If: Schedule conflicts continue between Landsat 9 and other projects that have a higher national priority for test facilities or other resources at the spacecraft contractor, Then: This could cause an adverse effect on the Landsat 9 mission schedule.	The Landsat 9 project management team, GSFC, and Science Mission Directorate senior management are proactively working with NGIS senior management to mitigate schedule conflicts as they arise.

LANDSAT 9

Formulation	Development	Operations

Acquisition Strategy

The acquisition strategy for Landsat 9 is the same strategy used for Landsat 8, formerly known as the Landsat Data Continuity Mission (LDCM). NASA selected Ball Aerospace to provide the OLI-2 instrument through a sole source procurement. NASA selected NGIS (formerly Orbital ATK) to provide the Landsat 9 spacecraft through the GSFC Rapid Spacecraft Development Office selection process. NASA assigned the TIRS-2 instrument as a directed development to GSFC. NASA selected United Launch Services LLC to provide an Atlas V launch vehicle through a competitive Launch Service Task Order evaluation under the NASA Launch Services II contract.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
OLI-2	Ball Aerospace	Boulder, Colorado
TIRS-2	GSFC	Greenbelt, Maryland
Spacecraft	Northrop Grumman Innovation Systems	Gilbert, Arizona
Launch Vehicle	United Launch Services LLC	Decatur, Alabama

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Strategic Review Board (SRB)	Jun 2016	System Requirements Review (SRR)	Successful	Sep 2017
Performance	SRB	Sep 2017	Preliminary Design Review (PDR)	Successful	Apr 2018
Performance	SRB	Apr 2018	Critical Design Review (CDR)	Successful	Jan 2020
Performance	SRB	Jan 2020	System Integration Review (SIR)	TBD	Mar 2021
Performance	SRB	Jan 2021	Operational Readiness Review (ORR)	TBD	N/A

SENTINEL-6

Formulation	Development	Operations

FY 2021 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	BTC	Total
Formulation	15.5	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	15.5
Development/Implementation	130.9	70.4	59.5	**18.4**	12.1	32.1	49.6	64.5	23.5	460.9
Operations/Close-out	0.0	0.0	0.0	**2.0**	2.8	3.2	3.3	3.5	23.6	38.4
2020 MPAR LCC Estimate	**146.4**	**70.4**	**59.5**	**20.4**	**14.9**	**35.3**	**52.9**	**68.0**	**47.1**	**514.8**
Total Budget	**146.4**	**70.4**	**59.5**	**20.4**	**14.9**	**35.3**	**52.9**	**68.0**	**47.1**	**514.8**
Change from FY 2020				**-39.1**						
Percentage change from FY 2020				**-65.7%**						

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

An artist's conception shows one of the two Sentinel-6 satellites. Sentinel-6's primary mission objective is to continue ocean surface topography measurements beyond TOPEX/Poseidon and the Jason series of satellites, providing measurements essential to climate studies and operational oceanography. As a secondary objective, Sentinel-6 will collect high-resolution vertical profiles of atmospheric temperature, using GNSS radio occultation sounding techniques to support numerical weather prediction.

Image Credit: ESA 2015, Airbus Defence and Space

PROJECT PURPOSE

The Sentinel-6 mission will provide continuity of ocean topography measurements beyond the Topography Experiment (TOPEX)/Poseidon (launched in 1992), Jason-1 (2001), Ocean Surface Topography Mission/Jason-2 (2008), and Jason-3 (2016) missions. The Sentinel-6 mission consists of two satellites, Sentinel-6 Michael Freilich and Sentinel-6B, that will launch approximately five years apart (2021 for Sentinel-6 Michael Freilich and 2026 for Sentinel-6B) to extend measurement continuity for at least another decade. This mission will serve both the operational user community and the scientific community by enabling the continuation of multi-decadal ocean topography measurements for ocean circulation and climate studies.

As a secondary mission objective, Sentinel-6 will characterize atmospheric temperature and

SENTINEL-6

Formulation	Development	Operations

humidity profiles by measuring bending angles of Global Navigation Satellite System (GNSS) signals occulted by the Earth's atmosphere. The project will process these measurement products on Earth within a few hours of acquisition on-board the satellite and make them available for ingestion into National Weather Service models to support weather forecasting capabilities.

Sentinel-6 is a collaborative mission with the National Oceanic and Atmospheric Administration (NOAA), the European Space Agency (ESA), and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT).

EXPLANATION OF MAJOR CHANGES IN FY 2021

On January 28, 2020, NASA along with its interagency and international partners, announced that the Sentinel-6A spacecraft has been renamed "Sentinel-6 Michael Freilich," in honor of NASA's recently retired Earth Science Division Director.

PROJECT PARAMETERS

NASA will provide the launch vehicle and launch services as well as a set of three instruments for each of the Sentinel-6 spacecraft. These two sets of instruments are Advanced Microwave Radiometer-Climate Quality (AMR-C), the GNSS-Radio Occultation (GNSS-RO) receiver, and the Laser Reflector Array (LRA). Additionally, NASA will provide support for instrument integration and testing on the satellites, mission operations support for the NASA-developed instruments, an operational AMR-C science data processor for EUMETSAT, near real-time and offline data processing for GNSS-RO data, and mission data product archiving and distribution. The Sentinel-6 Michael Freilich and Sentinel-6B observatories have a five-and-a-half-year prime mission.

ACHIEVEMENTS IN FY 2019

The Sentinel-6 project completed the development and testing of the Sentinel-6 Michael Freilich NASA instrument payload. The project shipped the instrument payload to the ESA spacecraft integrator (Airbus) and completed the System Integration Review (SIR).

WORK IN PROGRESS IN FY 2020

The Sentinel-6 project will complete the Sentinel-6 Michael Freilich Operational Readiness Review (ORR) and begin its launch campaign following completion of observatory-level integration and testing at Airbus and the IABG environmental test facility. The Sentinel-6 project will complete the development and testing of the Sentinel-6B NASA instrument payload and ship it to the ESA spacecraft integrator (Airbus).

SENTINEL-6

Formulation	Development	Operations

KEY ACHIEVEMENTS PLANNED FOR FY 2021

The Sentinel-6 project will complete the launch campaign for the Sentinel-6 Michael Freilich spacecraft, early operations, and begin its commissioning phase. The Sentinel-6 project will support the Storage Review for the Sentinel-6B spacecraft following completion of observatory-level integration and testing at Airbus and the IABG environmental test facility.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2021 PB Request
Key Decision Point (KDP-C)	Apr 2017	Apr 2017
CDR	Oct 2017	Oct 2017
Sentinel-6 Michael Freilich US Payload delivery to ESA	Mar 2020	Mar 2020
Sentinel-6B US Payload delivery to ESA	Oct 2020	Oct 2020
Launch (Sentinel-6 Michael Freilich)	Nov 2021	Nov 2021
Start Phase E (Sentinel-6 Michael Freilich)	Feb 2022	Feb 2022
End Prime Mission (Sentinel-6 Michael Freilich)	Aug 2027	Aug 2027
Launch (Sentinel-6B)	Nov 2026	Nov 2026
Start Phase E (Sentinel-6B)	Feb 2027	Feb 2027
End Prime Mission (Sentinel-6B)	Aug 2032	Aug 2032

SENTINEL-6

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2017	465.9	>70%	2020	460.9	-1%	LRD of Sentinel-6 Michael Freilich	Nov 2021	Nov 2021	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**465.9**	**460.9**	**-5.0**
Aircraft/Spacecraft	0	0	0
Payloads	65.8	87.7	+21.9
Systems I&T	8.8	8.5	-0.3
Launch Vehicle	280.7	280.7	0
Ground Systems	9.7	3.8	-5.9
Science/Technology	4.4	5.1	+0.7
Other Direct Project Costs	96.5	75.1	-21.4

SENTINEL-6

Formulation	Development	Operations

Project Management & Commitments

The Earth Systematic Missions program at Goddard Space Flight Center (GSFC) has program management responsibility for Sentinel-6. NASA assigned project management responsibility to the Jet Propulsion Laboratory (JPL). Sentinel-6 is a partnership with NOAA, the ESA, and the EUMETSAT.

Element	Description	Provider Details	Change from Baseline
AMR-C	Provides high spatial resolution wet tropospheric path delay corrections for the ESA-supplied Ku/C-Band Altimeter	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
GNSS-RO	Supports secondary mission objectives for weather modeling and forecasting	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
LRA	Provides orbit determination	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
Ku/C-Band Altimeter	Measures Jason-heritage ocean surface topography at nadir	Provider: ESA Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS)	Provides orbit determination	Provider: ESA Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Spacecraft Bus	Provides instrument platform	Provider: ESA Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Launch Vehicle	Delivers spacecraft to orbit	Provider: NASA Lead Center: JPL Performing Center(s): Kennedy Space Center (KSC) Cost Share Partner(s): N/A	N/A

SENTINEL-6

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: The AMR-C Supplemental Calibration System (SCS) becomes stuck at some location away from the science position due to an operational failure of the mechanism, Then: The baseline AMR-C measurements will be lost.	The project has followed processes for eliminating foreign object debris in mechanical assemblies, ensured large torque margins, conducted a robust test program, built an engineering model, and performed a full life test. The project is using on-orbit torque/drag monitoring to park the SCS in science position and discontinue routine internal calibrations, if required. The engineering technical authority reviewed and approved these risk mitigations.

Acquisition Strategy

Sentinel-6 leverages Jason heritage by using JPL legacy instrument designs (AMR-C, GNSS-RO, and LRA) and in-house build with a combination of sole source and competitive procurements. NASA selected SpaceX to provide a Falcon 9 launch vehicle through a competitive Launch Service Task Order evaluation under the NASA Launch Services II contract.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
GNSS-RO Electronics	MOOG	Golden, CO
AMR-C Antenna	Northrop Grumman Innovation Systems	San Diego, CA
LRA	ITE	Laurel, MD
Launch Services	SpaceX	Los Angeles, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Strategic Review Board (SRB)	Aug 2016	Mission Concept Review (MCR)/Systems Requirement Review (SRR) Mission Design Review (/MDR)	Successful	Feb 2017
Performance	SRB	Feb 2017	Preliminary Design Review (PDR)	Successful	Oct 2017

SENTINEL-6

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Oct 2017	Critical Design Reviews (CDR)	Successful	Apr 2019
Performance	SRB	Apr 2019	Project System Integration Review (P-SIR)	Successful	Aug 2021
Performance	SRB	Aug 2021	Sentinel-6 Michael Freilich ORR	TBD	Aug 2026
Performance	SRB	Aug 2026	Sentinel-6B ORR	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Earth Systematic Missions (ESM) Research	20.6	--	**24.9**	23.9	27.0	30.5	30.5
Ocean Surface Topography Science Team (OSTST)	5.7	--	**5.8**	5.9	6.0	6.2	6.2
Earth Observations Systems (EOS) Research	14.1	--	**10.7**	10.7	10.7	10.7	10.7
Sage III	5.0	--	**4.6**	4.6	4.7	4.8	4.8
Plankton,Aerosols,Clouds,ocean Ecosystem (PACE)	161.0	131.0	**0.0**	0.0	0.0	0.0	0.0
Radiation Budget Instrument (RBI)	3.5	--	**0.0**	0.0	0.0	0.0	0.0
Sustainable Land Imaging	9.7	--	**19.8**	100.6	100.8	129.2	129.2
Earth from ISS	1.5	--	**1.6**	1.7	0.0	0.0	0.0
Total Solar Irradiance Sensor-2 (TSIS-2)	8.7	--	**30.9**	41.8	13.4	7.3	7.3
Earth Radiation Budget Science	13.6	--	**14.0**	14.3	14.7	15.1	15.1
Ozone Mapping and Profiler Suite (OMPS)	1.7	--	**7.4**	4.9	3.2	2.5	1.5
Total Solar Irradiance Sensor-1 (TSIS-1)	4.0	--	**4.9**	4.7	4.8	4.9	4.9
CLARREO Pathfinder	18.0	--	**0.0**	0.0	0.0	0.0	0.0
Decadal Survey Missions	14.8	--	**38.3**	153.2	247.4	178.8	325.4
Earth Science Program Management	37.9	--	**44.9**	44.5	43.9	44.1	44.4
Precipitation Science Team	6.2	--	**6.4**	6.5	6.6	6.8	6.8
Ocean Winds Science Team	3.0	--	**3.0**	3.1	3.2	3.3	3.3
Land Cover Science Project Office	1.3	--	**1.3**	1.3	1.4	1.4	1.4
Ocean Salinity Science Team	7.3	--	**7.5**	7.6	7.8	8.0	8.0
Soil Moisture Active and Passive (SMAP)	12.4	--	**10.9**	11.1	10.8	11.0	11.0
Quick Scatterometer	0.4	--	**0.0**	0.0	0.0	0.0	0.0
Deep Space Climate Observatory	0.7	--	**1.7**	1.7	1.7	1.7	1.7
Global Precipitation Measurement (GPM)	18.8	--	**20.9**	21.4	21.5	22.1	22.1
Ocean Surface Topography Mission (OSTM)	2.3	--	**2.0**	0.0	0.0	0.0	0.0
Suomi National Polar-Orbiting Partnership (Suomi NPP)	3.5	--	**3.7**	3.8	3.9	4.0	4.0
Terra	24.8	--	**27.9**	28.5	17.2	9.0	9.0
Aqua	28.6	--	**30.3**	31.0	19.8	11.7	11.7
Aura	23.2	--	**22.4**	22.8	12.4	9.0	9.0
SORCE	5.5	--	**0.0**	0.0	0.0	0.0	0.0
Ice, Cloud, and land Elevation Satellite (ICESat-2)	22.2	--	**20.5**	21.5	17.3	17.7	17.7
GRACE Follow-On	1.3	--	**11.6**	11.1	11.2	11.5	11.5
Total Budget	**481.2**	**--**	**377.8**	**582.2**	**611.5**	**551.1**	**697.1**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

OTHER MISSIONS AND DATA ANALYSIS

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Earth Systematic Missions Other Missions and Data Analysis includes operating missions and their science teams and competed research projects. Mission science teams define the scientific requirements for their missions and generate algorithms used to process the data into useful data products. The research projects execute competitively selected investigations related to specific mission measurements.

Also included here are Sustainable Land Imaging activities, as well as smaller missions in formulation and development, such as the Ozone Mapping and Profiler Suite Limb Sounder and Total and Spectral solar Irradiance Sensor-2.

Mission Planning and Other Projects

EARTH SYSTEMATIC MISSIONS (ESM) RESEARCH

ESM Research funds various science teams for the Earth Systematic missions. These science teams are composed of competitively selected individual investigators who analyze data from the missions to address related science questions.

Recent Achievements

Recent studies reconstructed the mass balance of the Greenland Ice Sheet and the Antarctic Ice Sheet using the mass balance method of estimating mass loss from the ice sheets. This method uses thickness, surface elevation, ice velocity, and surface mass balance to calculate how much ice is being lost. Advantages of this method are that it allows partitioning between different processes responsible for mass loss and the ability to extend the estimate further into the past using Landsat images to estimate glacier fluxes. The mass balance of the Greenland Ice Sheet over the 46-year period from 1972 to 2018 found that, since the 1980s, mass loss has increased six-fold as the mass balance began to deviate from its natural range of variability. The study concludes that Greenland has contributed 13.7 mm of sea level rise since 1972 with more than half coming in the last eight years. The mass balance of the Antarctic Ice Sheet over the 40-year period from 1979 to 2017 showed a six-fold increase in the rate of mass loss, contributing 14.0 mm of sea level rise during that time.

The high temporal resolution of satellite surface salinity enabled a better understanding of large-scale intra-seasonal phenomena, such as the Madden-Julian Oscillation (MJO), which is the dominant climate mode at sub-seasonal time scales in the tropics that impacts the global weather and climate. Researchers used SMAP satellite salinity observations to detect the existence of 30- to 90-day period intra-seasonal oscillations in Bay of Bengal associated with MJO and the related impacts on surface density variations, emphasizing the role of upper-ocean dynamics in regulating MJO. The ability to detect such oscillations in salinity data will have direct bearing on our ability to understand and model the air-sea interaction processes, including development and intensification of weather disturbances.

OTHER MISSIONS AND DATA ANALYSIS

Scientists obtained accurate measurements of stratospheric aerosol optical depth from a multi-decade series of SAGE solar occultation instruments. These measurements have been continuous since the 1980's, except for a gap between the end of SAGE II in 2005 and the start of the SAGE III record in 2017. A recent study analyzes CALIPSO observations from 2006 to 2015 to fill in this gap. Scientists constructed a record of aerosol optical depth from the tropopause to the mid-stratosphere and estimated the climate forcing from stratospheric aerosol over the period. They identified volcanic influences on stratospheric aerosol loading, finding a 40 percent increase in stratospheric aerosol forcing during 2006-2015 due to a series of moderate volcanic eruptions. This represents an important observational constraint on radiative forcing of the climate in recent decades.

Small flashes of reflected light—called glint—are found regularly in images taken by spacecraft observing the Earth and occur due to reflected solar radiation. While glint over water surfaces (oceans, but also lakes and rivers) are common, researchers found glint in Earth Polychromatic Imaging Camera (EPIC) images also over land. Using the Deep Space Climate Observatory (DSCOVR) spacecraft, which affords a continuous view of the "Earth at noon" observations, they show glint over land is due to specular reflection off horizontally oriented ice platelets floating in the air, while glint over oceans have contributions from reflection off either platelets floating above the ocean or a relatively smooth ocean surface. This technique of comparing observations of terrestrial glint with model simulations may provide new information not only for Earth sciences but also for planetary sciences (e.g., on atmospheric dynamics and the search for habitable exoplanets). Similarly, the NISTAR instrument on DSCOVR observes seasonal changes in Earth's total outgoing radiation. The radiation energy balance measurement is important because it is the fundamental energy constraint on climate models, and difficult because reflected solar and emitted thermal radiation depend strongly on the viewing geometry. NISTAR's unique viewing geometry for monitoring the Earth's energy budget amounts to observing the Earth as an exoplanet, which opens a new perspective on exoplanet observation.

OCEAN SURFACE TOPOGRAPHY SCIENCE TEAM (OSTST)

Ocean Surface Topography Science Team (OSTST) uses scientific data from the Ocean Surface Topography Mission and Jason radar altimetry satellites, together with data from international altimetry satellites such as the European Space Agency's (ESA) Sentinel-3a, to measure global sea surface height. Data from tide gauges and a handful of calibration stations such as the Harvest oil platform help validate the satellite data.

Recent Achievements

OSTST produced high-precision records of sea surface height, which indicated acceleration in rise of the global mean sea level over the past two decades and suggested the emergence of the human-induced changes in sea level. The science team also used ocean altimetry records to improve our understanding and forecasting of climate events, such as El Nino, and extreme events such as hurricanes and marine heat waves. OSTST produced enhanced coastal tidal models and estimates of general ocean circulation and large-scale transports (e.g., Meridional Overturning circulation), which improve our knowledge of distribution of heat in the climate system.

OTHER MISSIONS AND DATA ANALYSIS

EARTH OBSERVATION SYSTEMS (EOS) RESEARCH

EOS Research funds science for the EOS missions, currently Terra, Aqua, Aura, and ICESat missions. The project competitively selects individual investigators to undertake research projects that analyze data from specific missions. Overall, most selected activities focus on science data analyses; however, some funded activities continue algorithm improvement and validation for the EOS mission instrument data products.

Recent Achievements

A space-qualified Lightning Imaging Sensor (LIS), built as the flight spare for the Tropical Rainfall Measuring Mission (TRMM), is operating on the ISS, extending the 17-year TRMM LIS record of tropical lightning measurements and expanding that coverage to higher latitudes missed by the previous mission. The ISS LIS measurements help calibrate and validate observations from the new Geostationary Lightning Mapper (GLM) sensors that are on NOAA's two newest weather satellites GOES-16 and 17. ISS-LIS also provides two unique contributions: real-time lightning data for operational forecasting and warning applications over data sparse regions (e.g., oceans) and simultaneous and complementary observations with the recently launched European Space Agency's Atmosphere-Space Interaction Monitor (ASIM), which is exploring connections between thunderstorms and lightning with terrestrial gamma-ray flashes (TGFs).

Scientists used tree cover information (from MODIS and Landsat) and topography (from SRTM) to model the distribution and vulnerability of more than 19,000 species of amphibians, mammals, and birds across the globe. These relationships enabled prediction of future extinction risk using a range of land use change scenarios derived from the Shared Socioeconomic Pathways and Representative Concentration Pathways scenarios to the year 2070. Scientists identified substantial declines in suitable habitat for species worldwide, with approximately 1,700 species expected to become imperiled due to land-use change alone.

Researchers developed a first-of-a-kind ASTER Volcanic Thermal Output Database (AVTOD) that used manual analysis to identify and collect data for volcanic thermal output with 90 meter/pixel spatial resolution for 330 potentially active volcanoes found in Latin America between the years 2000–2017. Researchers found that 88 of these volcanoes to have some type of volcanic thermal feature detected by ASTER, including 16 which were detected from space for the first time. This database provides new insights about volcanic activity as well as a data-driven approach to improve key features in future sensors.

Researchers investigated the relative contribution of the Taklamakan and Gobi deserts to dust loadings through long-range transport in an observational study. They used stereo observations of dust sources from MISR combined with observation-initiated trajectory modeling. MISR-derived dust plume top height and dust plume motion vectors confirm the peak of dust activation and transport potential in spring over the Gobi Desert and in both spring and summer over the Taklamakan Desert. Researchers assessed long-range trajectory patterns of Asian dust, including the influence on North America through trans-Pacific transport, using forward trajectories initiated by MISR dust plume observations. The trajectory patterns show substantial seasonal and interannual variability. Trajectory analysis reveals latitude-dependent spread of dust trajectories from the Taklamakan and Gobi deserts, with Taklamakan dust dominant southward of 50ºN and Gobi dust dominant northward of 50ºN in North America.

OTHER MISSIONS AND DATA ANALYSIS

The Korean Peninsula has experienced degradation in air quality both from rapid increases in local emissions and influences from external sources. As part of the Korea–United States Air Quality Study (KORUS-AQ) research, investigators incorporated data from the Aura, GOME-2, MOPITT, and the new AIRS/OMI ozone profile into a chemical data assimilation system to quantify the balance of meteorology and local emissions on Korean air quality. They showed that nitrogen oxides and carbon monoxide emissions were 40 percent and 83 percent higher, respectively, than previous inventories leading to an increased mean ozone concentration. They further showed that mean ozone concentrations were persistently higher over Seoul than the broader KORUS-AQ domain.

NASA scientists compared surface temperature anomalies derived from the Atmospheric Infrared Sounder (AIRS) satellite with the Goddard Institute for Space Studies (GISS) surface temperature anomaly data set over the period 2003 to 2017. The GISS data set is derived from ISS data, so scientists produce the two data sets with completely different methodologies. There is a substantial agreement between the two data sets, providing support to the longer GISS data set and the methodology employed to derive it.

SUSTAINABLE LAND IMAGING

The Sustainable Land Imaging (SLI) program enables the development of a multi-decade, space-borne system that will provide U.S. users with high quality global land-imaging measurements. These measurements will be compatible with the existing 47-year Landsat record and will address near- and long-term issues of continuity risk. They will also evolve flexibly and responsibly through investment and introduction of new sensor and system technologies. Under the SLI framework, NASA will maintain responsibility for developing, launching, and initial checkout of space systems. The United States Geological Survey (USGS) will be responsible for collecting and documenting user needs, developing the associated ground systems, operating the on-orbit spacecraft, and collecting, calibrating, archiving, processing, and distributing SLI system data to users.

Through the implementation of SLI technology activities, NASA will enable new SLI measurement technologies, capabilities, and architectures. The Sustainable Land Imaging-Technology (SLI-T) program aims to: (1) demonstrate improved, innovative, full-instrument concepts for potential infusion into the architecture and design of the next generation of Landsat missions; and (2) develop technologies at the component and/or breadboard-level that have long-term potential to improve future land imaging instruments and systems significantly through substantial architecture changes. NASA will solicit instrument and subsystem development activities, coordinated with the Landsat science community.

In order to minimize the risk of gaps while taking advantage of cost savings and capability enhancements resulting from the technology development activity outlined above, the Administration will make key strategic decisions on the next generation of Landsat observing system approaches as part of the FY 2022 budget process.

Additional SLI activities support efforts to minimize costs and maximize the overall utility for U.S. users by responsibly engaging with international partners to ensure access to high-quality data and fusion of those measurements with those from the U.S. Landsat missions. In particular, NASA and USGS conducted pre-launch cross-calibration investigations with the European developers of the Sentinel-2A/B land imaging system, ensuring uniform calibration of both Landsat 8 and Sentinel-2A/B instruments to the same standards. The USGS, supported by NASA and other agencies, is serving as the primary U.S.

Government point of contact to ensure access to and archiving of Sentinel-2 data products for U.S. research and operational users.

Recent Achievements

In FY 2019 work continued on the second Sustainable Land Imaging Architecture Study Team (AST 2019). The study will inform the design and implementation approach for the next phase of a sustainable and evolvable space-borne system to provide global, continuous Landsat-quality multispectral and thermal infrared measurements. The team produced a SLI Request for Information and completed an assessment of industry capabilities. The AST also engaged in international partnership discussions with multiple international entities. The AST completed two progress reviews and plans to deliver its findings to NASA and USGS leadership in FY 2020.

The six ongoing investigations under the SLI-T element continue to make progress. Two of the three Advanced Technology Demonstration (ATD) instruments have completed engineering aircraft flight demonstrations and will complete science aircraft flight demonstrations in early FY 2020. The third concept will be undergoing fixes to the image quality and lab demonstrations in early FY 2020.

All three of the SLI-T Technology Investments (TI) technology activities continue to mature cutting edge technologies with the potential to significantly improve future land imaging instruments and systems through substantial architecture changes. In FY 2020, NASA will release a new SLI-T solicitation covering both ATD and TI elements.

TOTAL SOLAR IRRADIANCE SENSOR-2 (TSIS-2)

The TSIS-2 instrument will maintain and extend the 40-year measurement record of total solar irradiance and spectral solar irradiance beyond 2023 provided by TSIS-1 and earlier missions. Researchers have used the solar irradiance data to understand how the solar energy affects the Earth system over an 11-year cycle and longer time scale. NASA is planning to implement TSIS-2 by leveraging the available spare parts from the TSIS-1 mission to the greatest degree possible. NASA will implement TSIS-2 as a Class D payload and as a free flyer. The mission will operate for no less than three years. Formulation began in FY 2019.

Recent Achievements

The TSIS-2 project officially began formulation in 2019. The project awarded a contract to the University of Colorado’s Laboratory for Atmospheric and Space Physics (LASP) in Boulder to build the two instruments, which are based on the TSIS-1 design. The contract takes advantage of existing parts and expertise at LASP from the development of the TSIS-1 instruments. The project also performed two separate market research efforts to determine interest and capability in US industry to provide (1) a Class D spacecraft and (2) a launch vehicle, with positive responses in both categories. In CY 2020, TSIS-2 will award contractors for the spacecraft and the launch vehicle.

EARTH RADIATION BUDGET SCIENCE

The Earth Radiation Budget Science (ERBS) project produces climate data records of Earth’s radiation budget and the associated cloud, aerosol, and surface properties. The project utilizes data from the multiple radiation budget instruments in orbit and ancillary measurements to produce integrated, selfconsistent data products over the entire suite of radiation budget instruments. The data products utilize coincident imager measurements and Clouds and the Earth's Radiant Energy System (CERES) instrument broadband radiative fluxes from Terra, Aqua, Suomi NPP, NOAA-20 and operational geostationary satellite observations. In total, scientists have used 30 instruments on 24 spacecraft thus far to produce an accurate and temporally consistent description of the radiation budget, not only at the top of the atmosphere but also at the surface and within the atmosphere. The ERBS project is the only project worldwide whose prime objective is to produce global, climate-quality ERB data from dedicated ERB satellite instruments.

Recent Achievements

In 2019, the scientific community used CERES data products in many areas of research, including Earth's energy imbalance, climate feedback, aerosol radiative forcing, atmospheric and oceanic energy transports, polar climate, and climate model evaluation. Scientists have also used CERES global flux data products to support monitoring of solar panel operations and crop modeling. The ERBS team generated data products from all six CERES instruments currently flying on four satellites. They performed inter-comparison campaigns between Terra, Aqua, Suomi-NPP, NOAA-20, and additional campaigns with the Geostationary Earth Radiation Budget instruments. After careful operational planning, the ERBS team placed the CERES instrument on Suomi-NPP in a rotating azimuth plane mode to enable the generation of new empirical angular distribution models for improved accuracy in determining radiative fluxes from measured radiances. The ERBS team also began a re-design of the CERES webpage to provide improved communication of mission science results to the public and ensure that the site is multi-platform compatible and adheres to rigid IT security guidelines.

OZONE MAPPING AND PROFILER SUITE LIMB SOUNDER (OMPS-L)

The advanced Ozone Mapping and Profiler Suite (OMPS) tracks the health of the ozone layer and measures the concentration of ozone in the Earth's atmosphere. OMPS is a three-part instrument: a nadir mapper that will map global ozone with about 50-km ground-resolution, a nadir profiler that will measure the vertical distribution of ozone in the stratosphere, and a limb profiler that will measure ozone in the lower stratosphere and troposphere with high vertical resolution. The entire OMPS suite currently operates on the Suomi NPP spacecraft. To ensure data continuity, a copy of this suite will fly on NOAA's Joint Polar Satellite System-2 (JPSS-2) mission, planned for launch in FY 2023. NASA is responsible for providing the OMPS-Limb profiler for integration on the OMPS instrument. The project budget also supports OMPS-Limb profilers for JPSS-3 and JPSS-4.

Recent Achievements

In FY 2019, NASA completed the development of the OMPS-Limb instrument for the JPSS-2 mission and successfully conducted the Pre-Ship Review. NASA finished assembly and functional testing of the JPSS-3 Limb instrument and will begin environmental testing in FY 2020.

DECADAL SURVEY MISSIONS

In January 2018, the National Academies released a new Earth Science Decadal Survey, entitled "Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space." This Decadal survey recommended completing missions that were already in formulation and development and additional observation capabilities including the following "designated observable" (DO) scientific areas:

OTHER MISSIONS AND DATA ANALYSIS

Aerosols; Clouds, Convection, and Precipitation; Mass Change; Surface Biology and Geology; and Surface Deformation and Change.

NASA has initiated studies that are expected to result in missions/observing systems to address the DO priorities. These missions/observing systems will be cost-constrained projects. The first mission resulting from the DO studies will begin formulation activities no earlier than FY 2021.

Recent Achievements

In FY 2019, NASA initiated four multi-year pre-formulation studies to address each of the DO priorities identified in the Decadal Survey, implemented by a team of NASA Centers. Each of these study teams presented a progress report to Earth Science Division management in September 2019 and NASA approved them to continue pre-formulation studies in FY 2020.

EARTH SCIENCE PROGRAM MANAGEMENT

The Earth Science Program Management budget supports critical flight project management functions executed by the ESM program offices at NASA Goddard Space Flight Center (GSFC) and the Jet Propulsion Laboratory (JPL), and the Earth System Science Pathfinder Program Office at NASA Langley Research Center (LaRC).This budget supports:

- The GSFC conjunction assessment risk analysis function, which determines maneuvers required to avoid potential collisions between spacecraft and to avoid debris;
- The technical and management support for the international Committee on Earth Observation Satellites, which coordinates civil space-borne observations of Earth. Participating agencies strive to enhance international coordination and data exchange and to optimize societal benefit;
- Senior Review Board teams, who conduct independent reviews of the various flight projects in Earth Science; and
- Earth Science division communications and public engagement activities.

PRECIPITATION SCIENCE TEAM

The Precipitation Science Team carries out investigations of precipitation using measurements from, but not limited to, the Tropical Rainfall Measuring Mission (TRMM) mission, which ended in 2015, the Global Precipitation Measurement (GPM) mission, which launched in February 2014, and GPM mission constellation partner spacecraft. GPM mission constellation partners include NOAA, Department of Defense, Centre National d'Études Spatiales (CNES), Japan Aerospace Exploration Agency (JAXA), and Exploitation of Meteorological Satellites (EUMETSAT). This program supports scientific investigations in three research categories:

- Development, evaluation, and validation of TRMM and GPM retrieval algorithms;
- Development of methodologies for improved application of satellite measurements; and
- Use of satellite and ground measurements for physical process studies to gain a better understanding of the global water cycle, climate, and weather and concomitant improvements in numerical models on cloud resolving to climate scales.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

Precipitation science team members actively used GPM Ground validation (GV) data and instruments in a wide range of precipitation studies related to validating space-borne rainfall and snowfall retrievals. Team members continued to use airborne and ground observations from GPM field campaigns to develop advanced algorithms for retrieving cloud microphysical properties of precipitation system for cold-season rain and snow over steep mountains and warm season convective storms. Scientists developed techniques to detect intense convection and hailstorms using data from GPM's microwave imager (GMI). Team members provided a comprehensive evaluation of the 2013 Iowa Floods Study (IFloodS) radar-based rainfall products for hydrologic model testing. They used GV-team-developed calibration adjustments and data from both TRMM and GPM to calibrate nearly 20 years of Australian radar data and incorporated current data into the GPM Validation Network architecture as a tropical maritime site for GPM validation. In early FY 2019, NASA completed the competitive selection process for 40 Principal Investigators to be three-year members of the Precipitation Measurement Missions Science Team.

OCEAN WINDS SCIENCE TEAM

The Ocean Winds Science Team uses scientific data received from the QuikSCAT satellite, RapidScat instrument, and other international missions, which measure ocean surface winds by sensing ripples caused by winds at the ocean's surface. From this data, scientists can compute wind speed and direction thus acquiring global observations of surface wind velocity each day. Wind data from ships and buoys serve to calibrate the satellite data.

Recent Achievements

Satellite scatterometer data enabled discoveries of new mechanisms of air-sea interaction, improved forecasting of tropical hurricanes and cyclones, and allowed NASA to monitor ongoing changes of the Earth's systems, including sea ice, land and snow cover, urban extent, carbon biomass, and ocean productivity. The science team is exploring a conceptually novel approach to measure winds from space, involving concurrent observation of ocean winds and currents in support of a potential future air-sea interaction mission recommended by the National Academies of Sciences.

LAND COVER PROJECT SCIENCE OFFICE

The Land Cover Project Science Office (LCPSO) maintains over 40 years of calibration records for the Landsat 1 through Landsat 8 series of satellites. The office also provides community software tools to make it easier for users to work with this data. In collaboration with USGS, LCPSO supports cross-calibration of the Landsat record with other international sensors, provision of preprocessed data sets for land-cover change analysis, and facilitates use of international data sets for improved land cover monitoring.

Recent Achievements

The LCPSO began migration of the Harmonized Landsat/Sentinel-2 (HLS) Product to global, operational capability. The HLS product merges surface reflectance observations from the US Landsat and European Sentinel-2 satellites to generate an improved data record of land and coastal change. The HLS project is working with NASA Earth Science Data Systems, Marshall Space Flight Center, and USGS to generate a global processing system for HLS data, leveraging commercial cloud capabilities. The office expects the rollout of the forward processing capability in early 2020. LCPSO also continued to support analysis of land surface temperature (LST) retrieval algorithms for Landsat 8 and the upcoming Landsat 9 mission, resulting in the USGS plan to deploy a single-channel LST algorithm for Landsat 9, followed by a split-window (two-channel) approach sometime after launch.

OCEAN SALINITY SCIENCE TEAM

The Ocean Salinity Science Team (OSST) supports the development and construction of surface salinity products from L-Band microwave radiometers such as Aquarius, SMAP, and data sets of opportunity such as ESA's Soil Moisture and Ocean Salinity (SMOS) mission. The team also seeks to understand upper-ocean processes that impact variability of surface salinity in order to improve interpretation of the space-based salinity products. The team is working on a SMAP salinity product that is consistent with the Aquarius salinity product, which ended in June 2015.

Recent Achievements

OSST produced global maps of ocean salinity with unprecedented coverage, accuracy, and resolution. New salinity maps improve the ability to study large-scale ocean processes, predict various climate phenomena (e.g., El Nino), and gain insights into the recent amplification of Earth's hydrological cycle. Recent studies also demonstrate the utility of satellite salinity as a new resource to monitor hurricanes and the ocean's response to tropical storms.

Operating Missions

ICE, CLOUD, AND LAND ELEVATION SATELLITE (ICESAT-2)

The ICESat-2 mission measures global elevation to provide an important multi-year record needed to determine sea ice thickness and ice sheet mass change. It also provides topography and vegetation data around the globe. These additional data products support estimates of biomass and carbon in aboveground vegetation in conjunction with related missions, measurements of ocean topography, inland water body elevation such as lakes and rivers, and cloud properties. The ICESat-2 observatory is comprised of one instrument, the Advanced Topographic Laser Altimeter System (ATLAS), which measures the round-trip time of laser light from the observatory to Earth and back as the basis for the mission's elevation measurements.

Recent Achievements

The ICESat-2 observatory and ATLAS instrument continue to operate nominally and have provided more than a trillion new elevation measurements since data collection began on October 14, 2018. NASA made ICESat-2 data available to the public on May 28, 2019 via the National Snow and Ice Data Center. To date, over 1,800 data users have downloaded over 1.1 million data files. The initial science results from ICESat-2 have demonstrated that the elevation data is accurate to less than 3 centimeters vertically, the location of each measurement on the surface of the earth is known to less than 10 meters horizontally, and that measurements from ICESat-2 are of comparable quality as measurements from low-flying aircraft. The data show the ongoing ice loss from the Greenland and Antarctic ice sheets, and that the ice shelves of Antarctica may be losing more ice than previously thought.

GRACE FOLLOW-ON

The Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) mission provides continuity of month-to-month mass change observations and high-resolution global models of Earth’s gravity field, as in the original GRACE mission (launched in 2002). The GRACE-FO mission allows scientists to gain new insights into the dynamic processes of Earth’s water cycle, including variations in water storage over land, the mass of glaciers and ice sheets, and sea level and ocean currents. GRACE-FO also maps large earthquakes and tectonic processes. Data from the mission, in combination with other existing sources of data, greatly improves scientific understanding of how Earth’s water cycle evolves. GRACE-FO data is vital to ensuring there is a minimal gap in mass change measurements following the decommissioning of the original GRACE mission. GRACE-FO is a partnership with the German Research Centre for Geosciences (GFZ).

Recent Achievements

NASA successfully launched the two GRACE-FO satellites on May 22, 2018. The mission transitioned into its operational science phase on January 28, 2019. The mission has delivered 14 complete monthly global mass change datasets as of the end of October 2019 and is currently meeting all mission science requirements. Accuracy of these global measurements is at a level consistent with the original GRACE mission and achieves vital continuity for stable long-term data analysis. GRACE-FO is now enabling scientists and resource managers worldwide to accurately and efficiently monitor changes in our Earth's ice sheets and glaciers, underground water storage, and crustal deformation due to major earthquakes. In addition, scientists will utilize data to track sea-level change and aid in the management of drought and water resources in the United States. The Laser Ranging Interferometer has also performed exceptionally well, reaching a precision factor 30 times better than the performance goal. This groundbreaking technology demonstration will serve as a foundational milestone for future gravity missions.

SOIL MOISTURE ACTIVE AND PASSIVE (SMAP)

The SMAP mission, launched in January 2015, provides a capability for global mapping of soil moisture with unprecedented accuracy, resolution, and coverage. The SMAP measurement system consists of a radiometer (passive) instrument and a synthetic aperture radar (active) instrument operating with multiple polarizations in the L-band range. Although the active radar instrument failed in July 2015, the radiometer is operating nominally, and continues to provide global mapping of soil moisture with accuracy, resolution, and coverage that exceeds the capability of other on-orbit systems. The SMAP project team has developed a blended data product that combines SMAP radiometer measurements with the European Copernicus Program’s Sentinel-1 active radar measurements. This operational product provides soil moisture information with higher spatial resolution whenever the two systems have coincident measurements.

SMAP’s prime mission ended in June 2018. The 2017 Earth Science senior review endorsed the SMAP mission for continued operations through 2020, and preliminarily, through 2023.

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Recent Achievements

SMAP science data products provide information on the status of surface soil moisture and vegetation water content conditions, allowing global monitoring every 1.5 days. The information is available to the science and applications communities. To-date, researchers have published over 800 studies in peer-reviewed journals in a range of disciplines such as hydrology and water resources, ecology and agronomy, and other Earth system science disciplines. These studies have advanced the understanding of how water storage at the land surface affects regional climate and vegetation and crop conditions. Several national agencies continue their evaluation of SMAP data, including the multi-agency National Drought Mitigation Center at the University of Nebraska-Lincoln. There, scientists use SMAP time series data across the U.S. for surface soil moisture and changes in these data (in addition to data from other sources) to issue the weekly U.S. Drought Monitor, which serves as the basis for drought disaster declarations and for determining low-interest loans or tax-deferral eligibility. SMAP has consistently produced soil moisture products with low latency to enable usage by the U.S. Air Force's 557th Weather Wing, which provides services to several defense-related applications. SMAP soil moisture data products are also an effective predictor of how much precipitation becomes storm streamflow. Forecasting streamflow conditions is important for minimizing loss of life and property during flooding, as well as adequately planning for low streamflow conditions accompanying drought. The U.S. Department of Agriculture (USDA) National Agriculture Statistics Service and the Foreign Agricultural Service also use the SMAP data for operational assessments.

GLOBAL PRECIPITATION MEASUREMENT (GPM)

The GPM mission, launched in February 2014, advances the measurement of global precipitation through the combined use of active and passive remote-sensing techniques. Tracking storms as they move within the tropics and higher latitudes, GPM provides a three-dimensional view of their structural and microphysical properties and provides estimates of storm rainfall accumulations for major storm events. The GPM Microwave Imager measures energy from different types of precipitation within clouds to estimate heavy to light rain and to detect falling snow. The Dual-frequency Precipitation Radar provides three-dimensional information about precipitation particles, including their size distributions and associated rainfall rates, derived from reflected energy at two radar wavelengths at different heights within the cloud system. GPM is a joint mission with the Japan space agency, JAXA.

GPM completed its prime mission in June 2017 and is now in extended operations. The 2017 Earth Science senior review endorsed the GPM mission for continued operations through 2020, and preliminarily, through 2023.

Recent Achievements

In 2019, GPM improved, validated, and transitioned to production its merged multi-satellite rainfall product called IMERG, GPM's most downloaded product. This will enable the generation of a consistent 20-year global rainfall dataset spanning the TRMM (2000-2015) and GPM (2014-present) missions. The GPM ground-validation group expanded IMERG validation efforts with a focus placed on evaluation of extreme events, including several recent U.S. hurricanes (e.g., Harvey, Florence). Scientists have made significant efforts in recent years to improve measurement of surface snowfall using NASA and NOAA/National Weather Service data in Michigan. They have incorporated these data and techniques into the GPM validation system for continental-scale use. GPM continued to leverage field measurements efficiently in collaboration with scientists in Finland and Canada to provide new ground-validation

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"benchmark" radar-based snowfall datasets for direct validation of satellite products. GPM continued to cultivate collaborations and partnerships with government and non-government organizations, and private groups, to facilitate crosscutting applications of the data within their environments in areas such as ecology, water and agriculture, energy, health, and disasters.

OCEAN SURFACE TOPOGRAPHY MISSION (OSTM)

OSTM (also known as Jason-2), launched in June 2008, measured sea surface height, and enabled scientists to track changes in ocean currents, assess climate variability, and make improved maps of the sea floor. This mission was the third in a series of four ocean surface topography missions (Jason-1, TOPEX/Poseidon, OSTM, and Jason-3). After the launch of Jason-3, OSTM moved into a new orbit configuration with very closely spaced ground tracks that scientists used to better understand gravity over the ocean, and make improved maps of the sea floor. OSTM was a joint mission with NOAA, CNES, and EUMETSAT.

Recent Achievements

Because of space radiation-induced anomalies to electrical components onboard the spacecraft, NASA decommissioned the OSTM mission in late 2019, exceeding its prime mission by eight years. Mission closeout is now underway, with reanalysis of the improvements to measurement of water depth and mean sea surface models. NASA will now reprocess all mission data to the state-of-the-art geophysical standards and will archive it for future use. The results from OSTM will be of great scientific benefit to the upcoming Surface Water and Ocean Topography mission, scheduled for launch in 2022.

SUOMI NATIONAL POLAR-ORBITING PARTNERSHIP (SUOMI NPP)

The Suomi NPP mission, launched in October 2011, is a partnership between NASA and NOAA. The five instruments on Suomi NPP provide visible and infrared multi-spectral global imagery, atmospheric temperature and moisture profiles, total ozone and stratospheric ozone profiles, and measurements of Earth's radiation balance. In addition to a wide range of applications studies, the NASA science focus areas served by Suomi NPP include atmospheric composition, climate variability and change, carbon cycle, ecosystems, water and energy cycles, and weather. Several primary Suomi-NPP products have demonstrated their capabilities to provide critical continuity and near-real-time data, extending the EOS observation long time-series in monitoring changes in land, ocean, and atmosphere as well as Earth's radiation budget. NASA built and launched Suomi NPP. NOAA operates the spacecraft and instruments. NASA and NOAA continue to collaborate to ensure meeting the shared objectives of both agencies.

Suomi NPP is currently in extended operations.

Recent Achievements

In 2019, researchers using the Visible Infrared Imaging Radiometer Suite (VIIRS) ocean color data unveiled the most comprehensive view of the distribution of a zooplankton species to date and altered our understanding of the behavior of this key zooplankton species. Ozone Mapping and Profiler Suite (OMPS) total ozone data indicate that the 2019 ozone hole is the smallest on record since its discovery in 1982, thanks to the unusual warmer temperatures during the 2019 Antarctic spring. OMPS Limb Profiler data have further revealed details of the development of the Antarctic ozone hole in 3D. By adding the VIIRS observations, the NASA land products have now built a more than 50-year time-series about land

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surface vegetation resources and monitoring with implications on carbon storage, biodiversity, coastal zone impacts, and progress in cropland monitoring, which can provide early and local insights on crop yield and is critical for farmers, government agencies, and the financial markets. In addition, scientists used VIIRS data extensively to provide timely information during disaster events such as the Alaska and California wildfires in 2019.

TERRA

Terra, launched in December 1999, is one of the Earth Observing System (EOS) flagship missions. It enables a wide range of interdisciplinary studies of atmospheric composition, carbon cycle, ecosystems, biogeochemistry, climate variability and change, water and energy cycles, and weather. The Terra mission has provided more than 19 years of continuous data collection, including fundamental observations of the Earth's climate system, high-impact events, and adding value to other satellite missions and field campaigns. The spacecraft platform and five sensors are all fully functional, with the exception of the shortwave infrared bands in the Advanced Space-borne Thermal Emission and Reflection Radiometer instrument. Terra is a joint mission with Japan and Canada.

Terra is currently in extended operations. The 2017 Earth Science senior review endorsed the Terra mission for continued operations through 2020, and preliminarily, through 2023.

Recent Achievements

The Terra mission provides a unique, cost-efficient, and long-term climate and environmental record not available from any other satellite platform. Recent work by the mission improved the spatial sampling and quality of Terra's data products. The products were also made easier to use and more widely available in response to feedback from the scientific community. As an example, a new global topography map had more than one million downloads within the first four weeks of its August 2019 delivery, highlighting both the accessibility and demand for the product. Multiple Federal agencies used Terra's land and atmosphere products for volcanic ash monitoring, weather forecasting, forest fire monitoring, carbon management, and global crop assessment. Fire monitoring is an excellent example of the community making use of all of Terra's five instruments to investigate fire location and intensity, burn areas and revegetation, and injection and transport of aerosols and carbon monoxide in the atmosphere. The mission's long-term record shows a greening of global lands, especially in China and India. Decreases in the concentration of atmospheric pollutants such as hazes and dust are seen in the US and Europe while parts of Asia and the Middle East have increasing concentrations, reflecting the impacts of transportation, industrial and agricultural activity, climate change, and pollution controls. Terra products also provided the data record needed to evaluate the impact of variations in Arctic sea ice and ocean heat transport leading to improved climate model accuracy. The Terra Team received the prestigious 2019 William T. Pecora Group Award for the mission's outstanding contributions toward understanding the Earth through remote sensing.

AQUA

Aqua, launched in May 2002, is one of the EOS flagship missions. Aqua improves our understanding of Earth's water cycle and the intricacies of the climate system by monitoring atmospheric, land, ocean, and ice variables. It was the first satellite launched into what has become the afternoon constellation of satellites, known as the A-Train, and remains the anchor satellite of that constellation. Four of Aqua's

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Earth observing instruments – the Atmospheric Infrared Sounder (AIRS), the Advanced Microwave Sounding Unit, Clouds and the Earth's Radiant Energy System (CERES), and the Moderate Resolution Imaging Spectroradiometer (MODIS) – continue to collect valuable data about the Earth's atmosphere, oceans, land, ice, and overall energy budget. These data are widely used by the science community, and in practical applications ranging from improved weather forecasting to monitoring forest fires, crop yields, volcanic ash plumes, and ice-infested waters. Aqua is a joint mission with Japan and Brazil.

Aqua is currently in extended operations. The 2017 Earth Science senior review endorsed the Aqua mission for continued operations through 2020, and preliminarily, through 2023.

Recent Achievements

The Aqua data are readily available to users worldwide and researchers used the data in thousands of scientific publications and in numerous practical applications. The remarkably stable AIRS measurements depict in a unique manner the evolution of the Earth's climate during the 21st century. They confirm the Earth's temperature evolution previously measured from ground-based instruments – including amplified warming in the Arctic region – doing so with the far greater spatial completeness allowed by the satellite perspective. Scientists have further used the AIRS data to discover new trends in cloud properties that may have a profound significance given the critical importance of the feedbacks between clouds and the Earth's climate system. Scientists have used CERES data products in research on Earth's energy imbalance, climate feedback, aerosol radiative forcing, atmospheric and oceanic energy transports, polar climate, and climate model evaluation. Research using CERES data has shown, for instance, that a complete disappearance of Arctic sea ice would contribute an additional heating (relative to a 1979 baseline) equal to the effect of one trillion tons of carbon dioxide emissions. The MODIS data have shown an increase in foliage around the planet over the last two decades that includes greening in the U.S., Mexico, and especially India and eastern China, in part due to extensive tree-planting programs. Among the many practical applications of the Aqua data are extensive use of AIRS data in weather forecasting, use of CERES data in monitoring of solar panel operations and crop modeling, and use of MODIS data in wildfire monitoring, including monitoring the highly destructive Camp Fire in California in November 2018 and major fires in Brazil in August 2019 and in Australia in September 2019.

AURA

Aura, launched in July 2004, is one of the EOS flagship missions. Aura advances the understanding of changes in the Earth's radiation balance, air quality, and the ozone layer that result from changes in atmospheric composition, climate variability, and weather by measuring atmospheric chemical composition, tropospheric/stratospheric exchange of energy and chemicals, chemistry-climate interactions, and air quality. Aura is also part of the A-Train. Two of Aura's four instruments are operational: the Microwave Limb Sounder and the Ozone Monitoring Instrument. Additional measurements include clouds, aerosols, solar spectral irradiance, and water vapor. Aura is a joint mission with the Netherlands, Finland, and the United Kingdom.

Aura is currently in extended operations. The 2017 Earth Science senior review endorsed the Aura mission for continued operations through 2020, and preliminarily, through 2023. The senior review also recommended the termination of operations for the Tropospheric Emission Spectrometer (TES) on Aura and in response, NASA decommissioned TES in January 2018.

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Recent Achievements

Aura observations continue to be used in a wide range of peer-reviewed scientific studies of processes affecting ozone layer stability, including those both comparing observations to predictions from state-of-the-art models, and studies assimilating Aura observations into models to further improve their predictive skill for a range of atmospheric phenomena. Aura observations have also provided new insights into processes controlling stratospheric humidity, an important climate variable. The annual number of human health studies that use Aura data continues to increase in 2019. Researchers are taking advantage of the long 15-year record and spatial coverage afforded by Aura data to strengthen inference of the relation between health outcomes and both pollutants and ultraviolet (UV) exposure. Scientists use Aura data for a variety of air quality applications. Scientists identified a new air quality application for Aura data in 2019, which uses the data to infer carbon dioxide emissions from cities and power plants around the world using data of co-emitted nitrogen dioxide. The International Ozone Monitoring Instrument Team received the prestigious 2018 USGS-NASA Pecora Award for "sustained team innovation and international collaboration to produce daily global satellite data that revolutionized air quality, stratospheric chemistry, and climate research."

STRATOSPHERIC AEROSOL AND GAS EXPERIMENT III (SAGE-III)

Stratospheric Aerosol and Gas Experiment III (SAGE-III), launched in February 2017, operates on the ISS, and provides global, long-term measurements of key components of Earth's atmosphere. The most important of these are the vertical distribution of aerosols and ozone from the upper troposphere through the stratosphere. In addition, SAGE-III provides unique measurements of temperature in the stratosphere and mesosphere and profiles of trace gases, such as water vapor and nitrogen dioxide, which play significant roles in atmospheric radiative and chemical processes. These measurements are vital inputs to the global scientific community for improved understanding of climate and human-induced ozone trends.

Recent Achievements

In its third operational year, the SAGE-III mission continues to demonstrate improvements in operational efficiency for payload commanding and science data collection. The SAGE-III instrument has observed the global impact of stratospheric aerosol loading from volcanic eruptions in the topics and Raikoke Island in 2019 and wildfires in both central Siberia in July/August 2019 and the northwestern regions of North America. The competitively selected SAGE-III/ISS Science Team held its second meeting in October 2019, and the mission continues to communicate with the international science community on the variations of stratospheric aerosol and ozone captured in the SAGE-III data products freely released to the public on a monthly schedule.

EARTH FROM ISS

NASA's ISS program sponsored the development of several earth science instruments for the ISS. The Earth from ISS project will ensure the appropriate processing of data and its availability to the earth science research community from the data collected by these instruments. This project will invest in algorithm development, data production and distribution, as well as data analysis and modeling for the currently planned ISS earth science payloads.

The ISS Lightning Imaging Sensor (LIS) makes space-based global lightning observations, using the backup flight spare for the instrument that operated for 17 years on the Tropical Rainfall Measuring

Mission. LIS provides a great opportunity to not only extend the TRMM record of tropical lightning measurements, but also to expand coverage to the higher latitudes missed by the previous mission. LIS observations continue to support, and are used by, the global scientific research community, across a wide range of disciplines that include weather and extreme storms, climate studies, atmospheric chemistry, and lightning physics. Researchers use LIS to help calibrate and validate the observations from the new Geostationary Lightning Mapper operating on NOAA's newest geostationary weather satellite, GOES-16.

Recent Achievements

The LIS successfully completed its two-year prime mission in 2019. The public release of validated data to the broader science community in the summer of 2019 represented an important milestone as the mission continues to support high-value science and applications activities. Another notable achievement has been comparing LIS observations with those of the Geostationary Lightning Mapper (GLM) operating on NOAA's newest weather satellites, the Geostationary Operational Environmental Satellite-16/17 (GOES-16/17), to help cross-validate both systems.

TOTAL SOLAR IRRADIANCE SENSOR-1 (TSIS-1)

The TSIS-1 mission provides absolute measurements of TSI and SSI, important for accurate scientific models of climate change and solar variability. TSIS-1 is comprised of two instruments, the Total Irradiance Monitor (TIM), and the Spectral Irradiance Monitor, which are the most accurate solar irradiance instruments in the world, allowing scientists to better understand solar variability at both short and long time scales. The Laboratory for Atmospheric and Space Physics built a highly sensitive thermal pointing system that the project uses to accommodate the instruments on the ISS.

Recent Achievements

The TSIS-1instrument tracked daily Total Solar Irradiance (TSI) variations consistently to within 0.004 percent and extended the TSI record to 40 years. New SSI data from TSIS-1 are the most accurate solar spectrum in the 200-2400 nanometer wavelength bands that help scientists evaluate the solar spectrum used in climate modeling. This solar spectral band accounts for 97 percent of solar energy input to the Earth system. Measuring the incoming solar energy at different spectral wavelengths provides critical elements for understanding how that energy is absorbed by the Earth's atmosphere and surface. The solar spectra measured during 2018-2019 established a new reference that allows cross-calibration with other satellite sensors for global climate and environmental studies. NASA has made the TSIS-1 SSI data available to Global Space-based Inter-Calibration System (GSICS) as an international collaborative effort under the World Meteorological Organization (WMO) and the Coordination Group for Meteorological Satellites (CGMS).

DEEP SPACE CLIMATE OBSERVATORY (DSCOVR)

DSCOVR, launched in February 2015, is a multi-agency (NOAA, United States Air Force, and NASA) mission with the primary goal of making unique space weather measurements from the Lagrange point L1. Lagrange point L1 is on the direct line between Earth and the Sun and provides about a 45-minute early warning for adverse space weather events. NASA provided the two Earth-observing instruments, the Earth Poly-Chromatic Imaging Camera (EPIC) and the National Institute of Standards and Technology Advanced Radiometer (NISTAR), to the DSCOVR satellite. NASA-processed EPIC and NISTAR data has been publicly available since June 2015 and includes: color images of the full sunlit disk of the Earth;

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maps of ozone, clouds, aerosols, and vegetation; and measurements of sulfur dioxide from volcanic eruptions.

The DSCOVR NASA provided instruments completed their prime mission in 2018 and are currently in extended operations. The 2017 Earth Science senior review endorsed the DSCOVR mission for continued operations through 2020. On June 27, 2019, NOAA placed DSCOVR in a long-term Safe Hold Mode due to the degradation of one of the inertial navigation system gyros. Regular operations are expected to resume in early 2020 once a new flight software is uploaded that relies on the DSCOVR star tracker and Sun sensors alone.

Recent Achievements

In 2019, the EPIC and NISTAR data production team successfully processed new and improved versions of EPIC and the latest NISTAR data. The main improvements in the EPIC data are: (1) improved geolocation of each image, which greatly reduces the noise inherent in combining multiple images; (2) use of extended in-orbit calibrations for both UV and visible channels; and (3) extended dark current corrections. Improved ozone, reflectivity, erythemal irradiance, sulfur dioxide, and aerosol data are now available publicly from the UV channels. Standard products include EPIC vegetation data and the daily variation of solar illuminated green leaf area, a key measure of photosynthesis. The unique backscattering observation geometry of EPIC allowed the revisiting of models of surface reflection near the hot-spot direction; such models are very important for monitoring vegetation, especially in the tropics. The near-real-time true color images of the Earth generated by EPIC remained highly popular with the public, especially during major storms.

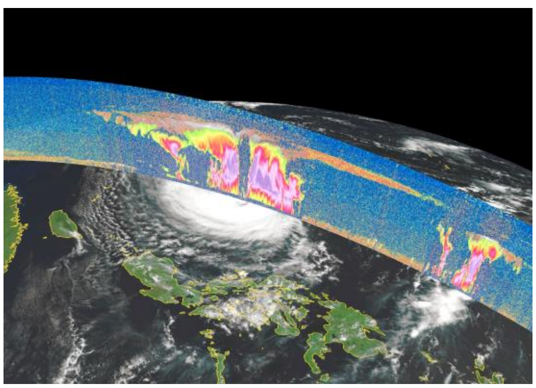
EARTH SYSTEM SCIENCE PATHFINDER

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Venture Class Missions	163.5	--	**263.6**	230.8	183.6	176.9	169.4
Other Missions and Data Analysis	60.2	--	**75.3**	70.4	68.0	64.9	64.9
Total Budget	**223.8**	**--**	**338.9**	**301.2**	**251.6**	**241.8**	**234.4**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.



CloudSat and CALIPSO show the detailed inner structure of Typhoon Yutu on October 28, 2018 as it heads towards the Philippines. Yutu was a Category 5 super typhoon that caused over $800 million dollars of damage and dozens of deaths. The CloudSat radar (bright purple and red) penetrates the intense inner eyewall at the heart of the storm while the CALIPSO lidar (dull red and yellow) show the large-scale cirrus clouds flowing out of the storm.

The Earth Science System Pathfinder (ESSP) program provides frequent, regular, competitively selected Earth science research opportunities that accommodate new and emerging scientific priorities and measurement capabilities. This results in a series of relatively low-cost, small-sized investigations and missions. Principal investigators lead these focused projects that contribute to studies of the atmosphere, oceans, land surface, polar ice regions, or solid Earth.

ESSP projects include space missions, remote sensing instruments for space-based missions of opportunity, and extended duration airborne science missions. The ESSP program also supports the conduct of science research utilizing data from these missions. ESSP projects may involve partnerships with other U.S. agencies and/or international organizations. This portfolio of missions and investigations provides opportunity for investment in innovative Earth science that enhances NASA’s capability for better understanding the current state of the Earth system.

EXPLANATION OF MAJOR CHANGES IN FY 2021

NASA selected Geosynchronous Littoral Imaging and Monitoring Radiometer (GLIMR) from the Earth Venture Instrument-5 solicitation within Venture Class and increased the GeoCarb lifecycle cost, reflecting more updated estimates for the cost of completing the instrument and obtaining a host spacecraft.

VENTURE CLASS MISSIONS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	163.5	--	263.6	230.8	183.6	176.9	169.4

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

GLIMR provides observations of ocean biology, chemistry, and ecology in the Gulf of Mexico, and portions of the southeastern United States from a commercial Geostationary satellite (shown in the figure above).

NASA's Earth Venture Class Missions provide frequent flight opportunities for high-quality, low-cost earth science investigations that can be developed and flown in five years or less. NASA selects the investigations through open competitions to ensure broad community involvement and encourages innovative approaches. Successful investigations enhance our capability to understand the current state of the Earth system and enable continual improvement in the prediction of future changes. Solicitations include both space-borne and airborne/suborbital opportunities.

NASA established Venture Class Missions in response to recommendations in the 2007 National Academies' report, "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond." The 2017 National Academies' report, "Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space," also endorses the Venture Class Missions.

The Earth Venture Class Missions include four components:

- Earth Venture Suborbital (EVS) investigations, which are sustained suborbital science investigations. NASA releases EVS solicitations every four years with a budget of approximately $120 million in FY 2018 dollars, and selects multiple investigations within each call, individually cost-capped at no more than $30 million.
- Earth Venture Missions (EVM) are small space-based missions. NASA releases EVM solicitations every four years at a cost cap of approximately $166 million in FY 2018 dollars.
- Earth Venture Instruments (EVI) are missions of opportunity hosted on space-borne platforms. NASA releases EVI solicitations every three years at a cost cap of approximately $108 million in FY 2018 dollars.
- Earth Venture Continuity (EVC), a new component in FY 2020, will fly on-orbit demonstrations of affordable measurement approaches for maintaining the long-term record of important Earth science measurements. NASA will release EVC solicitations every three years at a cost cap of approximately $150 million in FY 2018 dollars.

VENTURE CLASS MISSIONS

The cadence of solicitations for EVI and EVC investigations will alternate every 18 months, releasing each approximately every three years. The cadence of EVS and EVM solicitation is independent of other Earth Venture solicitations.

EXPLANATION OF MAJOR CHANGES IN FY 2021

NASA confirmed the TROPICS instrument to proceed into development and increased its lifecycle cost for possible launch opportunities. NASA selected Geosynchronous Littoral Imaging and Monitoring Radiometer (GLIMR) from the Earth Venture Instrument-5 solicitation within Venture Class and increased the GeoCarb lifecycle cost, reflecting more updated estimates for the cost of completing the instrument and obtaining a host spacecraft.

Program Elements

VENTURE CLASS FUTURE MISSIONS

Earth Venture Class Future Mission funding supports the selection of new missions through Announcement of Opportunity (AO) solicitations at intervals of every four years for EVS and EVM; EVI and EVC will alternate every 18 months, each released approximately every three years. NASA released a solicitation for EVC-1 in December 2018 to address radiation budget measurement continuity. Proposals received in July 2019 are currently under review. NASA will select the first EVC-1 investigation and initiate project formulation in FY 2020.

CYCLONE GLOBAL NAVIGATION SATELLITE SYSTEM (CYGNSS) (EVM-1, SELECTED IN 2012)

CYGNSS data enables scientists to probe from space key air-sea interaction processes that take place near the inner core of the storms and which play large roles in the genesis and intensification of hurricanes. The CYGNSS measurements also provide information to the hurricane forecast community, potentially enabling better modeling to predict the strength of hurricanes as they develop. CYGNSS also makes measurements over land that are used to image flood inundation, wetland extent, and surface soil moisture.

CYGNSS's eight micro-satellite observatories receive both direct and reflected signals from Global Positioning System (GPS) satellites. The direct GPS signals pinpoint CYGNSS observatory positions and track fluctuations in GPS power, while the reflected signals are indicative of ocean surface roughness. Scientists use both measurements to derive the critical measurement of wind speed over ocean and water properties over land. CYGNSS launched in December 2016 and entered its extended mission phase in March 2019. NASA has approved CYGNSS for operation through September 2020.

Recent Achievements

CYGNSS calibration improvements resulted in a significant reduction in the uncertainty of its high wind speed measurements. As a result, scientists now have better knowledge of surface wind speed and associated latent heat flux in the inner core of storms. CYGNSS also provides valuable insight into the relationship between wind-driven surface fluxes and general tropical oceanic convection. Oceanographic studies are also underway to utilize CYGNSS's altimetric ability to measure sea level, ocean currents, and eddy circulation.

A study on new uses of CYGNSS measurements over land confirms the ability to retrieve volumetric soil moisture content at a level consistent with that of the NASA Soil Moisture Active Passive (SMAP) mission. The hydrology community released an initial global soil moisture data product. In addition, CYGNSS is able to map flood inundation in the aftermath of hurricane landfall and wetland extent under heavy vegetation. Electromagnetic modeling studies are underway to understand and characterize the extremely high quality, spatially resolved imagery that is possible with CYGNSS over calm inland water bodies.

Planned Future Achievements

The recent improvements in instrument calibration and resulting ocean wind measurement uncertainty will enable more comprehensive applications of CYGNSS measurements to forecast studies. These include data assimilation into hurricane forecast models for a large number of past storms to improve the statistical characterization of forecast skill improvement. Additionally, they will pave the way for eventual operational data usage, and data assimilation into storm surge prediction models, to assess the potential improvement in storm surge forecasting that will result from the frequent measurements of inner core wind strength and structure enabled by CYGNSS.

A comprehensive effort to calibrate the land measurements will support the new measurements of soil moisture and inland waterway extent and validate the new data products derived from them. The calibration and validation activities will provide the data quality characterization needed for the land hydrology research and applications communities to engage with the new data products.

TROPOSPHERIC EMISSIONS: MONITORING OF POLLUTION (TEMPO) (EVI-1, SELECTED IN 2012)

The TEMPO instrument will measure atmospheric pollution covering most of North America. A commercial communications satellite will host the instrument and launch no earlier than 2021. On an hourly basis, TEMPO will measure atmospheric pollution from Mexico City to the Canadian tar/oil sands and from the Atlantic to the Pacific. TEMPO will provide measurements that include the key elements of air pollution chemistry (e.g., ozone, nitrogen dioxide) in the lowest part of the atmosphere. Measurements from geostationary orbit will capture the inherent high variability in the daily cycle of emissions and chemistry. Measuring across both time and space will create a revolutionary dataset that provides understanding and improves prediction of air quality and climate forcing.

Maxar Technologies of Westminster, Colorado will provide satellite integration, launch, and data transmission services for TEMPO.

Recent Achievements

The TEMPO Instrument successfully completed a System Acceptance Review and is safely in storage at a Ball Aerospace facility in Colorado. Through the Hosted Payload Solutions contract, the U.S. Air Force Space and Missile Systems Center selected Maxar Technologies (formerly Space Systems/Loral) of Palo

Alto, California in June 2019 as NASA's first Geostationary Earth Orbit (GEO) hosting services effort. In addition, the project has completed the development of the Instrument Operations Center (IOC) software (a TEMPO-specific software exclusive of the host spacecraft interfaces), and Version 1 of the Science Data Processing Center (SDPC) software.

Planned Future Achievements

TEMPO will begin formulating technical documents in FY 2020 to address host spacecraft integration needs such as interface documents, integration plans, and test procedures. Additionally, the project plans to start integration with the host spacecraft and to complete Version 2.0 of the Science Data Processing Center (SDPC) software during FY 2021.

ECOSYSTEM SPACEBORNE THERMAL RADIOMETER EXPERIMENT ON SPACE STATION (ECOSTRESS) (EVI-2, SELECTED IN 2014)

ECOSTRESS observes changes in global vegetation from the ISS. The sensors give scientists new ways to see how changes in climate or land use affect forests and ecosystems. ECOSTRESS uses a high-resolution thermal infrared radiometer to measure plant evapotranspiration and the loss of water from growing leaves and evaporation from the soil. These data reveal how ecosystems change with climate and provide a critical link between the water cycle and effectiveness of plant growth, both natural and agricultural.

Recent Achievements

NASA has now collected over 45,000 ECOSTRESS scenes and achieved an acquisition rate that is approximately double the proposed acquisition rate. The data shows variations in plant water use and plant stress over different regions together with differences in plant water uptake over the daily cycle. Scientists have used measurements of water consumption over the contiguous United States and throughout the world to detect droughts. ECOSTRESS completed its prime mission on August 19, 2019 and successfully transitioned to extended operations approved through FY 2020.

Planned Future Achievements

Now in extended operations, ECOSTRESS plans to have acquisitions through 2020 with further extensions beyond that date subject to successfully completing the Senior Review. A recently expanded science team will use the ECOSTRESS measurements for a variety of earth studies.

GLOBAL ECOSYSTEM DYNAMICS INVESTIGATION (GEDI) LIDAR (EVI-2, SELECTED IN 2014)

GEDI is a geodetic-class laser ranging system that provides 3-dimensional measurements of the Earth’s forests from the ISS. GEDI measures the height of the Earth’s temperate and tropical forests and their vertical structure. These data will help scientists to determine, for the first time, how much carbon forests are storing as biomass, and the net impact of deforestation and subsequent regrowth on atmospheric carbon dioxide that results from human-influenced activities and climate variations. GEDI is the first mission optimized for vegetation measurements from space and provides the first, global, and transparently available data set that can be used by various US agencies at relevant scales for both policy and land management. GEDI is in prime operations phase.

VENTURE CLASS MISSIONS

Recent Achievements

NASA successfully launched GEDI from Kennedy Space Center on December 5, 2018, six-months earlier than scheduled due to excellent cost and schedule management. GEDI completed its on-orbit checkout in April 2019 and has been collecting data as planned. GEDI has already reached its success criteria of 1 billion observations over the land surface. This represents a 100-times increase over data previously available from the NASA ICESat mission.

Planned Future Achievements

GEDI will begin public release of its data sets in late 2019 to make the world's most accurate maps of canopy height, structure, and biomass. In addition, GEDI is collaborating with the German Space Agency (DLR) to fuse its observations with the commercial archive of their TanDEM-X radar satellites and to produce more accurate estimates of height and biomass.

EARTH VENTURE MANAGEMENT

Earth Venture Management provides for the development of AO solicitations and the Technical, Management, and Cost evaluations of proposals received in response to the AO solicitations. Additionally, it supports the airborne assets that the EVS investigations rely on for their airborne campaigns.

MULTI-ANGLE IMAGER FOR AEROSOLS (MAIA) (EVI-3, SELECTED IN 2016)

MAIA will use a multi-angle imager to assess linkages between different airborne particulate matter types and human health (including adverse birth outcomes, cardiovascular and respiratory disease, and premature death). This project will retrieve concentrations of fine and coarse particles, sulfate, nitrate, organic and black carbon, and mineral dust particles in major urban areas around the globe on a one-kilometer grid. The MAIA science team will correlate the data with birth, death, and hospital records and will use established epidemiological methodologies to correlate the exposure to particulate matter with adverse health outcomes. General Atomics will provide services required to host the MAIA instrument on a commercial satellite in low-Earth orbit.

Recent Achievements

The MAIA instrument successfully passed the instrument Critical Design Review and continues fabrication in preparation for instrument integration and testing. General Atomics successfully completed the Hosting Services Requirements Review and the Hosting Services Preliminary Design Review.

Planned Future Achievements

MAIA plans to complete its instrument integration and majority of testing in order to deliver the instrument directly to General Atomics in early FY 2021 to begin integration to the host spacecraft. MAIA anticipates no storage time for the instrument. Meetings and reviews with the host will continue and include the Hosting Services Critical Design Review.

VENTURE CLASS MISSIONS

TIME-RESOLVED OBSERVATIONS OF PRECIPITATION STRUCTURE AND STORM INTENSITY WITH A CONSTELLATION OF SMALLSATS (TROPICS) (EVI-3, SELECTED IN 2016)

TROPICS will make measurements over the tropical latitudes to observe the thermodynamics and precipitation structures of Tropical Cyclones (TCs) over much of the storm systems' lifecycles. TROPICS will take measurements of the temperature within the atmosphere, spatially and vertically resolved, as well as humidity, cloud ice, precipitation horizontal structure, and instantaneous surface rain rates. These measurements and the increased temporal resolution provided by the CubeSat constellation will enable better understanding of the TC lifecycles and the environmental factors that affect the intensification of TCs.

The TROPICS mission consists of six CubeSats, which will each have a cross-track scanning multiband passive microwave radiometer in a 1U payload (1U, a CubeSat unit, is roughly equivalent to a 4-inch cubic box). NASA will place TROPICS in secured storage after completion while evaluating suitable launch opportunities.

Recent Achievements

TROPICS completed the System Integration Review (SIR) for delivery-to-storage.

Planned Future Achievements

TROPICS scheduled the System Acceptance Review in January 2020. NASA will assess launch opportunities.

GEOSTATIONARY CARBON CYCLE OBSERVATORY (GEOCARB) (EVM-2, SELECTED IN 2016)

GeoCarb will advance our understanding of Earth's natural exchanges of carbon between the land, atmosphere, and ocean. The primary goals of the mission are to monitor plant health, vegetation stress throughout the Americas, and to probe, in unprecedented detail, the natural sources, sinks, and exchange processes that control carbon dioxide, carbon monoxide, and methane in the atmosphere.

The mission will launch on a commercial communications satellite to make observations over the Americas from an orbit of approximately 22,000 miles (35,400 kilometers) above the equator. GeoCarb will measure daily the total concentration of carbon dioxide, methane, and carbon monoxide in the atmosphere with a horizontal ground resolution of 3 to 6 miles (5 to 10 kilometers). GeoCarb also will measure solar-induced fluorescence, a signal related directly to changes in vegetation photosynthesis and plant stress.

Recent Achievements

The project was approved to proceed into the implementation phase in December 2019.

Planned Future Achievements

In FY 2020, GeoCarb will begin final design and fabrication and proceed to its Critical Design Review. GeoCarb will continue instrument development, ground system development and host selection.

VENTURE CLASS MISSIONS

EARTH VENTURE SUBORBITAL-3 (EVS-3; SELECTED IN 2018)

Five investigations will start in 2020 to look into a range of pressing research areas such as intense East Coast snowfall events and the impact of small-scale ocean currents on global climate. These investigations are:

- Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) studies the formation of snow bands in East Coast winter storms. Better understanding of the mechanisms of snow band formation and the factors that influence the location of the most intense snowfall will help improve forecasts of these extreme weather events.
- Aerosol Cloud Meteorology Interactions over the Western Atlantic Experiment (ACTIVATE) identifies how aerosol particles change cloud properties in ways that affect Earth's climate system. The investigation will focus on marine boundary layer clouds over the western North Atlantic Ocean that have a critical role in our planet's energy balance.
- Delta-X investigates the natural processes that maintain and build land in major river deltas threatened by rising seas. The project will improve models that predict loss of coastal land from sea level rise by improving estimates of how deltas add land—a process that involves trapping sediments and creating organic soils as plants grow.
- Dynamics and Chemistry of the Summer Stratosphere (DCOTSS) explores how strong summertime convective storms over North America can change the chemistry of the stratosphere. These storms regularly penetrate deep into the lower stratosphere, carrying pollutants that can change the chemical composition of this atmospheric layer, including ozone levels.
- Sub-Mesoscale Ocean Dynamics and Vertical Transport (S-MODE) examines the potentially large influence that small-scale ocean eddies have on the exchange of heat between the ocean and the atmosphere. The project will collect a benchmark data set of climate and biological variables in the upper ocean that influence this exchange.

Recent Achievements

After EVS-3 commenced in FY 2019, all investigations proceeded in developing their Investigation Implementation Plans. The Earth System Science Pathfinder Program Office (ESSP PO) assembled a board to assess readiness for confirmation, and held Confirmation Assessment Meetings for ACTIVATE, DCOTSS, and IMPACTS. NASA approved the same three investigations to move into their implementation/deployment phase upon successful Investigation Confirmation Reviews. ACTIVATE, Delta-X, IMPACTS, and S-MODE held Science Team Meetings during FY 2019.

Planned Future Achievements

S-MODE and Delta-X will complete the ESSP PO Assessment and conduct Confirmation Assessment Meetings and Investigation Confirmation Reviews during FY 2020.

In FY 2020, all five investigations will begin deployments and will hold science team meetings.

EARTH SURFACE MINERAL DUST SOURCE INVESTIGATION (EMIT) (EVI-4; SELECTED IN 2018)

EMIT will use a sensor mounted to the exterior of the ISS to determine the mineral composition of natural sources that produce dust aerosols around the world. Scientist do not currently have a global inventory of the natural mineral sources of dust, and as a result, the global impacts of dust on weather, atmospheric circulation, and other aspects of Earth's environment are not well established.

EMIT's hyperspectral instrument will measure the different wavelengths of light emitted by minerals on the surface of deserts and other dust sources in order to determine their composition. By measuring in detail which minerals make up the dust, EMIT will help answer the critical question of whether mineral-based dust has a cooling or warming effect on the atmosphere. EMIT's modeling component will use the data collected to advance the understanding of the role of atmospheric dust in Earth's climate and better predict how it can be expected to change in the future.

Recent Achievements

The EMIT project is currently completing preliminary design and technology completion in preparation for the Preliminary Design Review (PDR) scheduled in FY 2020.

Planned Future Achievements

EMIT will conduct its PDR, followed by a confirmation review in early FY 2020. The project will also prepare for its critical design review in late FY 2020.

POLAR RADIANT ENERGY IN THE FAR INFRARED EXPERIMENT (PREFIRE) (EVI-4; SELECTED IN 2018)

PREFIRE will fly miniaturized thermal spectrometers on a pair of small CubeSat satellites to measure far-infrared emissions and how they change throughout the day and over seasons. These CubeSats will orbit Earth's poles to probe a little-studied portion of the radiant energy emitted by Earth for clues about Arctic warming, sea ice loss, and ice-sheet melting. These observations will allow scientists to assess how changes in thermal infrared emissions at the top of Earth's atmosphere are related to changes in cloud cover and surface conditions below, such as the amount of sea ice and meltwater on the surface of ice.

Recent Achievements

The PREFIRE project is currently completing preliminary design and technology. The project is working toward a PDR in FY 2020.

Planned Future Achievements

PREFIRE plans to conduct its confirmation review in late FY 2020.

GEOSYNCHRONOUS LITTORAL IMAGING AND MONITORING RADIOMETER (GLIMR) (EVI-5; SELECTED IN 2019)

GLIMR will provide unique observations of ocean biology, chemistry, and ecology in the Gulf of Mexico, portions of the southeastern United States coastline, and the Amazon River plume – where the waters of the Amazon River enter the Atlantic Ocean. It will closely monitor the health of our oceans and assess risks for coastal communities to protect both our environment.

VENTURE CLASS MISSIONS

NASA will integrate GLIMR on a NASA-selected platform and launch in the 2026-2027 timeframe into a geosynchronous orbit where it will be able to monitor a wide area, centered on the Gulf of Mexico, for up to 15 hours a day. From this vantage point, the hyperspectral ocean color radiometer will measure the reflectance of sunlight from optically complex coastal waters in narrow wavebands. GLIMR will gather many observations of a given area each day in a way that would not be possible from a satellite in a low-Earth orbit. This is a critical capability in studying phenomena, such as the lifecycle of coastal phytoplankton blooms and oil spills.

Recent Achievements

NASA selected GLIMR in August 2019. In October 2019, NASA held a kick-off meeting with the PI institution (University of New Hampshire), with the project management team and its major contractors.

Planned Future Achievements

GLIMR will begin formulation activities in FY 2020. The project will complete System Requirement Review (SRR)/Mission Definition Review (MDR) followed by KDP-B in FY 2020.

VENTURE CLASS MISSIONS

Program Schedule

Date	Significant Event
FY 2020	TROPICS Instrument Delivery to storage
FY 2020	EVI-6 (instrument) solicitation released
FY 2020	EMIT Preliminary Design Review
FY 2020	EMIT Confirmation Review
FY 2020	PREFIRE Preliminary Design Review
FY 2020	PREFIRE Confirmation Review
FY 2020	GeoCarb Confirmation Review
FY 2020	GLIMR Key Decision Point-B Review
FY 2021	MAIA Instrument Delivery host spacecraft
FY 2021	TEMPO launch readiness
FY 2021	EVS-4 (suborbital) solicitation released
FY 2022	EVC-2 (Continuity Measurement) solicitation released
FY 2023	MAIA launch readiness
FY 2023	GeoCarb launch readiness
FY 2023	EVM-4 (mission) solicitation released
FY 2024	EVI-7 (instrument) solicitation released
FY 2025	EVS-5 (suborbital) solicitation released

Program Management & Commitments

The Earth System Science Pathfinder (ESSP) program at Langley Research Center (LaRC) manages the Venture Class projects. The “Provider” in the following table lists the PI institution for each project.

Program Element	Provider
EVS-3: IMPACTS	Provider: University of Washington Lead Center: LaRC Performing Center(s): ARC, AFRC, GSFC Cost Share Partner(s): N/A
EVS-3: ACTIVATE	Provider: University of Arizona Lead Center: LaRC Performing Center(s): LaRC Cost Share Partner(s): N/A

VENTURE CLASS MISSIONS

Program Element	Provider
EVS-3: DCOTSS	Provider: Texas A&M University Lead Center: LaRC Performing Center(s): AFRC, ARC, GSFC Cost Share Partner(s): N/A
EVS-3: S-MODE	Provider: Woods Hole Oceanographic Institute Lead Center: LaRC Performing Center(s): JPL, JSC Cost Share Partner(s): N/A
EVS-3: Delta-X	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A
EVM-1: CYGNSS	Provider: University of Michigan Lead Center: LaRC Performing Center(s): N/A Cost Share Partner(s): N/A
EVM-2: GeoCarb	Provider: University of Oklahoma Lead Center: LaRC Performing Center(s): ARC, GSFC, JPL Cost Share Partner(s): N/A
EVI-1: TEMPO	Provider: Smithsonian Astrophysical Observatory Lead Center: LaRC Performing Center(s): LaRC, GSFC Cost Share Partner(s): N/A
EVI-2: ECOSTRESS	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): USDA
EVI-2: GEDI	Provider: University of Maryland Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A
EVI-3: TROPICS	Provider: MIT Lincoln Laboratory Lead Center: LaRC Performing Center(s): GSFC Cost Share Partner(s): N/A

VENTURE CLASS MISSIONS

Program Element	Provider
EVI-3: MAIA	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A
EVI-4: EMIT	Provider: JPL Lead Center: JPL Performing Center(s): GSFC, JPL Cost Share Partner(s): N/A
EVI-4: PREFIRE	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A
EVI-5: GLIMR	Provider: University of New Hampshire Lead Center: LaRC Performing Center(s): LaRC, GSFC Cost Share Partner(s): N/A

Acquisition Strategy

NASA will issue Venture Class solicitations at intervals of every four years for EVS and EVM, and every 3 years for EVI and EVC, alternating every 18 months. NASA will select all Venture Class missions through full and open competition.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
CYGNSS	PI Institution: University of Michigan Instrument Provider: Southwest Research Institute Launch Vehicle Provider: NASA	PI: Ann Arbor, MI Instrument: San Antonio, TX Launch Vehicle: Cape Canaveral, FL
TEMPO	PI Institution: Smithsonian Astrophysical Observatory Instrument Provider: Ball Aerospace & Technologies Corp. Host Services Provider: Maxar Technologies	PI: Cambridge, MA Instrument: Boulder, CO Host Services: Westminster, CO
GeoCarb	PI Institution: University of Oklahoma Instrument Provider: Lockheed Martin Launch Vehicle Provider: TBD	PI Institution: Norman, OK Instrument: Palo Alto, CA Launch Vehicle Provider: TBD

VENTURE CLASS MISSIONS

Element	Vendor	Location (of work performance)
GLIMR	PI Institution: University of New Hampshire Instrument provider: Raytheon Host Services Provider: TBD	PI: Durham, New Hampshire Instrument: El Segundo, CA Host Services: TBD

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board (SRB)	Q1 FY 2020	EMIT PDR	Successful	Q4 FY 2020
Performance	SRB	Q2 FY 2020	GeoCarb CDR	TBD	Q3 FY 2022
Performance	SRB	Q3 FY 2020	PREFIRE PDR	TBD	Q4 FY 2020
Performance	SRB	Q4 FY 2020	PREFIRE CDR	TBD	Q1 FY 2021
Performance	SRB	Q4 FY 2020	EMIT CDR	TBD	Q1 FY 2022
Performance	SRB	Q1 FY 2021	PREFIRE ORR	TBD	Q1 FY 2022
Performance	SRB	Q1 FY 2022	EMIT ORR	TBD	N/A
Performance	SRB	Q1 FY 2022	PREFIRE ORR	TBD	N/A
Performance	SRB	Q3 FY 2022	GeoCarb ORR	TBD	N/A
Performance	SRB	Q2 FY 2023	TEMPO ORR	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
ESSP Missions Research	13.0	--	**18.5**	20.7	26.3	29.3	29.3
Orbiting Carbon Observatory-3	6.5	--	**7.0**	6.5	2.8	0.0	0.0
Commercial SmallSat Data Acquisition	19.0	--	**25.0**	25.0	25.0	25.0	25.0
OCO-2	6.4	--	**9.9**	10.1	10.4	10.7	10.7
GRACE	3.4	--	**0.0**	0.0	0.0	0.0	0.0
CloudSat	5.4	--	**8.7**	4.8	0.3	0.0	0.0
Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO)	6.5	--	**6.2**	3.3	3.3	0.0	0.0
Total Budget	**60.2**	**--**	**75.3**	**70.4**	**68.0**	**64.9**	**64.9**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Earth System Science Pathfinder (ESSP) Other Missions and Data Analysis projects include operating missions and mission-specific research. These innovative missions will enhance understanding of the current state of the Earth system and enable continual improvement in the prediction of future changes.

Mission Planning and Other Projects

ESSP MISSIONS RESEARCH

ESSP Missions Research provides funds for the science teams supporting ESSP operating missions. The science teams are comprised of competitively selected individual investigators who analyze data from the missions to address relevant science questions. A solicitation for a new science team for Ecosystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) will be competed in ROSES 2019 and awards made in FY 2019 and FY 2020. In addition, a Global Ecosystem Dynamics Investigation (GEDI) science team will begin in FY 2020.

Recent Achievements

Convective clouds produce a significant proportion of the global precipitation and play an important role in the energy and water cycles. From CloudSat and CALIPSO observations, researchers found that aerosols can inhibit or invigorate convection, depending on aerosol type and concentration. On average, smoke tends to suppress convection and results in lower cloud altitudes than clean clouds. Polluted continental aerosol tends to invigorate convection and promote higher cloud altitudes. The dust aerosol effects are regionally dependent and their signs differ from place to place in South America, Central

OTHER MISSIONS AND DATA ANALYSIS

Africa, and Southeast Asia. The observational findings indicate that aerosol type is one of the key factors in determining the aerosol effects on convective clouds.

The GRACE mission unveiled Earth's changing freshwater landscape, which has profound implications for water, food, and human security. Global estimates based on GRACE trends suggest increasing water storage in high and low-latitudes (wetting), with decreased storage in mid-latitudes (drying). Even though the GRACE record is relatively short, this observation of large-scale changes in the global hydrological cycle shows an important early confirmation of the changes predicted by climate models through the twenty-first century. Of the world's 37 largest aquifer systems, 13 suffered critical depletion during the GRACE observational period, with many linked to anthropogenic activities. Additionally, the integration of GRACE terrestrial water storage data and other observations within a land-data assimilation system produced significant improvement in the accuracy of drought tools (e.g., U.S. Drought Monitor).

Researchers compared the capability of Global Navigation Satellite Systems Reflectometry (GNSS-R) with respect to imaging radar (SAR) to characterize surface inundation dynamics in a tropical wetlands complex to assess capabilities of each and potential for synergistic use of these technologies for mapping inundation dynamics under dense tropical forest canopies. They examined JAXA PALSAR-2 L-band radar, CYGNSS GNSS-R, and ground measurements of vegetation structure and surface inundation and found that the capability of CYGNSS for mapping wetland extent and inundation dynamics in complex tropical landscapes, alone or in combination with other remote-sensing techniques such as those based on imaging radar, contributed to enhanced mapping of these regions. CYGNSS data were useful in mapping relatively high resolution (approximately 1 kilometer) changes in inundation extent with high temporal fidelity (approximately 7 days), which will allow for better mapping of inundation dynamics in tropical wetlands, providing the potential for stand-alone mapping of inundation processes or extending the utility of existing techniques (e.g., SAR).

A study estimated the spatio-temporal variations of groundwater storage between January 2003 and September 2010 in the Amazon Basin by decomposing the total terrestrial water storage measured by GRACE into the individual contributions of other hydrological reservoirs, using multi-satellite data for the surface waters and floodplains, and using model outputs for the soil moisture. Finding includes the seasonal variations of groundwater storage represent between 20 and 35 percent of the terrestrial water storage seasonal volume variations of the Amazon.

GRACE estimates key changes in the ice sheets, as it is the only direct measure of changes in mass. The footprint of GRACE allows detection of regional changes that indicates mass loss along the entire perimeter of Greenland and loss focused along the Amundsen Sea Embayment in Antarctica. During the GRACE period, Greenland measured an average mass loss of 258 gigatons (Gt) per year, while Antarctica measured an average mass loss of 137 Gt per year. GRACE also allowed monitoring of interannual variability in mass loss from the ice sheets and estimates of mass change trends in areas outside the poles.

COMMERCIAL SMALLSAT DATA ACQUISITION

The Commercial SmallSat Data Acquisition (CSDA) project, (previously known as the Small Satellite Constellation Initiative) identifies, evaluates, and acquires data from commercial sources to support NASA's Earth science research and applications activities. This will provide a cost-effective means to augment and/or complement the suite of Earth observations acquired by NASA and other U.S.

OTHER MISSIONS AND DATA ANALYSIS

Government agencies, as well as those acquired by international partners and made available to NASA and its stakeholders. Emphasis is placed on data acquired by small-satellite constellations, affording the means of complementing NASA acquired data with higher resolutions, increased temporal frequency or other novel capabilities in support of existing Earth science and application activities.

NASA-funded researchers examine and analyze the data set(s) to determine the utility of the commercial data products. The evaluation phase takes approximately 12-18 months. NASA may enter into a longer term agreement for continued access to data pending a favorable evaluation. CSDA provides an opportunity for vendors with new or significantly enhanced capabilities to have their data evaluated by NASA for longer-term procurement.

Recent Achievements

In FY 2019, NASA initiated the first evaluation activities of the commercial data. NASA purchased data from Planet Labs Inc., DigitalGlobe Inc., and Spire Global Inc. and provided it to over 35 individual evaluators. NASA plans to complete evaluations from the pilot activities by mid-FY 2020. NASA will begin contracts for longer-term access to favorably evaluated commercial data.

NASA released a Request for Information announcing the second evaluation opportunity in September 2019.

Operating Missions

OCO-3

Orbiting Carbon Observatory-3 (OCO-3) is a complete stand-alone payload built using the spare OCO-2 flight instrument, with additional elements added to accommodate installation and operation on the ISS. The OCO-3 instrument consists of three high-resolution grating spectrometers that collect space-based measurements of atmospheric carbon dioxide with the precision, resolution, and coverage needed to assess the spatial and temporal variability of carbon dioxide over an annual cycle.

Recent Achievements

NASA successfully launched OCO-3 on May 4, 2019 and installed the instrument on the ISS Japanese Experiment Module – Exposed Facility. After a successful on-orbit checkout, the three-year prime mission is now underway. The project began delivering lower-level science data products in FY 2020.

OCO-2

Orbiting Carbon Observatory-2 (OCO-2), launched in July 2014, collects precise carbon dioxide measurements across the globe each day from its vantage point in low-Earth orbit. With these data, scientists are gaining greater insight into how much carbon dioxide the Earth emits by natural sources and human activities and the natural processes removing carbon dioxide from the atmosphere. This information may help decision-makers to manage carbon dioxide emissions and reduce the human impact on the environment.

OTHER MISSIONS AND DATA ANALYSIS

The OCO-2 instrument has collected almost 1 million soundings globally each day since September 2014, completed its prime mission in October 2016, and is now conducting extended mission operations. The 2017 Earth Science Senior Review endorsed the OCO-2 mission for continued operations through 2020, and preliminarily through 2023.

Recent Achievements

The OCO-2 measurements of carbon dioxide, now spanning five years, include a major El Nino event and the subsequent La Nina. The science community is studying and using the impacts to prevailing weather patterns and the consequent changes in carbon dioxide uptake and release around the globe. The project team works closely with science team members responsible for making and testing laboratory measurements of the fundamental properties of carbon dioxide and oxygen. These new parameters have been integrated into a new version of the data processing algorithms and make clear improvements in the quality of the project data products. This update will form the basis of a new data version in FY 2020 for public distribution. The OCO-3 project team will use the updated data processing algorithms as the basis of their first release of data products from their observations aboard the ISS.

CLOUDSAT

CloudSat, launched in April 2006, measures cloud characteristics to increase understanding of the role of clouds in Earth’s radiation budget. This mission provides estimates of the percentage of Earth’s clouds that produce rain, provides vertically-resolved estimates of how much water and ice are in Earth’s clouds, and estimates how efficiently the atmosphere produces rain from clouds. CloudSat collects information about the vertical structure of clouds and aerosols that other Earth-observing satellites do not collect. These data improve models and provide a better understanding of the human impact on the atmosphere.

CloudSat is currently in extended operations. The 2017 Earth Science senior review endorsed the CloudSat mission for continued operations through 2020, and preliminarily through 2023.

Recent Achievements

In the past year, significant effort has continued to refine estimates of cloud heights, boundaries, and dangerous overshooting convection from the new Geostationary Operational Environmental Satellite sensors using CloudSat as a verification dataset. The project continues to exploit synergies with other NASA missions. For example, CloudSat released and continues refinement of a new synergy cloud product that combines information from CALIPSO and the OCO-2 satellite with CloudSat, resulting in the first ever direct measurements of cloud thickness of low altitude clouds and fog. The project also continues to collaborate with NASA’s Global Precipitation Measurement mission to routinely produce a data product of coincident satellite overpasses to improve estimates of rain and snow around the globe, which now spans from the GPM launch to the present date. The utility of CloudSat to the science community is evident in the more than 2,600 peer-reviewed publications that cite the data.

CLOUD-AEROSOL LIDAR AND INFRARED PATHFINDER SATELLITE OBSERVATION (CALIPSO)

The CALIPSO mission, launched in April 2006, provides the first comprehensive three-dimensional measurement record of aerosols, helping to better understand how aerosols form, evolve, and are transported over the globe. The mission provides data on the vertical structure of clouds, the geographic and vertical distribution of aerosols, and detects sub-visible clouds in the upper troposphere. CALIPSO also indirectly estimates the contribution of clouds and aerosols to atmospheric temperature.

CALIPSO is currently in extended operations. The 2017 Earth Science senior review endorsed the CALIPSO mission for continued operations through 2020, and preliminarily through 2023.

Recent Achievements

CALIPSO continues to provide unique profile observations of clouds and atmospheric particle (aerosol) layers over the globe. Last year, CALIPSO lowered its orbit to resume flying in formation with CloudSat to maximize science value with their combined measurements. The team released improved three-dimensional monthly averaged cloud and aerosol products that help consolidate the CALIPSO observations in more accessible formats for the science communities. The team further prepared and published journal papers describing new aspects of algorithms used in the generation of the CALIPSO data product suite. In addition, the mission supported NASA field missions exploring the impact of forest fires on weather and air quality in the western United States and on the impact of aerosols on convective cloud formation and precipitation in the Philippines. The team also supported validation activities for the new European Aeolus Wind/Aerosol satellite mission.

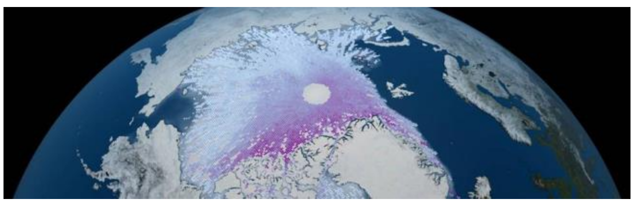
EARTH SCIENCE DATA SYSTEMS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**202.0**	**--**	**245.4**	**259.9**	**263.2**	**278.7**	**277.7**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.



Data from NASA's Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2) are now available at NASA's National Snow and Ice Data Center Distributed Active Archive Center (NSIDC DAAC). ICESat-2 launched on September 15, 2018 on a three-year mission to measure Earth's height in unprecedented detail. This composite image is a measurement of Artic sea ice freeboard taken by ICESat-2's instrument: the Advanced Topographic Laser Altimeter System (ATLAS). Freeboard is the difference between the top of the ice and the ocean. Pink equals higher elevation. Blue/white equals lower elevation. White circle equals no data.

The Earth Science Data Systems (ESDS) program oversees the life cycle of Earth science data with the principal goal of maximizing the scientific return from NASA's missions and experiments for research and applied scientists, decision makers, and the United States.

The ESDS program acquires, processes, preserves, and distributes observational Earth science data from spacecraft, aircraft, and in-situ sensors to support Earth Science research focus areas. The ESDS program primarily accomplishes this via the Earth Observing System Data and Information System (EOSDIS), which has been in operation since 1994.

Over the past 24 years, EOSDIS has continuously evolved to take advantage of improved technology to meet the increasing demands of data providers and users. By 2022, the ingest rate of data into the EOSDIS archive is projected to grow from the current 3.9 petabytes (PB) per year to as much as 47.7 PB per year. As this ingest rate increases, the total volume of data stored in the EOSDIS archive is also expected to grow—from its current size of 27 PB to more than 37 PB by 2020; by 2025, the volume of data in the EOSDIS archive is projected to be 250 PB.

This anticipated growth in both the data ingest rate and the overall archive volume poses challenges for archiving, distribution, and analysis of data. To address these challenges, the ESDS program adopted a strategic vision to develop and operate multiple components of EOSDIS in a commercial cloud environment to meet the needs of future missions with high data volumes (e.g., Surface Water Ocean Topography (SWOT) and NASA-ISRO Synthetic Aperture Radar (NISAR)) as well as providing improved data management and user access for many ongoing Earth science missions.

The program continuously evolves its capabilities by communicating with users, adopting new technologies, and supporting vibrant competitive research elements within the Data System Evolution

(DSE) project. These activities help prioritize data system investments to more efficiently manage user needs and identify technologies to improve the processing, preservation, and access to the diverse data NASA collects.

For more information, go to: https://earthdata.nasa.gov

EXPLANATION OF MAJOR CHANGES IN FY 2021

The Program will expand its capabilities to support data from new missions, including SWOT and JPSS-2. In response to recent recommendations from the interagency Satellite Needs Working Group, the program will also begin producing additional data products, including a data product for subweekly global surface water extent and a data product for subweekly 10 meter to 30 meter land surface change detection.

ACHIEVEMENTS IN FY 2019

The EOSDIS archives grew to over 33 petabytes in FY 2019. EOSDIS distributed over 1.9 billion data products to 4 million users around the world. EOSDIS provided data stewardship to over 11,000 unique data products from more than 100 instruments.

The program released several new datasets from new on-orbit missions for public access, including GRACE-Follow On, ECOSTRESS, and ICESat-2. The program provided the ability to search over 34,000 data collections in the Common Metadata Repository, with 98 percent of queries completing in less than one second. The Common Metadata Repository itself has grown to manage over 464 million records describing NASA Earth science data collection.

ESDS continued development of a commercial cloud environment in order to meet the needs of future high data volume missions such as SWOT and NISAR, as well as providing data management and user access for many ongoing Earth science missions. NASA deployed the NASA Compliant General Application Platform (NGAP), which provides underlying capabilities needed by cloud applications to meet NASA security, business, and financial requirements. NASA deployed and integrated the initial version of Cumulus, a lightweight cloud-native framework for data ingest, archive, management, and distribution with NGAP. The program developed a transition plan for defining high priority data sets as candidates to migrate to the commercial cloud. Finally, EOSDIS completed 100 percent of technical qualification requirements for the SWOT archive and distribution.

The NASA Sentinel Gateway continued to serve data from our partnership with the European Space Agency (ESA), delivering over 2 million files (over 2.7 petabytes) of data from the ongoing acquisition and distribution of data from the ESA's Sentinel 1-A/B, 3-A/B, and 5-P missions for NASA researchers and application scientists.

The Land, Atmosphere Near real-time Capability for EOS (LANCE) system maintained over 530 unique, near real-time datasets and produced one petabyte of data within three hours of satellite acquisition. ESDS added new products from Ozone Mapping and Profiler Suite (OMPS), Visible Infrared and Imaging Radiometer Suite (VIIRS) and supported both the assessment of the Satellite Needs Working Group survey as well as developing a response to those needs.

EARTH SCIENCE DATA SYSTEMS

During FY 2019, 24 competitively selected Making Earth System Data Records for Use in Research Environments (MEaSUREs) activities completed their first year. NASA made these awards via the ROSES 2017 solicitation and the awards have a total performance period of five years. The following are selected highlights:

- High Latitude Improvement of Long-term GPCP Precipitation Products Using Recent NASA Missions: The Global Precipitation Climatology Project (GPCP) provides a monthly precipitation dataset from 1979 to the present by combining observations and satellite precipitation data into 2.5°x2.5° global grids. Researchers use GPCP frequently to study trends, changes, closure in water and energy cycles, and for evaluation of climate models. The overall goal of this MEaSUREs activity is to improve GPCP precipitation data records in high-latitudes, where important new sources of calibration are now available. The proposed work will complement previous investments by MEaSUREs, and other programs, to ensure that GPCP will continue to serve as a science community standard product with global coverage.
- Greenland Ice Mapping Project-3 (GIMP-3): The technology for deriving ice velocity in Greenland is mature as demonstrated through ongoing and past Greenland Ice Mapping Projects (GIMP-1&2). Through these projects, this team repeatedly measured ice velocity in Greenland, establishing a record since 2000. Through GIMP-3 they continue this effort to extend the record of ice flow velocity through 2022, a period when Greenland will likely continue to evolve rapidly with the current warming. The GIMP-3 products will be entirely compatible with prior products but will take advantage of new sensors launched in the last five years (e.g., Landsat 8, Sentinel 1A/B, and Sentinel 2A/B) to greatly improve temporal and spatial sampling.
- A Moderate Spatial Resolution Data Record of 21st Century Global Land Cover, Land Use, and Land Cover Change: The goal of this MEaSUREs activity is to create a 30-meter spatial resolution data record that provides a high-quality representation of current and past global land cover, land use, and land cover change at annual time steps for the period 2001-2020. To achieve this goal, the project will: (1) develop and maintain a global database of high-quality training and validation data that will be used to estimate classification models and quantify the accuracy of mapped products; (2) implement land cover and land cover change algorithms at global scale using Landsat data; and (3) distribute science data sets at multiple spatial resolutions, including characterization of errors and uncertainty, that support the user community who require information related to land cover, land use, and land cover change at local-to-global scales.
- Multi-decadal time series of vegetation chlorophyll fluorescence and derived gross primary production: Measurements of Solar Induced chlorophyll Fluorescence (SIF) emitted from plants have provided a novel measure of photosynthetic activity (or Gross Primary Production, GPP) that instruments can measure globally from space and which yields significant insights for studying terrestrial carbon cycle dynamics. This activity will deliver a set of observational SIF Earth System Data Records (ESDR), which calibrates and blends together independent retrievals from multiple satellites into a consistent, multi-decadal record spanning the period 1996-2020.
- Creating an extended and consistent ESDR of the ocean surface winds, stress and their dynamically-significant derivatives for the period 1999-2022: Ocean surface winds and wind stress are key components of the Earth system. They are a major driver of the ocean circulation and affect the air-sea interactions, providing fuel to the weather systems by modulating the sensible and latent heat fluxes. This activity will develop a consistent data record of the ocean surface winds as observed by the two technologically different observing systems: the Ku-band pencil beam (all NASA and ISRO instruments) and the C-band push-broom (all EUMETSAT instruments).

EARTH SCIENCE DATA SYSTEMS

WORK IN PROGRESS IN FY 2020

Work will continue on the development of open source cloud optimized software that provides a cloud-based framework for data ingest, archive, distribution, and management of the Earth science data archives. ESDS will also improve cloud processes for cost monitoring, reporting, budgeting, and execution activities. ESDS is prioritizing EOSDIS data products for cloud migration by defining a mechanism for selecting high priority datasets that maximize use of commercial cloud technology for data access and exploitation. Activities will continue in support of several flight projects, instrument teams, and science teams to prepare for upcoming missions, including the Earth Venture Suborbital-3 (EVS-3) investigations.

All 24 MEaSUREs activities will continue work according to the established cooperative agreement plans and milestones.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

The program will expand its capabilities to support data from new missions, including: SWOT, JPSS-2, Multi-Angle Imager for Aerosols (MAIA), Sentinel-6A, NISAR, and SWOT.

Program Elements

EARTH SCIENCE DATA AND INFORMATION SYSTEM (ESDIS)

The ESDIS project manages the geographically distributed science systems of EOSDIS including the Distributed Active Archive Centers (DAAC), Science Investigator-led Processing Systems (SIPS), the Land, Atmosphere Near real-time Capability for the Earth Observing System (LANCE), and core systems. Together these systems support processing of satellite data and seamless interdisciplinary access to EOSDIS data, including data products, data services, and data handling tools for a broad range of user communities including scientists, U.S. Government agencies, commercial users, and the general public.

- SIPS generate high-quality science products from Terra, Aqua, Aura, S-NPP, and JPSS missions at facilities under the direct control of the instrument principal investigators / team leaders. Products produced at SIPS undergo extensive quality assurance before the Program transfers them to DAACs for archiving and distribution to users.
- DAACs archive, document, and distribute data and provide user support for NASA's past and current Earth-observing satellites, Sentinel 1, 3, and 5P satellites, airborne investigations, and field measurement programs. Acting in concert, the DAACs provide reliable, robust services to users whose needs may cross the traditional boundaries of a science discipline, while continuing to support the unique needs of users within specific science discipline communities. The DAAC facilities, hosted at NASA or other institutions, each specialize in a science discipline such as atmosphere, calibrated radiance, solar radiance, cryosphere, human dimensions, land, or ocean science.
- LANCE generates and provides access to near real-time products from the Atmospheric Infrared Sounder, Advanced Microwave Scanning Radiometer 2, Microwave Limb Sounder, Moderate Resolution Imaging Spectroradiometer, Measurement of Pollution in the Troposphere, Ozone

Monitoring Instrument, Ozone Mapping Profiler Suite, and Visible Infrared Imaging Radiometer Suite (VIIRS) (VIIRS-Land and VIIRS Atmosphere) instruments in less than three hours from the time of observation. The data support NASA applications users who are interested in monitoring and analyzing a wide variety of natural and man-made phenomena.

The EOSDIS system supports a number of core systems to provide a common entry point to discover access and visualize data from the distributed DAACs and SIPS. The program developed core systems to reduce duplication and improve user access to EOSDIS data, including:

- Common Metadata Repository (CMR) is a high-performance, high-quality, continuously evolving metadata system that catalogs all data and service metadata records for EOSDIS;
- Global Imagery Browse Services (GIBS) provides visual representations of NASA Earth science data at full resolution in a free, open, and interoperable manner;
- NASA-compliant General Application Platform is a cloud-based platform that provides a scalable and flexible application platform solution;
- Cumulus is a cloud optimized software package for performing Earth science data ingest, archive, and distribution capabilities to support all EOSDIS missions;
- Earth Observing System Networks provide end-to-end network connectivity between users and geographically distributed DAACs via a variety of physical networks including wide area and local area networks;
- The NASA Earthdata website (see: https://earthdata.nasa.gov) integrates information from across EOSDIS. Earthdata is the entry point for EOSDIS data, articles, documentation, and collaboration; and
- The NASA Sentinel Gateway transfers data from the European Commission's Copernicus Programme Sentinel 1-A/B, 3-A/B, and 5P satellites to DAACs for archival and distribution to users.

DATA SYSTEM EVOLUTION (DSE)

The Data System Evolution project funds various research opportunities, as well as interagency initiatives and promotion of data and service interoperability through development and implementation of standards. DSE is composed of two competitive components: Advancing Collaborative Connections for Earth System Science (ACCESS), and Citizen Science for Earth Systems Program (CSESP). DSE also supports the Interagency Implementation and Advance Concepts Team (IMPACT) activity, and the development of long-term data records needed by NASA scientists.

- IMPACT at NASA’s Marshall Space Flight Center (MSFC) works with other Government agencies to increase the use of NASA Earth observation data. The team also assesses, independently evaluates, and makes recommendations to improve EOSDIS services and processes, leads stewardship of airborne science observations, and develops proof of concept data system capabilities. IMPACT works closely with the Satellite Needs Assessment Working Group (SNWG) and collaborates with other agencies to design and implement systematic plans to assist other agencies in incorporating NASA Earth observation data into their workflows.
- ACCESS supports the evolution of ESDIS by investing in technology to enhance the analysis, delivery, and preservation of Earth science data. NASA solicits proposals in this competitive program element every two years. The intent is to identify and develop promising technology prototypes into operational tools to infuse into the EOSDIS.

- CSESP consists of two elements: (1) the collection and analysis of data by citizen scientists across all Earth Science focus areas and (2) technological development and production of low-cost sensors for measurement and monitoring. NASA solicits proposals in this competitive program element every three years.

DSE activities also support the widespread use of NASA Earth science observations through the development and implementation of standards, through collaborations with other space agencies and by leading activities to improve discoverability of NASA data within Geoplatform.gov (see: https://www.geoplatform.gov/).

MAKING EARTH SYSTEM DATA RECORDS FOR USE IN RESEARCH ENVIRONMENTS (MEASURES)

The overall objective of MEaSUREs is to provide Earth science higher-level data products and services driven by NASA's Earth science goals. These data products, called Earth Science Data Records, are critical for understanding Earth System processes; assessing variability, long-term trends, and changes in the Earth System; and providing input and validation means to modeling efforts. MEaSUREs is a competitive program element solicited every five years.

MEaSUREs emphasizes linking together multiple satellites into a constellation, developing the means of utilizing a multitude of data sources to form a coherent time series, and facilitating the use of NASA's extensive data in the development of comprehensive Earth system models. In addition, MEaSUREs activities include infusion or deployment of applicable science tools that contribute to data product quality improvement, consistency, merging or fusion, or understanding.

Program Schedule

The ESDS program solicits research opportunities approximately every two years for ACCESS, every three years for Citizen Science for Earth System Science, and every five years for MEaSUREs. The ESDIS project continuously delivers software to improve functionality and improve efficiency.

Date	Significant Event
Q3 FY 2020	Cumulus Operational Release
Q4 FY 2020	Cumulus Operational Qualification Test for SWOT
Q1 FY 2021	ROSES ACCESS Solicitation Released
Q2 FY 2021	ROSES CSESP Solicitation Released
Q4 FY 2021	Cumulus Operational for SWOT
Q2 FY 2022	ROSES MEaSUREs Solicitation Released
Q1 FY 2023	ROSES ACCESS Solicitation Released
Q2 FY 2024	ROSES CSESP Solicitation Released

EARTH SCIENCE DATA SYSTEMS

Date	Significant Event
Q1 FY 2025	ROSES ACCESS Solicitation Released

Program Management & Commitments

The Earth Systematic Missions program at GSFC provides program management for the ESDIS project. NASA Headquarters manages the DSE and MEaSUREs projects.

Program Element	Provider
EOSDIS core system	Provider: Various Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A
Alaska SAR Facility (Fairbanks, AK)	Provider: University of Alaska Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A
Atmospheric Science Data Center (Hampton, VA)	Provider: LaRC Lead Center: LaRC Performing Center(s): LaRC Cost Share Partner(s): N/A
Goddard Earth Science Data and Information System Center (Greenbelt, MD)	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A
Land Processes Data Center (Sioux Falls, SD)	Provider: USGS Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A
National Snow and Ice Data Center (NSIDS; Boulder, CO)	Provider: University of Colorado Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A
Oak Ridge National Laboratory DAAC (Oak Ridge, TN)	Provider: Oak Ridge National Laboratory Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A

EARTH SCIENCE DATA SYSTEMS

Program Element	Provider
Physical Oceanography DAAC (Pasadena, CA)	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A
Socio-economic Data and Applications Center (SEDAC; Palisades, NY)	Provider: Columbia University Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A
Crustal Dynamics Data Information System (Greenbelt, MD)	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A
Global Hydrology Research Center (Huntsville, AL)	Provider: University of Alabama Lead Center: MSFC Performing Center(s): MSFC Cost Share Partner(s): N/A

Acquisition Strategy

Research opportunities within DSE are available through NASA's ROSES announcements. NASA competitively selects ESDIS support contracts through full and open competition.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
EOSDIS Evolution & Development	Raytheon	Riverdale, MD
NSIDC	University of Colorado	Boulder, CO
Alaska SAR Facility	University of Alaska	Fairbanks, AK
SEDAC	Columbia University	Palisades, NY

INDEPENDENT REVIEWS

The American Customer Satisfaction Index measures customer satisfaction with the NASA Earth Observing System Data and Information System (EOSDIS) at a national level for each Distributed Active Archive Center (DAAC) on an annual basis. The average aggregate Customer Satisfaction Index score for NASA EOSDIS over the last 11 years is 77. It also identifies the key areas that NASA can leverage across the DAACs to continuously improve its service to its customers.

EARTH SCIENCE DATA SYSTEMS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	American Customer Satisfaction Index	2019	Survey current EOSDIS users to assess satisfaction with current services	Customer Satisfaction Index: 77	2020

EARTH SCIENCE TECHNOLOGY

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**63.4**	**--**	**74.2**	**82.8**	**84.6**	**86.4**	**86.4**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Developed at the Laboratory for Atmospheric and Space Physics, the Compact Spectral Irradiance Monitor (CSIM), shown above, is an ultra-compact, solar spectral irradiance (SSI) monitor covering 200-2400 nanometer with the SI-traceable accuracy and on-orbit stability to meet solar input measurement requirements for establishing benchmark climate records. Launched on December 3, 2018, onboard a SpaceX Falcon 9 rocket, the CSIM instrument design marks a significant departure from the previous spectral irradiance monitor instruments – such as those on the SORCE and TSIS missions – achieving large reductions in mass, volume, and power requirements, and enabling a flight-qualified instrument on a six-unit CubeSat.

Advanced technology plays a major role in enabling Earth science research and applications. The Earth Science Technology Program (ESTP) enables previously infeasible science investigations, improves existing measurement capabilities, and reduces the cost, risk, and/or development times for Earth science instruments and information systems.

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

ACHIEVEMENTS IN FY 2019

The ESTP worked on 119 active projects in FY 2019. For projects eligible to do so, 39 percent advanced at least one Technology Readiness Level (TRL) during FY 2019, and at least eight projects advanced more than one TRL. Nearly 100 students from 37 institutions nationwide were involved with ESTP-funded projects during the year.

The program infused several projects, past and present, into science measurements, airborne campaigns, data systems, or other follow-on activities during the year. For example, the Hyper-Angular Rainbow Polarimeter 2 is a wide-angle imaging polarimeter with direct heritage from the HARP CubeSat. The HARP CubeSat is a technology validation project that launched in November 2019. Once on-orbit, HARP will demonstrate its ability to provide science-quality multi-angle imaging data of clouds and aerosols at four wavelengths.

EARTH SCIENCE TECHNOLOGY

Another ESTP-funded project, OceanWorks, created a data analytics platform – the Apache Science Data Analytics Platform (SDAP) – for ocean science that is now in use by the Physical Oceanographic Data Active Archive Center at the Jet Propulsion Laboratory. SDAP enables web-based analysis of massive oceanographic data sets that scientists previously needed to download to analyze offline.

The program awarded 22 proposals through a competitive solicitation under the Advanced Information Systems Technology (AIST) program element. The projects fall under one of two thrusts, the New Observing Strategy or Analytic Center Framework. The former includes technology looking for new ways to design and approach Earth observing missions and the latter seeks new ways to process and understand big and often complex Earth science data. Both thrusts aim to reduce the overall risk and cost of achieving NASA's goals to effectively monitor and understand our planet. The new awards will commence in FY 2020.

A project funded by the In-Space Validation of Earth Science Technologies (InVEST) was launched into orbit onboard a SpaceX Falcon 9 on December 3, 2018. The project, Compact Spectral Irradiance Monitor (CSIM), is an ultra-compact solar spectral irradiance (SSI) monitor covering 200-2400 nanometer with the SI-traceable accuracy and on-orbit stability to meet solar input measurement requirements for establishing benchmark climate records. The CSIM instrument design marks a significant departure from previous instruments, achieving large reductions in mass, volume, and power requirements, and enabling a flight-qualified instrument on a six-unit CubeSat. With operations planned for one year, the CSIM project is demonstrating that a CubeSat-sized instrument can maintain climate data record measurements.

WORK IN PROGRESS IN FY 2020

With emphasis on the measurements identified by the 2017 Earth Science Decadal Survey, the ESTP plans to issue solicitations in FY 2020 for the Advanced Component Technology (ACT) and In-Space Validation of Earth Science Technologies (InVEST) program elements. Additionally, under the Decadal Incubation program element, ESTP anticipates the competitive selection of two study teams. These teams will perform investigations to define the needs and capabilities of their relevant target observable area, in either Planetary Boundary Layer or Surface Topography and Vegetation. The findings of each study team will recommend activity areas including but not limited to modeling, observing system simulation experiments, field campaigns, and emerging technology developments that the program will use in developing subsequent solicitations of this project.

The program also plans technology demonstration launches in FY 2020, beginning with the Hyper-Angular Rainbow Polarimeter HARP CubeSat, which launched in November 2019. NASA also expects to launch the Compact Infrared Radiometer (CIRiS) CubeSat later in FY 2020.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

In FY 2021, the program plans to release solicitations under the Instrument Incubator Program (IIP), the Advanced Information Systems Technology (AIST), and the Decadal Incubation (DI) program elements. This will be the first competitive solicitation for technology projects under the DI program element.

EARTH SCIENCE TECHNOLOGY

Program Elements

ADVANCED TECHNOLOGY INITIATIVES (ATI)

This project enables development of critical component and subsystem technologies for instruments and platforms, mostly in support of the Earth Science decadal survey. Current awards focus on areas such as space-qualified laser transmitters, passive optical technologies, and microwave and calibration technologies. Other awards support measurements of solar radiance, ozone, aerosols, and atmospheric gas columns for air quality and ocean color for coastal ecosystem health and climate emissions.

The InVEST program element selects new technologies to validate in space prior to use in a science mission. This is necessary because the space environment imposes stringent conditions on components and systems, some of which we cannot test on the ground or in airborne systems. Validation of earth science technologies in space will further reduce the risk of new technologies in future Earth Science missions.

INSTRUMENT INCUBATOR

This project develops instruments, instrument concepts, and measurement techniques at the system level, including laboratory breadboards and operational prototypes that often lead to ground or airborne demonstrations. NASA currently funds 29 Instrument Incubator efforts. These instrument prototypes support several measurements such as carbon dioxide, carbon monoxide, ocean color, and solar spectrum from ultraviolet to infrared for earth science. Instrument Incubator supports the development of instrument design and prototyping through laboratory and/or airborne demonstrations for innovative measurement techniques that have the highest potential to meet the measurement capability requirements of the NASA earth science community in both the optical and the microwave spectrum.

DECADAL INCUBATION

NASA created this project in response to the recommendation of the 2017 Earth Science Decadal Survey. It focuses on maturing observing systems, instruments, technologies, and measurement concepts to address high priority science for the next decade (2027 – 2037) in two targeted observable areas. These observable areas are the Planetary Boundary Layer and Surface Topography and Vegetation. Anticipated developments in this project include various observation and information system technologies, modeling/system design, analysis activities, and small-scale pilot demonstrations in support of the two observables.

ADVANCED INFORMATION SYSTEMS TECHNOLOGY (AIST)

This project develops end-to-end information technologies that enable new Earth observation measurements and information products. The technologies help process, archive, access, visualize, communicate, and understand science data. Currently, AIST activities focus on two primary thrust areas needed to support future Earth science measurements:

EARTH SCIENCE TECHNOLOGY

- Analytic Center Framework (ACF): ACF technology projects aim to harmonize tools, data, and computing environments to meet the needs of Earth science investigations of physical processes and natural phenomena. These investigations integrate new or previously unlinked datasets, tools, models, and a variety of computing resources together into a common platform to address previously intractable scientific questions. Additionally, these projects seek to generalize custom or unique tools used by a limited community in order to make them accessible and useful to a broader community.
- New Observing Strategies (NOS): NOS technologies support planning, evaluating, implementing, and operating a dynamic set of observing assets consisting of various instruments located at different vantage points (e.g., in situ, airborne, and on-orbit) to create a more complete picture of a natural phenomenon or physical process. The emergence of new sources of observational data, including high-quality instruments on smallsats, CubeSats, and commercial space platforms, allows measurement of phenomena that could not be studied using previously available observational techniques.

Program Schedule

Date	Significant Event
Q1 FY 2020	ROSES-2019 selection no earlier than six months of receipt of proposals
Q2 FY 2020	ROSES-2020 solicitation
Q1 FY 2021	ROSES-2020 selection no earlier than six months of receipt of proposals
Q2 FY 2021	ROSES-2021 solicitation
Q1 FY 2022	ROSES-2021 selection no earlier than six months of receipt of proposals
Q2 FY 2022	ROSES-2022 solicitation
Q1 FY 2023	ROSES-2022 selection no earlier than six months of receipt of proposals
Q2 FY 2023	ROSES-2023 solicitation
Q1 FY 2024	ROSES-2023 selection no earlier than six months of receipt of proposals
Q2 FY 2024	ROSES-2024 solicitation
Q1 FY 2025	ROSES-2024 selection no earlier than six months of receipt of proposals
Q2 FY 2025	ROSES-2025 solicitation

EARTH SCIENCE TECHNOLOGY

Program Management & Commitments

Program Element	Provider
Instrument Incubator	Provider: Various Lead Center: HQ Performing Center(s): GSFC, JPL, LaRC, ARC, AFRC Cost Share Partner(s): N/A
Advanced Information Systems	Provider: Various Lead Center: HQ Performing Center(s): GSFC, JPL, LaRC, MSFC, ARC, GRC Cost Share Partner(s): N/A
Advanced Technology Initiatives	Provider: Various Lead Center: HQ Performing Center(s): GSFC, JPL, LaRC Cost Share Partner(s): N/A
Decadal Incubation	Provider: Various Lead Center: HQ Performing Center(s): TBD Cost Share Partner(s): N/A

Acquisition Strategy

NASA primarily procures tasks through full and open competition, such as through the ROSES announcements. The solicitation of technology investments is competitive and selected from NASA Centers, industry, and academia as well as other Government agencies, Federally Funded Research and Development Centers, and nonprofit organizations.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	National Academies of Science, Committee on Earth Science, and Applications from Space (CESAS)	Mar 2018	Provide results of the ESTP and outline program's ongoing response to 2017 decadal survey	CESAS was pleased with the current status of the program	2020

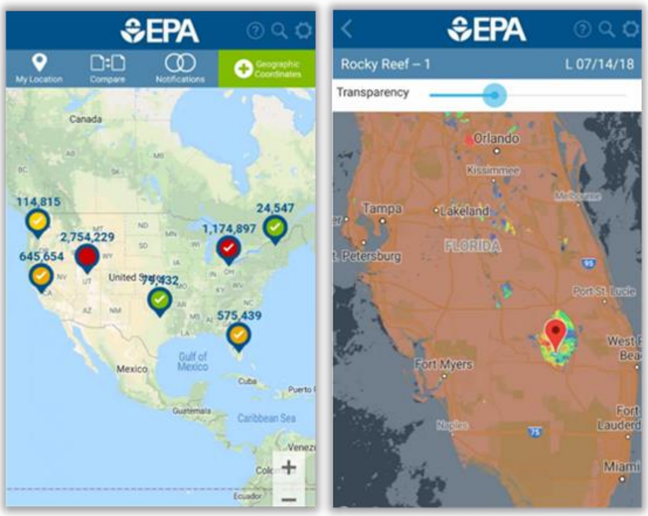
APPLIED SCIENCES

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**55.1**	**--**	**53.9**	**56.3**	**57.0**	**58.5**	**58.5**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.



This image shows the Cyanobacteria Assessment Network (CyAN) mobile application (app), which uses satellite data to alert users that a harmful algal bloom could be forming based on specific changes in the color of the water in more than 2,000 of the largest lakes and reservoirs across the United States. NASA funded the app together with EPA, NOAA, and USGS, and the app debuted in July 2019. The image on the left shows how users can drop pins in locations of interest. The image on the right shows satellite data.

The Applied Sciences program leverages NASA Earth Science satellite measurements and new scientific knowledge to enable innovative and practical uses by public and private sector organizations. It supports near-term uses of Earth science knowledge, discovers and demonstrates new applications, facilitates adoption of applications, and builds capabilities.

Applied Sciences projects improve decision-making activities to help the United States better manage its resources, improve quality of life, and strengthen the economy. NASA develops Earth science applications in collaboration with end-users in public, academic, and private organizations.

The program supports activities in thematic Earth science applications areas, in capacity building with uses of Earth observations, and in planning for future NASA missions.

Examples of these applications include:

- The U.S. Department of Agriculture uses NASA soil moisture data to support its monthly global crop production estimates;
- The U.S. Forest Service uses wildfire detection data and progression predictions to improve determination of fire boundaries and to expedite restoration of key ecosystems;
- Inclusion of satellite data in the Centers for Disease Control and Prevention’s Environmental Public Health Tracking Network data for county-level UV exposure information;

APPLIED SCIENCES

- State and local government use of satellite-based water quality data to assess algal bloom magnitude, frequency, duration, and extent and to map indicators and threats to human health from harmful algal blooms;
- Disaster-response organizations use of data from multiple Earth observing satellites during volcanic eruptions, including surface deformation, sulfur dioxide monitoring, and damage proxy maps;
- Application of land cover information by the Nature Conservancy to conduct a reverse auction, pay landowners, and increase prime habitat for migrating wild birds;
- Local governments use of satellite-based land-surface temperature data, emissivity data, and imagery to identify populations most vulnerable to extreme heat and guide service efforts;
- Use of satellite images and data to support companies' fishing operations and support sustainable fisheries; and
- Use of satellite observations of volcanic ash to inform air traffic controllers and the aviation industry of hazards along major airplane routes.

The program supports the sustained use of these products in the decision-making process of user organizations. The program also encourages potential users to envision and anticipate possible applications from upcoming satellite missions and to provide input to mission development teams to increase the societal benefits of NASA missions.

For more information, go to: https://appliedsciences.nasa.gov/

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

ACHIEVEMENTS IN FY 2019

RTI International and partners have assimilated Global Precipitation Measurement (GPM) and other satellite data to deploy and operationalize a forecast system that provides improved water supply forecasts for the Colorado River basin for better water management decisions.

South Dakota's Department of Health operationalized a previously piloted and satellite-enhanced West Nile Virus model, which provides weekly and seasonal risk forecasts at the county-level by assimilating data from MODIS and North American Land Data Assimilation System.

Through NASA support of U.S. humanitarian interests, Kenya's Crop Insurance Program uses Landsat-based crop masks to expand their coverage, enhancing economic resilience of affected farmers and reducing costs 70 percent.

During the U.S. Midwest floods, the State of Missouri used flood products derived from MODIS, Landsat, and other satellites to survey flood extent and crop damage. FEMA, National Guard, South Carolina, and others used NASA data for situational awareness during Hurricane Dorian. Satellite-based damage and flood-proxy maps supported the deployment of rapid damage assessment teams in the Bahamas.

APPLIED SCIENCES

The investment industry used the Sargassum Watch System, which uses Landsat and MODIS to map and forecast harmful algal blooms in the Caribbean to forecast demand in hotels and flights. The U.S. Agency for International Development's (USAID) Famine Early Warning System Network (FEWS NET) now integrates drought forecasting capabilities based on an Applied Sciences-sponsored seasonal water deficit forecasting system using downscaled and bias corrected GEOS-5 forecasts and land surface models in NASA’s Land Information System for the Middle East and Africa. The monthly predictions of seasonal water deficits using NASA data and models inform decision makers on droughts that can affect food vulnerability and security. FEWS NET produces those forecasts and uses the NASA products at monthly climate forecast discussions to support food aid decision-making.

The DEVELOP program, an endeavor for early career professionals to work with user organizations to apply Earth science data, engaged 255 young professionals working on 54 activities. Their work involved 127 unique partner organizations and served efforts in 40 U.S. states.

The Applied Remote Sensing Training program (ARSET) conducted 15 virtual and in-person trainings, with a record reach of 16,431 instances of participation from all 50 U.S. states and 148 countries, representing 4,048 organizations worldwide. ARSET partnered with Conservation International to increase the reach of NASA Earth observations with indigenous peoples. A bilingual training on “Earth Observations for Indigenous-Led Land Management” reached 34 tribal entities, which was more than ARSET had reached over the previous 10-years combined.

The SERVIR program (managed jointly with USAID) and partners conducted 48 activities and 51 trainings that reached 791 individuals from 45 organizations in 51 countries. Sixteen activities in the SERVIR Applied Sciences Team concluded, delivering results on food security, weather and climate, disasters, and water management activities. SERVIR launched its fifth hub, SERVIR-Amazonia, in late 2018 in partnership with a consortium led by the International Center for Tropical Agriculture in Cali, Colombia. SERVIR published the Synthetic Aperture Radar (SAR) Handbook in a collaboration with SilvaCarbon to provide comprehensive guide for SAR-based methods to monitor forests and estimate biomass.

The United Nations Development Program and other organizations worked with Applied Sciences to use data derived from MODIS, Landsat and other sources to develop landslide risk products for southeast Bangladesh, where nearly one million Rohingya refugees have fled to since 2017. The UN agencies integrated the data into their early warning systems for use in reducing landslide risk in fragile camps areas during the 2019 monsoon and cyclone season. These products helped them better identify potential evacuation routes, supported the development of future camp planning and design, and reflected greater uses of satellite-derived data for reducing risk before a disaster occurs.

Applied Sciences launched the Space for U.S. website (see: https://www.nasa.gov/SpaceforUS/) highlighting uses of Earth observations by each State. Applied Sciences completed a technical content strategy to improve its communications activities, including content across technical, narrative, and personal stories to broaden awareness and induce uptake of NASA Earth observations in decision making. The Water Resources applications team conducted a dedicated science communications training, including guidance on story telling of technical topics.

Applied Sciences expanded future applications and diversified engagement with users for upcoming satellites, including the Early Adopters program for missions in formulation and development. Ten missions now have Early Adopter programs, helping organizations' become familiar with expected data products and prepared to use the data soon after launch, accelerating societal benefits from the missions. As a result of engagement with Early Adopters, the SWOT Applications and Science Teams decided to reduce data latency for SWOT products from 45 days to less than three days, enabling short-latency oceanographic and hydrologic applications for societal benefit. Mission application teams worked with ARSET and the NASA Distributed Active Archive Centers on technical training courses, providing hands-on experiences with pre-launch mission data products and application scenarios.

WORK IN PROGRESS IN FY 2020

Eleven activities in the Health and Air Quality applications area continue, addressing topics on malaria control decision making, respiratory health of U.S. military personnel deployed in Asia, Midwest state implementation plans for air quality, dust forecasting for Valley Fever in Southwestern US, ambient air pollution in cities, and cholera risk early warning. The current, 13-member Health and Air Quality Applied Sciences Team (HAQAST) will conclude, completing four Tiger Team activities with health managers and stakeholders on uses of Earth observations for regional haze planning, background ozone for state implementation plans, air pollution and climate indicators, and health burden of wildfires. Applied Sciences will conduct a competitive solicitation to select members for a new HAQAST.

In the disaster applications area, 10 activities selected in FY 2019 will commence. Emphasizing a multi-hazard risk assessment and aligned with the goals of the Sendai framework, these activities address topics of floods, wildfires, landslides, oil spills, volcanic ash for aviation safety, hailstorm risk, and rapid damage mapping. The Sendai framework is a United Nations initiative to help communities worldwide manage, mitigate and plan responses to a wide array of disasters.

Twenty-eight activities in the Ecological Forecasting applications area continue, addressing topics of wetlands management, land conservation, dynamic seascapes, ecosystem accounting, agribusiness and extractive industry sustainability, and coastal resiliency. Nine activities support the use of NASA Earth observations by 19 countries to implement their response to the United Nations Sustainable Development Goals 14 (Life below Water) and 15 (Life on Land).

The next SERVIR Applied Sciences Team commences with 20 applications activities conducted in partnership with regional hubs in Eastern and Southern Africa, West Africa, Lower Mekong, Hindu Kush Himalaya, and Amazonia to address challenges in food security, weather and climate, land cover, disasters, and water resources. The 20 activities include work from 50 research institutions from 22 U.S. states. The SERVIR Amazonia hub has its first full year of activities and operation. DEVELOP will again sponsor three terms, expecting to conduct at least 50 feasibility studies applying Earth observation to localized decision making in at least 35 U.S. states. ARSET will develop at least 10 trainings from introductory to advanced level, which they will deliver online and in-person, expecting to reach over 10,000 people in over 130 countries around the world. All learning materials will be available in English and Spanish, with some trainings delivered in both languages.

Eight activities in the Water Resources applications area will finalize results related to uses of Earth observations to address global water security, threats to water quality, and imbalances between agricultural water supplies and agricultural water requirements. The Western Water Applications Office will deliver assessments of two water basins to identify stakeholder priorities for future activities and will also deliver initial results on soil moisture and evapotranspiration (water use) products in Western states. The NASA Harvest Consortium on food security will deliver a new Agriculture Knowledge Hub interface through Amazon Web Services, enabling more users to access global agriculture information from Earth observations.

Applied Sciences will develop a plan to expand NASA's Prediction of Worldwide Energy Resource (POWER) tool, supporting use of NASA Earth observations by the renewable energy and building design industries. Applied Sciences will determine efforts required to improve engagement with the private sector for expanding the user base for, and applications of, NASA's Earth observations.

The Program will conduct a peer review evaluation of the Valuation of Applications Benefits Linked to Earth Science (VALUABLES) consortium, which conducts impact assessments on the socioeconomic benefits resulting from uses of Earth observations. This peer review shifted from late FY 2019 to early FY 2020 and will assess progress toward NASA's objectives.

For more information, go to: https://www.rff.org/valuables/

Applied Sciences will continue its engagement with the applications community as part of current and future NASA Earth science missions, expand the number of Early Adopters, and support satellite mission teams to implement new guidance on the inclusion of applications in flight mission concepts.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

Eleven Ecological Forecasting applications activities and six Water Resources applications activities will conclude in FY 2021. Thirty-two activities will complete supporting nine specific elements in the Group on Earth Observations (GEO) Work Programme. Applied Sciences will conduct the mid-point peer review for the NASA Harvest consortium focused on food security and agriculture applications. Additionally, NASA’s Western Water Applications Office (WWAO) will complete the assessments of all six western water basins, enabling analysis and synthesis on ways to replicate applications projects effectively across basins.

The Applied Sciences program will initiate a range of activities for strengthening engagement with the private sector to expand uses of Earth observations. Partnerships with incubators and accelerators will support applications with early-stage and developing companies. Activities with academic technology transfer offices, cooperatives, and multi-sector consortia will enable uses of commercialization mechanisms to expand applications and identify types of engagement. The program will implement user analysis research in the applications themes to characterize user communities and opportunities to refine priorities. The activities will support, and are in alignment with, the 2019 National Plan for Civil Earth Observations.

NASA will initiate improvements for an enhanced POWER tool supporting the building design and energy efficient industries. The next Health and Air Quality Applied Sciences Team will commence, including new tiger team activity for agile, rapid response to near-term activities identified together with state and local officials. The Capacity Building program expects its engagements and trainings to reach over 15,000 people and 125 countries worldwide as well as continue its success in reaching people in all 50 U.S. States.

Program Elements

CAPACITY BUILDING

The Capacity Building project enhances U.S. and developing countries' capacity (e.g., human, scientific, technological, institutional, and resource capabilities) to make decisions informed by Earth science data and models. Capacity Building builds skills in current and future workforce and creates opportunities in under-served areas to broaden the benefits of Earth observations. This project supports training, information product development, internships, data access tools, short-term application test activities, user engagement, and partnership development. This project has three primary elements:

- SERVIR: A joint venture with USAID that supports developing countries to improve their environmental management and resilience to climate change through uses of Earth observations in development decision making.
- ARSET: A professional-level training program for accessing and using Earth observations data through computer-based webinars and hands-on courses for all types of organizations.
- DEVELOP: A national training and development program for individuals to gain experience applying Earth observations through 10-week interdisciplinary activities to address community needs.

MISSION AND APPLIED RESEARCH

The Mission and Applied Research project enables involvement by applications-oriented users in the planning, development, and other activities of Earth Science satellite missions. It enables end-user engagement to identify applications early in and throughout the mission life cycle, and integrates end-user needs in design and development, enabling user feedback and broadening advocacy. Mission and Applied Research organizes community workshops to identify priority needs as well as studies to inform design trade-offs and identify ways to increase the applications value of missions. This project advises flight projects on activities to develop the applications dimension of a mission in development to help broaden benefits and maximize the return from the investment in the mission.

DISASTER SUPPORT

The Disaster Support project enables development of innovative applications using NASA satellite mission data as well as other activities to ensure timely, valuable support to responders when disasters occur. The Disaster Support project sponsors the use and integration of Earth observations in the decisions and actions of disaster-related organizations, including use of feasibility studies, in-depth activities, workshops, and needs assessments. The project also sponsors activities to improve a preparatory-based approach to enhance value and usability of NASA Earth Science products in support of disaster response and recovery across a wide range of disaster types including floods, earthquakes, volcanoes, and landslides. This project pursues partnerships with disaster groups that can carry forward NASA-developed information and tools to support the responders they serve. The project will begin to focus greater attention on supporting disaster risk assessment and disaster resilience.

APPLIED SCIENCES

APPLICATIONS

The Applications project sponsors the integration of Earth observations in the decisions and actions of community organizations. There are formal applications areas in Ecological Forecasting, Food Security and Agriculture, Health and Air Quality, and Water Resources. The applications areas support feasibility studies, in-depth activities, applied science teams, consortia, workshops, and needs assessments. Each applications area participates in major conferences and events that their partners attend in order to meet and engage managers and users.

- Ecological Forecasting: The ecological forecasting applications area promotes the use of Earth observations and models to analyze and forecast changes that affect ecosystems and to develop effective resource management strategies. Primary user communities are natural resource managers (both land and marine) and those involved in conservation and sustainable ecosystem management.
- Food Security and Agriculture: The food security and agriculture applications area promotes the use of Earth observations along the value chain for the functioning and resilience of food systems. The area supports a multi-organizational consortium to enhance domestic and international food security and improved agricultural practices, especially for economic progress and humanitarian pursuits.
- Health and Air Quality: The health and air quality applications area promotes the use of Earth observations data & models in the implementation of air quality standards, policy, and regulations for economic and human welfare (particularly involving environmental health and infectious diseases). This area addresses issues of toxic and pathogenic exposure and health-related hazards and their effects for risk characterization and mitigation.
- Water Resources: The water resources applications area supports the use of Earth observations in water resources management related to water demand, supply, and quality. The area includes five functional themes: drought, streamflow and flood forecasting, evapotranspiration and irrigation, water quality, and climate effects on water resources.

In addition to these activities, the Applications project supports the following initiatives:

- NASA Harvest Consortium: The program sponsors a multi-organizational consortium to advance the use of Earth observations for enhanced food security and improved agricultural practices, especially benefitting private sector stakeholders domestically and humanitarian efforts internationally.
- Group on Earth Observations (GEO) Work Programme: Applied Sciences supports specific elements in the GEO Work Programme to further U.S. and NASA interests internationally, leveraging resources of other countries and organizations. This initiative specifically fosters a broader involvement of domestic organizations in a U.S. national approach to GEO and the Work Programme, increasing opportunities for these organizations.
- VALUABLES Consortium: The Valuation of Applications Benefits Linked to Earth Science. The program supports a multi-organizational consortium to support the development of analytic techniques to quantify the benefits, in social and economic terms, from uses of Earth observations to improve decisions. VALUABLES also helps build familiarity in the Earth science community with concepts and methods and helps communicate the benefits of Earth observations.
- Western Water Applications Office: The Western Water Applications Office (WWAO) is a targeted initiative to contribute Earth observations to help solve important and pressing water-

resource problems faced by the western United States. WWAO involves several NASA Centers to engage public and private sector stakeholders in the western water management community for innovative ways to apply Earth observations in managing water supply and accommodating a growing demand.

Program Schedule

Date	Significant Event
Q1 FY 2020	ROSES-2019 selection within six to nine months of receipt of proposals
Q2 FY 2020	ROSES-2020 solicitation release
Q1 FY 2021	ROSES-2020 selection within six to nine months of receipt of proposals
Q2 FY 2021	ROSES-2021 solicitation release
Q1 FY 2022	ROSES-2021 selection within six to nine months of receipt of proposals
Q2 FY 2022	ROSES-2022 solicitation release
Q1 FY 2023	ROSES-2022 selection within six to nine months of receipt of proposals
Q2 FY 2023	ROSES-2023 solicitation release
Q1 FY 2024	ROSES-2023 selection within six to nine months of receipt of proposals
Q2 FY 2024	ROSES-2024 solicitation release
Q1 FY 2025	ROSES-2023 selection within six to nine months of receipt of proposals
Q2 FY 2025	ROSES-2024 solicitation release

Program Management & Commitments

Program Element	Provider
Applications	Provider: Various Lead Center: HQ Performing Center(s): ARC, GSFC, JPL, LaRC, MSFC Cost Share Partner(s): U.S. Forest Service, National Park Service (NPS), U.S. Department of Agriculture, NOAA, USGS, U.S. Fish and Wildlife Service, Environmental Protection Agency (EPA), Bureau of Land Management, Centers for Disease Control and Prevention

APPLIED SCIENCES

Program Element	Provider
Capacity Building	Provider: Various Lead Center: LaRC, MSFC, GSFC Performing Center(s): ARC, GSFC, JPL, MSFC, LaRC Cost Share Partner(s): USGS, Groundwork USA, U.S. Department of Agriculture, University of Georgia, NOAA, Arizona State University, Boston University, USAID, EPS, NOAA, NWS
Disaster Support	Provider: Various Lead Center: HQ Performing Center(s): ARC, GSFC, JPL, LaRC, MSFC Cost Share Partner(s): Department of Homeland Security (DHS), NOAA, USDA, USGS, USAID, USACE, National Guard
Mission and Applied Research	Provider: Various Lead Center: HQ Performing Center(s): ARC, GSFC, JPL, LaRC, MSFC Cost Share Partner(s): USDA, CNES, ISRO, Joint Research Centre (JRC), European Space Agency

Acquisition Strategy

NASA bases the Earth Science Applied Science acquisitions on full and open competition. Grants are peer reviewed and selected based on NASA research announcements and other related announcements.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Relevance	Applied Sciences Advisory Committee	Nov 2019	Review strategy and implementation.	Provided recommendations on private sector engagement, and suggested several modes of engagement such as incubators and accelerators. Endorsed the technical content strategy and recommended full implementation to advance communications	May 2020; semi-annual
Relevance	Applied Sciences Advisory Committee	May 2020	Review strategy and implementation	TBD	Nov 2020: semi-annual

PLANETARY SCIENCE

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Planetary Science Research	276.6	--	**305.4**	288.6	285.1	295.2	286.7
Planetary Defense	150.0	--	**150.0**	147.2	97.6	98.0	98.0
Lunar Discovery and Exploration	188.0	--	**451.5**	517.3	491.3	458.3	458.3
Discovery	409.5	--	**484.3**	424.4	434.8	570.1	505.8
New Frontiers	93.0	--	**179.0**	314.3	332.8	326.9	285.0
Mars Exploration	712.7	--	**528.5**	588.4	671.2	798.7	855.3
Outer Planets and Ocean Worlds	793.6	--	**414.4**	370.7	239.4	192.3	171.7
Radioisotope Power	123.3	--	**146.3**	150.1	162.8	165.4	169.8
Total Budget	**2746.7**	**2713.4**	**2659.6**	**2800.9**	**2714.9**	**2904.8**	**2830.7**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Planetary Science

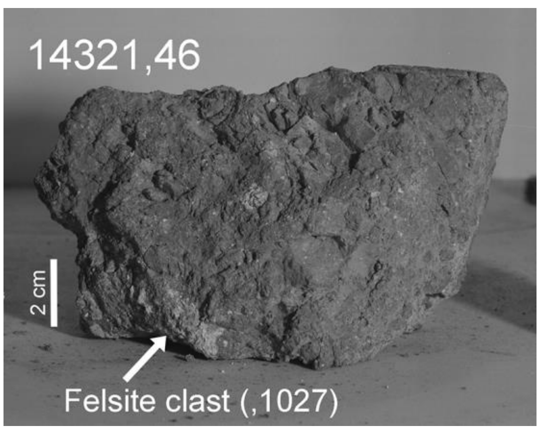
PLANETARY SCIENCE RESEARCH

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Planetary Science Research and Analysis	195.7	--	**223.0**	206.2	204.4	207.1	204.4
Other Missions and Data Analysis	80.9	--	**82.4**	82.4	80.7	88.1	82.3
Total Budget	**276.6**	**--**	**305.4**	**288.6**	**285.1**	**295.2**	**286.7**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.



Scientists associated with NASA's Solar System Exploration Research Virtual Institute may have discovered the oldest Earth rock ever—on the Moon. A lunar sample returned by the Apollo 14 astronauts may contain a bit of Earth from about 4 billion years ago. The two-gram fragment of rock is composed of quartz, feldspar, and zircon - all commonly found on Earth, but highly unusual on the Moon. Chemical analyses show the fragment crystallized in a terrestrial-like oxidized system at terrestrial temperatures, rather than in the reducing and higher temperature conditions characteristic of the Moon.

The Planetary Science Research program provides the scientific foundation for data returned from NASA missions exploring the solar system. It is also NASA's primary interface with university faculty and graduate students in this field and with the research community in general. The program develops analytical and theoretical tools, as well as laboratory data, to support analysis of flight mission data. These capabilities allow Planetary Science to answer specific questions about, and increase the understanding of, the origin and evolution of the solar system. The research program achieves this by supporting research grants solicited annually and subjected to a competitive peer review before selection and award. The Planetary Science Research program focuses on five key research goals:

- Advance the understanding of how the chemical and physical processes in our solar system operate, interact, and evolve;
- Explore and observe the objects in the solar system to understand how they formed and evolve;
- Explore and find locations where life could have existed or could exist today;
- Improve our understanding of the origin and evolution of life on Earth to guide our search for life elsewhere; and
- Identify and characterize objects in the solar system that pose threats to Earth or offer resources for human exploration.

PLANETARY SCIENCE RESEARCH

EXPLANATION OF MAJOR CHANGES IN FY 2021

The budget for competed research and analysis is intended to support an overall 25 percent proposal selection rate and initiates the 2023 Decadal Survey in June 2020, with a final delivery in 2022.

ACHIEVEMENTS IN FY 2019

After three years orbiting Jupiter, Juno confirmed minute but distinct changes in Jupiter's internal magnetic field over time. It is the first observation of this phenomenon, called secular variation, outside of Earth. Jupiter's deep atmospheric winds shearing the magnetic fields as they pull electrically conductive hydrogen around the planet best explains the variation. Improving the understanding of Jupiter has important implications for studying and anticipating changes in Earth's magnetic field.

Latest analysis of data from the Lunar Atmosphere and Dust Environment Explorer revealed that meteoroid bombardment ejects water from the Moon's surface. New findings show meteoroids excavate 50 – 200 tons of lunar water annually, and that ejected water is partially lost into space and partially redeposited into lunar soil. These results show that meteoroid strikes likely contribute to polar ice deposits found in "cold traps" on the Moon, improving our understanding of a critical lunar resource for future robotic and human exploration.

A recent study proposes that prior to the development of photosynthesis, early life-forms on Earth may have been able to generate metabolic energy from sunlight using a purple-pigmented molecule called retinal. Scientists have observed a number of pigments containing the retinal molecule that absorb light, including one called bacteriorhodopsin found in early haloarchaeal life forms. The strong absorption peak of retinal is different from, but complementary to that of the green chlorophyll pigment. These absorption properties may create unique spectral signatures on exoplanets that telescopes could remotely detect. Expanding the categories of surface signatures to include light-harvesting life that use pigments other than chlorophyll is an important step in life-detection efforts.

The distinction between cometary and asteroid impact craters on Mars has been historically difficult to determine, but computational simulations and laboratory experiments by researchers have produced significant insight into this problem. The research showed that impacts from comets produce radial, thermal wind streaks due to their higher speed and volatile content and concluded that approximately one percent of the craters on Mars formed in the last two billion years are due to Long-Period cometary impacts. Researchers then extrapolated this finding to the Earth-Moon system. The analysis of NEOWISE data tells us that, cometary impacts should be about six times more frequent on Earth. After including the Jupiter-family and Haley-type comets, the model predicts that approximately 16 percent of all terrestrial impacts are cometary. This study has important implications for understanding both the past impact environment of Mars and future impact hazards for Earth.

WORK IN PROGRESS IN FY 2020

In pursuit of fundamental science that guides planetary exploration, the Planetary Science Research program will continue to select highly rated Research and Analysis (R&A) proposals that support planetary missions and goals. Planetary science will continue archiving and distributing relevant mission data to the science community and the public in a timely manner. The Planetary Science Research program will continue to work with the other divisions of NASA's Science Mission Directorate to further research exoplanets by continuing and furthering the multi-division, multi-disciplinary approach to this topic.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

In pursuit of fundamental science that guides planetary exploration, the Planetary Science Research program will continue to select highly rated R&A proposals that support planetary missions and goals. Planetary science will continue archiving and distributing relevant mission data to the science community and the public in a timely manner.

Program Elements

PLANETARY SCIENCE RESEARCH AND ANALYSIS (R&A)

Planetary Science R&A enhances the scientific return from on-going and completed spaceflight missions and provides the foundation for the formulation of new scientific questions and strategies for answering those questions. R&A develops new theories and instrumentation concepts that enable the next generation of spaceflight missions. R&A funds research tasks in areas such as astrobiology and cosmochemistry; the origins and evolution of planetary systems; the observation and characterization of extra-solar planets (i.e., exoplanets) and the atmospheres, geology, and chemistry of the solar system's bodies other than the Earth or the Sun.

Program Schedule

The Planetary Science Research Program will conduct its next call for research proposals as part of the Science Mission Directorate's annual Research Opportunities in Space and Earth Sciences (ROSES) research calls in February 2020. The program issues solicitations every year. A Senior Review process assesses all missions in the extended operations phase every three years and all data archives every three or four years.

Date	Significant Event
Feb 2020	ROSES-2021 NRA solicitation release
Mar 2020	Planetary Data System Senior Review
Mar-Apr 2020	Out-of-Cycle Senior Review (InSight and Juno)
Q1 FY 2021	ROSES-2021 selection within six to nine months of receipt of proposals
Feb 2021	ROSES-2022 NRA solicitation release
Q1 FY 2022	ROSES-2022 selection within six to nine months of receipt of proposals
Feb 2022	ROSES-2023 NRA solicitation release

PLANETARY SCIENCE RESEARCH

Date	Significant Event
Mar-Apr 2022	Senior Review Operating Missions
Q1 FY 2023	ROSES-2023 selection within six to nine months of receipt of proposals
Feb 2023	ROSES-2024 NRA solicitation release

Program Management & Commitments

Program Element	Provider
R&A	Provider: NASA Lead Center: Headquarters (HQ) Performing Center(s): Ames Research Center (ARC), Glenn Research Center (GRC), Goddard Space Flight Center (GSFC), Jet Propulsion Laboratory (JPL), Johnson Space Center (JSC), Langley Research Center (LaRC), Marshall Space Flight Center (MSFC), HQ Cost Share Partner(s): N/A

Acquisition Strategy

The R&A budget will fund competitively selected activities from the ROSES omnibus research announcement.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	Planetary Science Advisory Committee (PAC)	2019	Review to assess progress against strategic objectives of Planetary Science.	Recommendation was to maintain a strong program consistent with the decadal survey.	2020
Quality	Planetary Science Advisory Committee (PAC)	2020	Review to assess progress against strategic objectives of Planetary Science.	TBD	2021

OTHER MISSIONS AND DATA ANALYSIS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Advanced Multi-Mission Operation System	40.2	--	**39.9**	40.8	38.2	38.3	38.3
Planetary Science Directed R&T	3.4	--	**3.7**	3.5	4.6	12.6	6.9
Planetary Data System	17.0	--	**19.1**	19.1	18.9	18.0	17.9
Astromaterial Curation	12.5	--	**12.9**	12.2	12.2	12.4	12.4
Science Data & Computing	2.7	--	**2.7**	2.7	2.8	2.8	2.8
Rosetta	1.0	--	**0.0**	0.0	0.0	0.0	0.0
Robotics Alliance	4.1	--	**4.0**	4.0	4.0	4.0	4.0
Total Budget	**80.9**	--	**82.4**	**82.4**	**80.7**	**88.1**	**82.3**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

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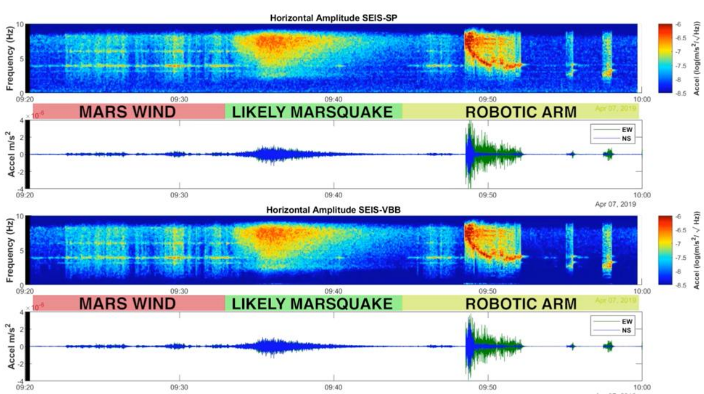


On April 6, 2019, NASA's Mars InSight mission measured and recorded, for the first time ever, a likely "marsquake." The figure above illustrates the seismic event detected by the lander. Three distinct kinds of ground vibrations were detected by the spacecraft's seismometer, called the Seismic Experiment for Interior Structure (SEIS): vibrations from Martian wind; the seismic event itself; and the spacecraft's robotic arm as it moved to take pictures.

Image Credit: NASA/JPL-Caltech

Other Missions and Data Analysis includes activities and infrastructure that support NASA planetary science research and missions, such as the Advanced Multi-Mission Operation System, Planetary Data System, and Astromaterial Curation.

Mission Planning and Other Projects

ADVANCED MULTI-MISSION OPERATION SYSTEM (AMMOS)

AMMOS provides multi-mission operations, navigation, design, and training tools and services for Planetary Science flight missions, as well as other Science Mission Directorate missions, and invests in improved communications and navigation technologies. The AMMOS project will continue to provide and develop multi-mission software tools for spacecraft navigation, command, control, assessment, mission planning, and data archiving. Utilizing the AMMOS common tools and services lowers individual mission cost and risk by providing a mature base for mission operations systems at significantly reduced development time. AMMOS also provides support to our international space agency partners on an as-needed basis. This support typically pertains to navigation assistance and scheduling of NASA's Deep Space Network (DSN) assets. AMMOS is a system of reusable software tools and services comprising a mission ground operations and ground data system that is used across multiple NASA missions.

Recent Achievements

AMMOS has grown its customer base to over 60 missions, including InSight, MarCO, Juno, MAVEN, OSIRIS-REx, Parker Solar Probe, New Horizons, MESSENGER, Hayabusa2, Chandrayaan-2, and ExoMars Trace Gas Orbiter. The growing list of customers and partners includes NASA centers, universities, industry, Federally Funded Research and Development Centers and international space organizations. The breadth of its support spans heliophysics, planetary science, and astrophysics and Earth-science missions. Recent accomplishments include increased open-sourcing of AMMOS software components. This open-sourcing has enabled increased adoption and long-term viability while reducing cost, a significant security expansion, and the dissemination of operations-enabling AMMOS software tools to GSFC, APL, ARC, and Morehead University.

PLANETARY SCIENCE DIRECTED RESEARCH AND TECHNOLOGY

This project funds the civil service staff that will work on emerging Planetary Science flight projects, instruments, and research. The workforce and funding will transfer to projects by the beginning of FY 2021.

PLANETARY DATA SYSTEM (PDS)

The PDS is an online data archive that furthers NASA's Planetary Science goals by efficiently collecting, archiving, and making accessible digital data produced by, or relevant to, NASA's planetary missions, research programs, and data analysis. The archive includes imaging experiments, magnetic and gravity field measurements, orbit data, and various spectroscopic observations. Space-borne data from over 50 years of NASA-funded exploration of comets, asteroids, moons, and planets is publicly available through the PDS archive.

Recent Achievements

PDS received data from 17 planetary missions since August 2018. PDS also received data sets from ground-based observations, laboratory data, and higher order data sets from NASA data analysis investigations. The archive grew by approximately 175 terabytes to a total of approximately 1.7 petabytes.

ASTROMATERIAL CURATION

The Astromaterials Acquisition and Curation Office at JSC curates extraterrestrial material under NASA control. Curation is an integral part of sample return missions. Activities conducted by the Curation office include: (1) research into advanced curation techniques to support future missions; (2) sample return mission planning; (3) archiving of witness, engineering, and reference materials related to sample return missions; (4) recovery and transport of returned materials; (5) initial characterization of new samples; (6)

OTHER MISSIONS AND DATA ANALYSIS

preparation and allocation of samples for research; and (7) providing clean and secure storage for the benefit of current and future generations.

Samples currently curated include Antarctic meteorites, cosmic dust, and samples collected on the Moon (Apollo and Luna), from the Sun (solar wind captured by Genesis), a comet (Stardust), an asteroid (Hayabusa), microparticle impact samples (on space-exposed hardware) as well as witness materials (small foils and plates placed in spacecraft assembly cleanrooms to collect molecules and particles) and coupons (representative pieces of materials used in construction of spacecraft) for several past, present, and future sample return missions (e.g., Apollo, Genesis, Stardust, OSIRIS-REx, Mars 2020). Planning and research efforts are currently underway to develop the technologies and procedures for proper curation of samples from future missions to asteroids (OSIRIS-REx and Hayabusa2), Mars, Mars' moons (Martian Moons eXploration), and comets. NASA plans to receive Hayabusa2 and MMX samples under international agreements with Japan Aerospace Exploration Agency (JAXA). New laboratory space is being constructed and outfitted within the curation facility to prepare for receipt of the OSIRIS-REx and Hayabusa2 samples, as well as to do advanced cleaning and curation research.

Recent Achievements

In March 2019, NASA began construction on the facilities that will house the new OSIRIS-REx and Hayabusa2 samples, as well as new advanced-curation and advanced-cleaning facilities to develop and implement new technologies and procedures for handling those samples. JSC is preparing to purchase a benchtop X-ray Fluorescence system and has installed a state-of-the-art scanning Raman system to use in concert with the existing X-ray computed tomography scanner for non-destructive characterization of astromaterials. NASA has made significant strides in advanced curation science by developing techniques for automated small particle manipulation, especially for samples inside dry-Nitrogen purged glove boxes.

NASA is working to ensure that the project properly curates samples returned as part of the Mars Sample Return program or the Artemis missions to the Moon to maximize future science results. These collections are in addition to the eight current collections housed in 22 clean rooms, from which the project has allocated more than 1,400 samples to more than 400 registered Principle Investigators (PIs) in more than 25 countries around the world for scientific research.

SCIENCE DATA AND COMPUTING

This project, through the National Space Science Data Coordinated Archive (NSSDCA), preserves NASA's science data collected since the first robotic missions in the 1960s. The NSSDCA also serves as the back-up archive for the PDS. In addition to serving as a depository that makes unique data and metadata available, the NSSDCA provides the space science community with stewardship, guidance, and support so that data made available to the research community is well documented to provide independent usability.

Recent Achievements

The NSSDCA has made great progress in converting many of the original data sets, which exist in analog form in their original media, to digital data sets accessible online by researchers. The Lunar Data Node continues to restore old Apollo data, packaging the data and overseeing their archive with the PDS. This process involves reading the data, converting it to standard digital formats, and collecting and making

OTHER MISSIONS AND DATA ANALYSIS

sense of the data formats and writing documentation so the researchers can easily access and use the data. NASA has archived 30 data sets within PDS, packaged seven data sets in PDS-compliant formats, and restored and are in the process of packaging 20 data sets, which should undergo review in 2020. NSSDCA is scanning selected critical parts of the microfilm archive into digital formats in an ongoing effort; approximately 250,000 frames of microfilm have been scanned to-date.

ROBOTICS ALLIANCE PROJECT

The Robotics Alliance Project (RAP) is dedicated to increasing interest in engineering, technology, science, and mathematics disciplines among youth in the United States. RAP's goal is to create an inspired, experienced, technical workforce for the aerospace community. Annual activities and events expose students to challenging applications of engineering and science. The RAP supports national robotic competitions in which high school students team with engineering and technical professionals from government, industry, and universities to gain hands-on experience and mentoring.

Recent Achievements

In FY 2019, RAP sponsored 300 FIRST (For the Inspiration and Recognition of Science and Technology) Robotics Competition teams (approximately 8,000 students), 50 VEX robotics teams (approximately 500 students), and sponsored and/or supported 18 FIRST Robotics Competition events (affecting approximately 50,000 students).

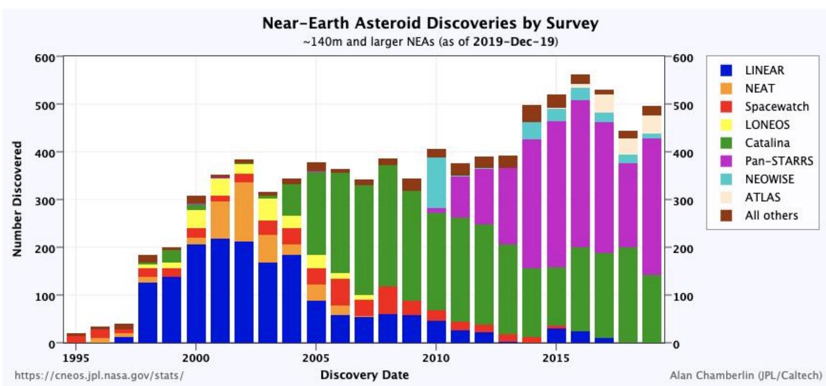
PLANETARY DEFENSE

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
DART	98.0	72.4	**66.4**	9.1	4.5	0.0	0.0
Other Missions and Data Analysis	52.0	--	**83.6**	138.1	93.1	98.0	98.0
Total Budget	**150.0**	**--**	**150.0**	**147.2**	**97.6**	**98.0**	**98.0**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.



Yearly progress in discoveries of near-Earth asteroids larger than 140 meters in size.

Image Credit: NASA/JPL-Caltech

The focus of planetary defense missions is to detect and provide follow-up observations for precision orbit determination and physical characterization of asteroids and comets with the potential to impact the Earth, as well as mounting efforts (from civil disaster response preparations to in space object deflection or disruption missions) to mitigate the effects of an impending near-Earth object (NEO) impact event.

The Planetary Defense Coordination Office (PDCO) manages the Planetary Defense program. PDCO administers the Near-Earth Object Observations (NEOO) project, which funds and coordinates efforts to find, track, and characterize any asteroid or comet that could become an impact hazard to Earth. Scientists conduct these NEO observation efforts at observatories supported by NASA on the ground and in space, as well as by the National Science Foundation and space situational awareness facilities of the United States Air Force.

In addition to finding, tracking, and characterizing NEOs, NASA's planetary defense goals include researching techniques for deflecting or disrupting, if possible, potentially hazardous objects (PHOs) that are determined to be on an impact course with Earth to provide options for United States government response to any detected impact threat. In the event that deflection or disruption of the PHO is not possible due to insufficient time available before impact, the PDCO is responsible for providing expert input to other government agencies, such as the Federal Emergency Management Agency (FEMA), for emergency response operations. The PDCO participates in implementing the U.S. National Near-Earth Object Strategy and Action Plan.

PLANETARY DEFENSE

For more information, go to: https://www.whitehouse.gov/wp-content/uploads/2018/06/National-Near-Earth-Object-Preparedness-Strategy-and-Action-Plan-23-pages-1MB.pdf

The PDCO responsibilities include:

- Managing NASA's Planetary Defense Program;
- Ensuring the early detection of PHOs - asteroids and comets whose orbit are predicted to bring them within 0.05 Astronomical Units, equal to about 5 million miles, of Earth's orbit, and of a size large enough to reach Earth's surface (i.e., greater than perhaps 30 to 50 meters);
- Tracking and characterizing PHOs and issuing warnings about potential impacts;
- Providing timely and accurate communications about PHOs; and
- Performing as a lead coordination node in U.S. Government planning for response to an actual impact threat (see: https://www.nasa.gov/planetarydefense/overview).

EXPLANATION OF MAJOR CHANGES IN FY 2021

This budget supports the initiation of an instrument project, the IR telescope, for detection and tracking of NEOs for use on a future space-based telescope spacecraft. The current mission concept, known as the NEO Surveillance Mission, would position a spacecraft at the Sun-Earth L1 gravity Lagrange point and would operate in the infrared part of the spectrum, which has the advantage of increased sensitivity to the objects as they are heated by the Sun and more accurate characterization of NEO sizes.

DOUBLE ASTEROID REDIRECTION TEST

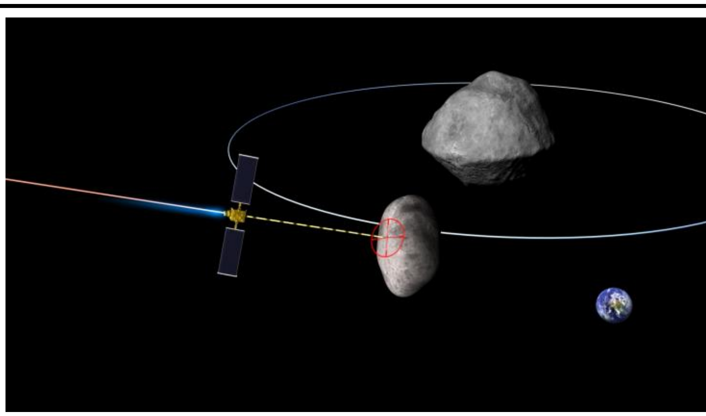
Formulation	Development	Operations

FY 2021 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	BTC	Total
Formulation	40.6	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	40.6
Development/Implementation	22.9	98.0	72.4	**65.0**	0.0	0.0	0.0	0.0	0.0	258.3
Operations/Close-out	0.0	0.0	0.0	**1.4**	9.1	4.5	0.0	0.0	0.0	15.0
2020 MPAR LCC Estimate	**63.5**	**98.0**	**72.4**	**66.4**	**9.1**	**4.5**	**0.0**	**0.0**	**0.0**	**313.9**
Total Budget	**63.5**	**98.0**	**72.4**	**66.4**	**9.1**	**4.5**	**0.0**	**0.0**	**0.0**	**313.9**
Change from FY 2020				**-6.0**						
Percentage change from FY 2020				**-8.3%**						

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.



Artists depiction (not to scale) of the DART spacecraft approaching impact with the moonlet of the double asteroid Didymos. Here, Didymos is close enough to the Earth to allow ground-based telescopes to measure the change in the moonlet's orbit caused by the impact.

PROJECT PURPOSE

The Double Asteroid Redirection Test (DART) is the first planetary defense mission demonstrating the kinetic impact technique to change the motion of an asteroid in space. The target asteroid for DART is the binary asteroid system Didymos. The Didymos system consists of the primary asteroid, Didymos A, that is about 780 meters (1/2 mile) across, and a "moonlet," Didymos B, that is about 163 meters (535 feet) across. The DART spacecraft will demonstrate the kinetic impact deflection method by deliberately crashing into Didymos B at a speed of approximately 13,000 miles per hour, with the aid of an onboard camera and sophisticated autonomous navigation software. The collision will change the period of the orbit of the moonlet around the main body by a fraction of one percent, enough to be measured using telescopes on Earth. By targeting the small moonlet in a binary system, the DART mission plan makes

DOUBLE ASTEROID REDIRECTION TEST

Formulation	Development	Operations

this demonstration possible without causing any detectable change to the orbit of the system about the Sun. The DART mission will demonstrate the effectiveness of the kinetic impact technique for deflecting a hazardous asteroid. NASA will use the mission to improve our understanding of the physics involved and our readiness to respond to an actual asteroid impact threat.

NASA's DART spacecraft has a launch readiness date of February 2022. The targeted impact date with the Didymos B is October 2022, when the Didymos system is within 11 million kilometers of Earth, enabling subsequent observations of the change the orbital period of the moonlet by ground-based telescopes and planetary radar.

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

PROJECT PARAMETERS

NASA plans to launch DART no later than February 2022. DART carries a single camera, the Didymos Reconnaissance and Asteroid Camera for OpNav (DRACO), used by the DART SMARTNav system to guide the spacecraft to impact the moonlet of the double asteroid Didymos. DART will use X-Band communications through the NASA Deep Space Network to downlink the DRACO images prior to impact, which will allow the reconstruction of where on the moonlet the impact occurred. Researchers will measure the change in the orbital period of the moonlet caused by the impact during the 2022 Didymos double asteroid close approach to the Earth, using the world-wide network of optical and radio telescopes.

The DART spacecraft will enable the demonstration of the NASA Evolutionary Xenon Thruster – Commercial (NEXT-C) solar electric propulsion system as a new technology for in-space propulsion systems. The next-generation NEXT-C system, based on the Dawn spacecraft propulsion system, will provide significant flexibility in future mission timelines, including significantly widening the viable launch period (compared to most planetary missions), as well as decreasing the cost of the launch service.

ACHIEVEMENTS IN FY 2019

DART passed its critical design review in June 2019.

WORK IN PROGRESS IN FY 2020

DART will continue final design and fabrication activities, complete its mission operations review, integration readiness review and test readiness review, and conduct its KDP-D gate review for entry into the assembly, integration and test phase.

DOUBLE ASTEROID REDIRECTION TEST

Formulation	Development	Operations

KEY ACHIEVEMENTS PLANNED FOR FY 2021

DART will complete its assembly, integration and test activities in preparation for launch.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2021 PB Request
Formulation Authorization	Mar 2016 (Rev B)	Mar 2016 (Rev B)
MCR	May 2015	May 2015
SRR/MDR	Sep 2016	Sep 2016
KDP-B	Mar 2017	Mar 2017
PDR	Apr 2018	Apr 2018
KDP-C	Aug 2018	Aug 2018
CDR	Jun 2019	Jun 2019
KDP-D	Apr 2020	Apr 2020
ORR/FOR	Mar 2021	Mar 2021
MRR/FRR	May 2021	May 2021
Launch Readiness	Feb 2022	Feb 2022
KDP-E	Mar 2022	Mar 2022
Asteroid Impact/End of Flight Operations	Oct 2022	Oct 2022
End of Ground Observations and Data Analysis	Sep 2023	Sep 2023

DOUBLE ASTEROID REDIRECTION TEST

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2019	258.3	70%	2020	258.3	0	LRD	2/22	2/22	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

NASA confirmed DART to proceed into implementation in August 2018. The NEXT-C electric propulsion technology demonstration system is contributed and is not included in the development cost of this mission.

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**258.3**	**258.3**	**0**
Aircraft/Spacecraft	71.7	95.4	+23.7
Payloads	5.3	6.3	+1.0
Systems I&T	16.5	19.4	+2.9
Launch Vehicle	41.0	68.8	+27.8
Ground Systems	5.7	6.8	+1.1
Science/Technology	3.2	3.8	+0.6
Other Direct Project Costs	114.9	57.8	-57.1

DOUBLE ASTEROID REDIRECTION TEST

Formulation	Development	Operations

Project Management & Commitments

The John Hopkins University/Applied Physics Laboratory (JHU/APL) has project management responsibility for DART.

Element	Description	Provider Details	Change from Baseline
DART Spacecraft	DART Project design and implementation, with the exception of subcontracted subsystems and the government-provided NEXT-C electric propulsion system	Provider: JHU-APL Lead Center: JHU-APL Performing Center(s): JHU-APL Cost Share Partner(s): N/A	N/A
DRACO	The Didymos Reconnaissance and Asteroid Camera for OpNav (DRACO)	Provider: JHU-APL Lead Center: JHU-APL Performing Center(s): JHU-APL Cost Share Partner(s): N/A	N/A
NEXT-C	Government-furnished electric propulsion system not included in LCC	Provider: Aerojet Lead Center: GRC Performing Center(s): GRC Cost Share Partner(s): N/A	N/A
Launch Vehicle	Launch vehicle and all launch services	Provider: Space-X Lead Center: KSC Performing Center(s): KSC Cost Share Partner(s): N/A	

DOUBLE ASTEROID REDIRECTION TEST

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: The SMARTNav autonomous guidance system used to guide the spacecraft during the final approach to impact is not sufficiently robust to variations in the observed binary system, Then: The spacecraft may not hit the target.	The Project has developed and is continuing to refine a high-fidelity emulator of the end-to-end performance of the DRACO camera, image processing pipeline, and SMARTNav algorithms. The Project is varying (in a Monte Carlo analysis) the characteristics of the Didymos system (e.g., size, shape, albedo of each body, orbit characteristics), the approach conditions, and the DRACO and spacecraft parameters to demonstrate the robustness of the design to the range of variations that DART may encounter when it arrives at Didymos.

Acquisition Strategy

NASA is acquiring the flight system for the DART mission from JHU/APL. NASA selected Space-X to provide a dedicated Falcon-9 launch vehicle through a competitive Launch Service task order awarded by NASA's Launch Services Program. NASA is acquiring the NEXT-C propulsion system via the Glenn Research Center from Aerojet.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Prime Contract, Mission Formulation, and Mission Implementation	JHU-APL	Laurel, MD
Launch Vehicle	SpaceX	Hawthorne, CA

DOUBLE ASTEROID REDIRECTION TEST

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Institutional Review Team (IRT)	Sep 2016	System Requirements Review (SRR) to assess readiness for preliminary design and technology completion (Phase B)	After the SRR, NASA decided to establish the DART SRB and insert an SRB Status Review before approving KDP-B	PDR
Performance	Standing Review Board (SRB)	Feb 2017	SRB Status Review to assess SRR results, progress/ resolution of SRR actions, changes since the SRR, and to assess readiness for Phase B	Successful	PDR
Performance	SRB	Apr 2018	Preliminary Design Review (PDR) to assess readiness for final design and fabrication (Phase C)	Successful	CDR
Performance	SRB	Jun 2019	Critical Design Review (CDR) to assess readiness for to assess readiness for project to begin system assembly, integration, and test (start of Phase D)	Successful	ORR
Performance	SRB	Mar 2021	Operational Readiness Review (ORR) to assess readiness for system launch, checkout, (completion of Phase D), operations, and sustainment (Phase E)	TBD	

OTHER MISSIONS AND DATA ANALYSIS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Near Earth Object Observations	52.0	--	**83.6**	138.1	93.1	98.0	98.0
Total Budget	**52.0**	**--**	**83.6**	**138.1**	**93.1**	**98.0**	**98.0**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

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Mission Planning and Other Projects

NEAR-EARTH OBJECT OBSERVATIONS (NEOO)

The NEOO project uses ground and space-based assets to look for Near-Earth Objects (NEOs) that have any potential to collide with Earth and characterizes them to assess if any could do significant damage to the planet. NEOs range in size from a few meters to approximately 34 kilometers. NEOs of one kilometer or larger in size are close to 1,000 in number, while those between one kilometer to 100 meters in size may number as much as 38,000.

The NEOO project supports a network of search and characterization observatories and the data processing and analysis required to understand the near-Earth population of small bodies. In accordance with the findings and recommendations of the National Academies studies on the NEO hazard in 2010 and on visible and infrared NEO survey capabilities in 2019, NASA continues to:

- Analyze the small body data collected by the reactivated the Wide-field Infrared Survey Explorer (WISE) mission, now called NEOWISE, and support increased follow-up and analysis of this data;
- Increase collection of NEO detection and characterization data by the Catalina Sky Survey, the Panoramic Survey Telescope and Rapid Reporting System (Pan-STARRS), and the United States Air Force’s (USAF) Space Surveillance Telescope;
- Support the operation of the four small telescope wide field survey sites called the Asteroid Terrestrial-impact Last Alert System (ATLAS), designed to detect smaller asteroids as they approach the Earth and warn of any imminent impact, two of which will operate at southern hemisphere sites;
- Support the continued and enhanced operation of planetary radar capabilities at the National Science Foundation’s Arecibo Observatory (now under University of Central Florida management) and NASA’s Goldstone Deep Space Network facilities; and
- Investigate both ground and space-based concepts for increasing capacity to detect, track, and characterize NEOs of all sizes.

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Since NASA's search started in 1998, the project has found over 96 percent of these objects that are one kilometer and larger, and about 36 percent of all those larger than 140 meters in size. NEOs discovered and characterized by the project may also be viable targets for future robotic and human exploration, and possible eventual candidates for asteroid resource utilization operations.

For more information on NEOO, go to: https://www.nasa.gov/planetarydefense/overview and https://cneos.jpl.nasa.gov/about/search_program.html

The Infrared Telescope Facility (IRTF) is NASA's infrared-optimized three-meter telescope sited at an altitude of 13,600 feet on the extinct volcano Mauna Kea on the Big Island of Hawai'i. The NEOO project funds IRTF operations and IRTF is a primary NASA planetary defense asset for NEO physical characterization. IRTF continues its mission of strategic support of NASA flight missions and science goals in both planetary science and astrophysics while being on-call for rapid response observations of NEO targets of opportunity and potential threats.

For more information on IRTF, go to: http://irtfweb.ifa.hawaii.edu/

The NEOWISE mission uses the Wide-field Infrared Survey Explorer (WISE) spacecraft, a 40-centimeter (16-inch) diameter infrared telescope in Earth-orbit that continues an all-sky astronomical survey with its two detectors, which remain in non-cryogenic operations. NEOWISE capabilities and vantage point enable contribution to NEO discovery and, more significantly, understanding the physical properties of large numbers of NEOs, comets, main-belt asteroids, and other minor planets.

For more information on NEOWISE, go to:
https://www.nasa.gov/mission_pages/neowise/mission/index.html

NASA will initiate a space-based infrared instrument for NEO search and characterization toward the goal of a NEO surveillance mission.

Recent Achievements

In FY 2019, asteroid search teams funded by the NEO Observations project found another six near-Earth asteroids (NEAs) larger than one kilometer (km) in size with orbits that come close to Earth's vicinity. Asteroid search teams also found 2,178 NEAs less than one km in size and observers found one additional Earth-approaching comet, bringing the total known population of NEOs to 20,944 NEAs and 108 Earth-approaching comets as of September 30, 2019. The high-precision orbit predictions computed by the Center for Near-Earth Object Studies at JPL show that none of these objects are likely to strike the Earth in the next century. However, as of October 24, 2019, there are 2,021 near-Earth asteroids (of which 156 are larger than one km in diameter), with 86 found in FY 2019, in orbits that could become a hazard in the more distant future and warrant continued monitoring.

NASA and the Johns Hopkins University Applied Physics Laboratory, with other space agencies and organizations participation, held the sixth International Academy of Astronautics Planetary Defense Conference on April 29- May 3, 2019. This key biannual worldwide meeting involved updates on planetary defense research and technology as well as an asteroid impact scenario to exercise the participating U.S. government agencies and international entities.

Researchers studied asteroids in detail during their close-approaches to Earth, characterizing small or potentially hazardous asteroids and yielding important new near-Earth asteroid discoveries. During FY

OTHER MISSIONS AND DATA ANALYSIS

2019, 74 asteroids passed Earth within the distance from the Earth to the Moon. Six of the smaller asteroids (less than 20 meters in size) passed within the distance of the geosynchronous satellites. All 74 asteroids were discovered in the days either just prior to or just following close-approach. Researchers discovered a larger asteroid, 2019 OK, just before it approached at one-fifth the distance to the Moon. NASA estimates the asteroid to be 60-130 meters in size, and is the largest asteroid known to pass that close to Earth in the last century. In July 2019, researchers found asteroid 2006 QV89, which has an uncertain orbit, not to be where it would need to have been for a possible impact to Earth in September 2019. This finding eliminated the small but finite impact probability.

The Center for Near-Earth Object Studies (CNEOS) in coordination with the NASA-sponsored Minor Planet Center that received the observations, with follow-up observers, and with ESA's Near-Earth Object Coordination Center confirmed the discovery of a second interstellar object, a comet designated 2I/Borisov (C/2019 Q4). The Scout system at CNEOS flagged the new discovery by an amateur astronomer on August 30, 2019 at the MARGO observatory in Nauchnij, Crimea. The team calculated the comet's precise trajectory to determine that it originated from outside our solar system. Characterization observations by NEOO-funded observers and the Hubble Space Telescope indicated that the comet is not unlike those in our own solar system.

NASA tasked the National Academies of Sciences, Engineering, and Medicine in 2018 to analyze the advantages and disadvantages of telescope capabilities in detecting NEOs. The findings in the report issued in June 2019 found that a space-based infrared NEO survey telescope would be more effective than space-based visible telescopes, providing much tighter constraints on NEO diameters for approximately the same costs. The report also pointed to the value of continued short and long-term ground-based observations for orbit determination and physical characterization to help assess risk.

During FY 2019, the NEOWISE mission completed its fifth year of NEO survey operations. The instrument recently surpassed 111 billion recorded measurements of asteroids, comets, stars, and galaxies, and provided critical data on near Earth objects as well as other objects in our solar system. The cumulative NEOWISE data release products from five years of operations include almost 15 million single exposure images, and 760 thousand confirmed detections of 32 thousand moving objects in the solar system. Scientists have referenced data from NEOWISE in over 1,000 separate astronomical publications and continue to use this data to generate major insights in the study of minor planets. NASA is extending operations to July 2020 when engineers expect the spacecraft to exceed usable temperatures. The mission will be complete at that time. Updates to PDS will occur at the end of the mission with the reprocessing results and other updated results.

A space-based infrared instrument for NEO search and characterization formulation continued its extended Phase A study. The instrument's focus is exclusively on planetary defense asteroid and comet survey requirements, with tasks targeted toward decreasing risk by procuring and developing components for the infrared focal plane detector and by conducting the modeling needed to define thermal and operational requirements.

WORK IN PROGRESS FY 2020

The NEOWISE spacecraft, whose orbit has been moving away from the ideal sun synchronous orbit alignment since its year of prime operations in 2010, will likely reach a point in summer 2020 where the Sun's light will reach too far down into the telescope. The heat will effectively blind the infra-red

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detectors, terminating the useful life of the spacecraft. NEOWISE has no orbital maintenance thrust capability, therefore, it cannot compensate for this natural movement.

NASA plans to initiate a space-based infrared instrument for NEO search and characterization toward the goal of a NEO surveillance mission. NASA plans to hold a KDP-B review for the instrument in FY 2020 allowing it to proceed to the preliminary design and technology completion phase.

The United States Air Force's (USAF) Space Surveillance Telescope is in the process of test and commissioning in Australia. NASA continues to coordinate with USAF Space Command on a logistical and funding path for transferring the data from Australia to the US used for asteroid detection and tracking. The Lincoln Near-Earth Asteroid Research team continues to prepare the data processing pipeline for the data.

The Asteroid Terrestrial-impact Last Alert System (ATLAS) team identified partners and sites in South Africa and Chile and will continue the component procurements and the development of the two new ATLAS observatory stations in those locations.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

NASA will continue to support a network of search and characterization observatories and the data processing and analysis required to understand the near-Earth population of small bodies. NASA will continue instrument formulation for a potential space-based infrared capability, the NEO Surveillance Mission, that would support NEO survey objectives as identified in the 2019 National Academies study and the goal of finding at least 90 percent of the 140 meter and larger near-Earth asteroids.

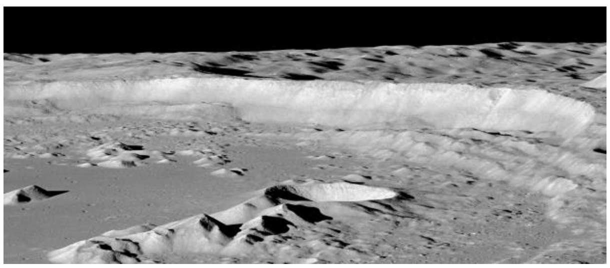
LUNAR DISCOVERY AND EXPLORATION

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Other Missions and Data Analysis	188.0	--	**451.5**	517.3	491.3	458.3	458.3
Total Budget	**188.0**	**--**	**451.5**	**517.3**	**491.3**	**458.3**	**458.3**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.



The Moon, shown above, is our nearest neighbor and a location rich in scientific interest and potential resources.

NASA's exploration strategy, including the Artemis program, will provide an innovative and sustainable approach to scientific and human exploration with commercial and international partners to enable human expansion across the solar system and to bring new knowledge and opportunities back to Earth. The Agency will achieve these accomplishments through public-private partnerships with emerging commercial capabilities and innovative approaches to achieving human and science exploration goals, including the return of humans to the Moon.

The Lunar Discovery and Exploration Program (LDEP) in the Science Mission Directorate is a key component of the Agency's exploration strategy. It includes the establishment of commercial contracts for lunar landing transportation services, the development of instruments that serve lunar science, long-term exploration and utilization needs, the development of smallsats that will provide innovative investigations, continued operations of the Lunar Reconnaissance Orbiter (LRO), and the development of long-duration lunar rovers that will utilize commercially developed landers to get to the lunar surface. NASA is prioritizing capabilities that support lunar resource analysis and prospecting to inform future human space flight objectives.

In partnership with United States industry and the scientific community, the program is developing lunar surface payloads (and supporting orbital payloads) along with cost-effective ways to deliver and provide services for these payloads. These payloads and services address the nation’s lunar exploration, science, and technology demonstration goals, many of which are outlined in the National Academies of Sciences 2011 Decadal Survey: Vision and Voyages for Planetary Sciences in the Decade 2013-2022, the National Research Council 2007 Report: The Scientific Context for the Exploration of the Moon, and the NASA Strategic Knowledge Gaps.

For more information, go to: https://www.nasa.gov/exploration/library/skg.html

LUNAR DISCOVERY AND EXPLORATION

NASA plans to fly NASA instruments and technology demonstration payloads on existing and forthcoming commercial missions and purchase transportation services to the Moon for the NASA payloads or instruments (to include landing and surface access to agreed-upon locations on the lunar surface). NASA payloads will obtain "utilities" from commercial landers such as power, communications, thermal control, etc., during launch integration, launch, and cruise phase, and potentially after landing. In addition, NASA will pursue the purchase of science or engineering data provided by contractor payloads and the return of payload and/or samples to the Earth.

One area of focus will be instrumentation to advance the knowledge and technologies for the use of local resources, such as lunar water ice. Working with the science and human exploration communities, our international partners, and United States industry, NASA will refine the goals and objectives for a robust and sustainable lunar exploration and science program.

EXPLANATION OF MAJOR CHANGES IN FY 2021

The budget for LDEP increases in FY 2021 to adequately fund the enhanced Commercial Lunar Payload Services (CLPS) landing capability to deliver the Volatiles Investigating Polar Exploration Rover (VIPER) to the lunar surface. NASA will award the procurement for the VIPER delivery service in FY 2020. The budget also supports planning for the delivery of larger scientific, exploration, and technology payloads.

ACHIEVEMENTS IN FY 2019

NASA released the CLPS Request for Proposal (RFP) to procure commercial lunar landing services and selected nine companies in November 2018 to receive CLPS contracts. NASA then issued its first delivery task order and two companies, Astrobotic and Intuitive Machines, are under contract to deliver NASA payloads to the surface of the Moon in 2021. The NASA payloads consist of science, technology, and exploration-focused instruments. Both Astrobotic and Intuitive Machines are delivering payloads provided by customers other than NASA. NASA also released a CLPS study task order relating to mobility and enhanced landing capability. This task order resulted in awards to Lockheed Martin and Astrobotic.

NASA continued operations of LRO. LRO provides a treasure trove of lunar data that helps to characterize and conduct detailed surveys of potential landing sites for commercial missions.

NASA released a call for smallsats through the Small Innovative Missions for Planetary Exploration (SIMPLEX) research announcement in support of planetary science investigations. NASA selected one prospective investigation of the Moon called Trailblazer for further mission concept study. In addition, NASA awarded grants to several teams of scientists through the Apollo Next Generation Sample Analysis NASA research announcement. These teams are analyzing specially curated lunar samples including an Apollo 17 lunar sample that has been sealed since it was returned to Earth in 1972.

WORK IN PROGRESS IN FY 2020

NASA awarded 12 NASA-provided lunar payloads and 12 lunar surface instrument and technology payloads to begin building a robust pipeline of instruments to fly on CLPS. Final development of these instruments continues in FY 2020. NASA conducted discussions between the instrument principal investigators and the awarded CLPS providers. Funding for future instrument development through the Development and Advancement of Lunar Instrumentation (DALI) research call continues. The VIPER rover development continues with the preliminary design review (PDR) planned for April 2020. In November 2019, NASA made selections of five new CLPS contracts for enhanced landing capability. NASA will release a task order and make an award to the CLPS providers to deliver the VIPER rover to the lunar surface in early FY 2023.

NASA continues to engage with the science community, NASA's international exploration partners, and United States industry to refine the exploration, scientific, and technology objectives in support of LDEP.

NASA continues to operate LRO in support of scientific research and future science and exploration mission planning. NASA will provide LRO landing site characterization capabilities to international partners for future lunar lander missions when requested.

NASA is conducting studies to develop mobility capabilities for future science and resource investigations. NASA will release a request for information (RFI) to obtain data concerning existing or future mobility capabilities that NASA could procure through commercial services.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

In FY 2021, NASA will continue to work with the selected CLPS providers to launch and land NASA scientific, exploration, and technology payloads on the surface of the Moon.

Planning for the delivery of larger scientific, exploration, and technology payloads will continue across the NASA mission directorates, utilizing the CLPS providers to deliver these payloads to the lunar surface.

The VIPER rover will complete its critical design. Integration discussions will continue between the VIPER project and the awarded landing delivery service provider.

NASA will competitively select additional robotic lunar surface payloads. These payloads will fly on the CLPS-provided launch and landing services to the lunar surface.

NASA will continue operations of LRO and offer LRO landing site characterization capabilities to international and commercial partners upon request.

LUNAR DISCOVERY AND EXPLORATION

Program Schedule

Date	Significant Event
FY 2019	Award first CLPS mission task order
FY 2019	Award Development and Advancement of Lunar Instrumentation (DALI) program procurements
FY 2019	Award robotic surface payloads procurements
FY 2019	Conduct rover capability studies/Assess commercial lander options for rover
FY 2020	Award second CLPS mission task order
FY 2020	Award CLPS on-ramp providers for enhanced landing capability
FY 2020	Award VIPER rover delivery services task order
FY 2020	Request for proposal for robotic surface payloads
FY2020	Release request for information for commercial lunar mobility services
FY 2020	Request for proposal for the DALI program
FY 2021	Request for proposal for Lunar Surface Instrument and Technology Payloads Awards
FY 2021	Request for proposal for the DALI program

Program Management & Commitments

Program Element	Provider
Lunar Reconnaissance Orbiter	Lead Center: Goddard Space Flight Center (GSFC) Performing Center(s): GSFC, Applied Physics Laboratory (APL), Jet Propulsion Laboratory (JPL) Cost Share Partner(s): N/A
Lunar Surface Instrument and Technology Payloads	Provider: Various Lead Center: Marshall Space Flight Center (MSFC) Performing Center(s): TBD Cost Share Partner(s): TBD
Commercial Lunar Payload Services	Provider: Various Lead Center: Johnson Space Center (JSC) Performing Center(s): TBD Cost Share Partner(s): TBD

Acquisition Strategy

LDEP uses flexible contract mechanisms, such as indefinite-delivery-infinite-quantity (IDIQ) contracts, to enable the flexible and rapid procurement of commercial transportation services to deliver NASA scientific, exploration, and technology development payloads to the surface of the Moon, plus potential supporting services (orbital assets) and sample return.

In parallel, NASA uses its established solicitation mechanisms, such as the Research Opportunities in Space and Earth Science (ROSES) NASA Research Announcement (NRA) and the Stand Alone Missions of Opportunity (SALMON) Announcement of Opportunity (AO) processes, to select and develop exploration, scientific, and technology development payloads for delivery to the Moon. In some cases, NASA may direct a NASA Center to develop a lunar capability or surface payload when it is in the Government's best interest, such as when that capability supports multiple NASA applications or when a commercial entity or international partner identifies a near-term opportunity for a lunar surface mission on a timeframe that does not support competitive selection. However, to the maximum extent possible, NASA will leverage commercial efforts.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Commercial Lunar Payload Services	Astrobotic Technology	Pittsburgh, PA
Commercial Lunar Payload Services	Intuitive Machines	Houston, TX
Commercial Lunar Payload Services	Lockheed Martin	Bethesda, MD

OTHER MISSIONS AND DATA ANALYSIS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Lunar Future	1.8	--	**70.0**	107.4	111.9	111.0	111.0
Lunar Reconnaissance Orbiter (LRO)	22.0	--	**22.0**	22.0	22.0	22.0	22.0
Lunar Instruments	55.7	--	**37.5**	70.8	75.8	70.8	70.8
Commercial Lunar Payload Services	68.4	--	**254.0**	254.0	254.0	254.0	254.0
Lunar Internationall Mission Collaboration	0.5	--	**0.5**	0.5	0.5	0.5	0.5
VIPER	39.7	--	**67.5**	62.6	27.0	0.0	0.0
Total Budget	**188.0**	--	**451.5**	**517.3**	**491.3**	**458.3**	**458.3**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

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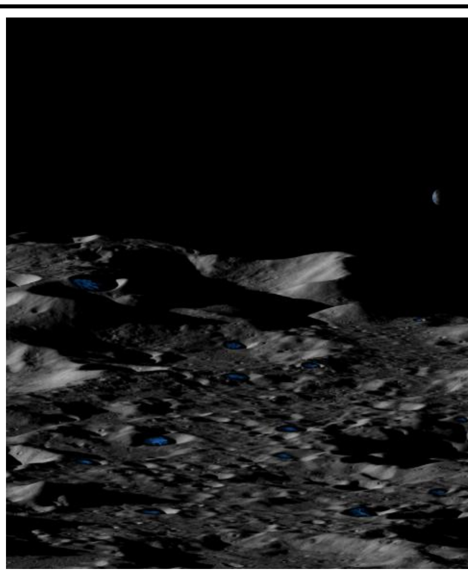
Mission Planning and Other Projects



New work with LRO raises the possibility that thick ice-rich deposits exist on the Moon. If confirmed, this potential reservoir of frozen water on the Moon, depicted above, may be sufficiently massive to sustain long-term lunar explorations.

COMMERCIAL LUNAR PAYLOAD SERVICES

With the strategic goal of supporting affordable commercial operations on and near the Moon that support NASA and the needs of an emerging private sector market, the Commercial Lunar Payload Services (CLPS) is opening competition to United States commercial providers of space transportation services, consistent with the National Space Transportation Policy and Commercial Space Act. CLPS consists of a multi-vendor catalog, 10-year indefinite-delivery-indefinite-quantity (IDIQ) contract, managed through task order competition for specific lunar surface transportation services of payloads with NASA being one of several customers.

Recent Achievements

NASA announced awards to an inaugural nine companies for the CLPS 10-year IDIQ contract in November 2018 for landed lunar payload delivery services. NASA then issued its first delivery task order, and two companies, Astrobotic and Intuitive Machines, are under contract to deliver NASA payloads to the surface of the Moon in 2021. The NASA

OTHER MISSIONS AND DATA ANALYSIS

payloads consist of science, technology, and exploration-focused instruments. Both Astrobotic and Intuitive Machines are delivering payloads provided by customers other than NASA. See the list of commercial service company awardees in the Major Contract/Awards table of the Lunar Discovery and Exploration Program section.

NASA released a CLPS study task order relating to mobility and enhanced landing capability. This task order resulted in awards to Lockheed Martin and Astrobotic.

In July 2019, NASA issued an on-ramp opportunity to add additional companies to the CLPS catalog. The on-ramp focused on adding additional enhanced landed capabilities to the CLPS contract for near-term Agency exploration needs. NASA selected five new CLPS providers in November 2019.

LUNAR INSTRUMENTS

NASA is developing instruments and technology payloads to manifest on both CLPS and international lunar lander missions. These instruments come from United States academia and industry, as well as from NASA Centers.

Recent Achievements

NASA announced awards in February and May of 2019 for near ready-to-fly lunar surface instruments and technology payloads to fly on the early CLPS missions. NASA awarded 12 NASA-provided lunar payloads and 12 lunar surface instrument and technology payloads to begin building a robust pipeline of instruments to fly on CLPS. Funding for future instrument development through the Development and Advancement of Lunar Instrumentation (DALI) research call will continue in FY 2020.

NASA provided the laser retro-reflector assembly (LRA) on the first Israeli lunar lander built by SpaceIL. The LRA provides a location marker for any lunar orbiting spacecraft, or future landers, which has a laser to obtain geolocation data relative to the LRA. NASA installed a similar LRA on the India Space Research Organization (ISRO) Chandrayaan-2 lunar lander. Unfortunately, neither lander was able to execute a soft landing on the lunar surface.

LUNAR INTERNATIONAL MISSION COLLABORATION

Under the Lunar International Mission Collaboration (LIMC) activity, NASA funds participating science investigators and provides international collaborators lunar landing site characterization data, as well as navigation and data relay services, in exchange for United States participation.

Recent Accomplishments

NASA signed agreements with the Israel Space Agency (ISA) and the India Space Research Organization (ISRO) to fly laser retro-reflectors assemblies on their respective lunar landers. A similar agreement is under discussion with the Japan Aerospace Exploration Agency (JAXA) to fly an LRA on their Smart Lander for Investigating Moon (SLIM) lander scheduled to fly in 2021. In addition to providing LRAs, NASA also provided Deep Space Network support to aid in mission communication for both ISA and ISRO during their respective lunar lander missions. NASA used the Lunar Reconnaissance Orbiter spacecraft to attempt to image the final landing sites of the ISA lander and the ISRO lander. LRO imaged the ISA lander location, while LRO is still searching for the ISRO lander location.

OTHER MISSIONS AND DATA ANALYSIS

NASA will continue to look for opportunities to fly LRAs and other instrumentation in collaboration with existing and future international partners.

VIPER

A CLPS provider will deliver the NASA-built Volatiles Investigating Polar Exploration Rover (VIPER) to the South Pole of the Moon in early FY 2023. The goal of VIPER is to provide key information on the distribution of volatiles (e.g., water, methane, hydrogen) on the lunar surface and within one meter below the surface. It will rove for tens of kilometers and operate for several months.

LUNAR FUTURE

Lunar Future supports a variety of activities that help NASA achieve human and science exploration goals, including the return of humans to the Moon. From the recent Small Innovative Missions for Planetary Exploration call, NASA selected a smallsat called Trailblazer for further mission concept study. Trailblazer will use a hyperspectral imager to map the mineralogy of the lunar surface. This data will provide new information on the migration of surface volatiles, as well as look for other resources (e.g., ice, water). NASA awarded several grants through the Apollo Next Generation Sample Analysis NASA research announcement to analyze specially curated lunar samples, including one Apollo 17 lunar sample sealed since it was returned to Earth in 1972. The purpose of keeping these samples in pristine condition was to wait for new analysis capabilities to come into existence.

NASA is also studying future lunar mission capabilities, including long-duration rovers that can survive a lunar night and future orbiters that would acquire new key data sets.

Operating Missions

LUNAR RECONNAISSANCE ORBITER (LRO)

Over the upcoming year, LRO will continue characterizing areas on the Moon that may contain volatiles at or near the surface. LRO's observations will continue to improve what we know about the interior of the Moon based on surface observations of geologically young volcanic deposits and apparently young tectonic features. LRO will also characterize landing sites in support of the upcoming United States commercial lunar lander missions. Such characterization leverages data from all instruments to identify not just safe landing sites but also ones that maximize the scientific return from a landed mission.

Recent Achievements

The LRO mission continues to focus on lunar volatiles (e.g., ice, water), where these volatiles come from, how they move about on the lunar surface, and where they end up. LRO has also been characterizing the thermal history of the Moon by identifying unusual volcanic features that may be geologically young, as young as 50 million years old. Such features are targets for all instruments as the mission works to use multiple datasets to investigate the Moon. By re-imaging the Moon to detect changes in the surface over the life of the mission, LRO continues to refine constraints on the rate at which meteor impacts disturb and overturn the surface.

OTHER MISSIONS AND DATA ANALYSIS

LRO data has put new constraints on the rate of crater formation on Earth. The LRO team discovered that the rate of large crater formation on the Moon has been two to three times higher over approximately the last 290 million years than it had been over the previous 700 million years. This discovery indicates that the Earth has fewer older craters on its most tectonically stable regions because the impact rate was lower about 290 million years ago and not because of erosion erasing them as had been previously thought.

DISCOVERY

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Lucy	165.5	210.8	**153.4**	63.7	16.5	18.6	22.9
Psyche	174.2	219.3	**187.4**	152.4	28.7	29.0	32.0
Other Missions and Data Analysis	69.8	--	**143.5**	208.3	389.6	522.5	450.9
Total Budget	**409.5**	**--**	**484.3**	**424.4**	**434.8**	**570.1**	**505.8**

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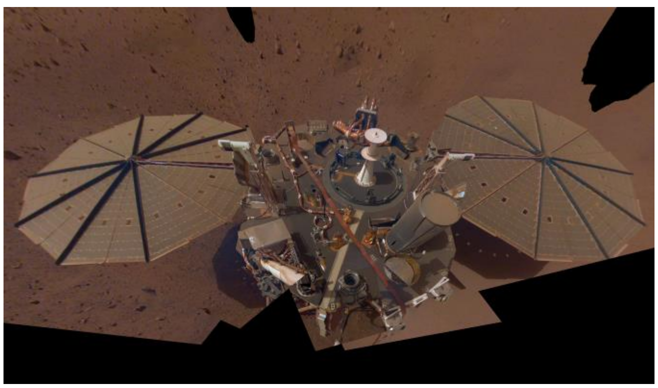

InSight lander on the surface of Mars. This 'selfie' is a mosaic made up of 14 images taken between March 15 and April 11, 2019, by InSight's Instrument Deployment Camera, located on its robotic arm.

Image Credit: NASA/JPL-Caltech

NASA's Discovery program supports innovative, competitively-selected Planetary Science missions. Discovery provides scientists the opportunity to identify innovative ways to unlock the mysteries of the solar system through missions to explore the planets, their moons, and small bodies, such as comets and asteroids.

The Discovery program currently has one operational spacecraft, the Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight), and two missions in development: Lucy and Psyche. The program has developed and delivered the Strofio instrument as a part of the joint European Space Agency (ESA) and Japanese Aerospace Exploration Agency (JAXA) BepiColombo mission to Mercury. NASA and JAXA are engaged in joint studies for NASA's participation in the Martian Moons eXploration (MMX) mission to the moons of Mars, planned for launch in 2024. NASA has competitively selected MEGANE (Mars-moon Exploration with Gamma rays and Neutrons), a neutron and gamma-ray spectrometer instrument, for flight on the MMX spacecraft.

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

DISCOVERY

ACHIEVEMENTS IN FY 2019

Psyche completed its preliminary design review in March 2019.

Psyche passed its Key Decision Point-C (KDP-C) gate review in May 2019 and entered its final design and fabrication phase (KDP-C).

WORK IN PROGRESS IN FY 2020

Lucy successfully completed its Critical Design Review (CDR) in October 2019. It will conduct its KDP-D gate review in August 2020 and proceed into its assembly, integration, and test phase (KDP-D).

Psyche will conduct its CDR in April 2020.

MEGANE will conduct its KDP-C gate review in May 2020 and enter its final design and fabrication phase (KDP-C).

NASA will select missions from the 2019 Discovery Announcement of Opportunity (AO) to develop concept study reports. NASA plans to receive the reports by October 2020.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

NASA will evaluate the concept study reports and down-select up to two missions to proceed into formulation from the 2019 Discovery AO.

Psyche will conduct is KDP-D gate review in January 2021 and begin its assembly, integration, and testing of the flight hardware in February 2021.

InSight will complete its prime mission.

Program Schedule

Date	Significant Event
2019	Release 2019 Discovery AO solicitation
2020	Select proposals from 2019 Discovery AO for concept study reports
2021	Lucy Launch
2021	Down-select up to two missions from 2019 Discovery concept study reports
2022	Psyche Launch
2023	Release 2023 Discovery AO solicitation

DISCOVERY

Program Management & Planned Cadence

The Discovery Program is a multiple-project program, with responsibility for implementation assigned to the Planetary Missions Program Office, located at the Marshall Space Flight Center (MSFC).

The Discovery Program has an objective to launch a flight mission an average of once every 36 months, with a goal of one every 24 months, commensurate with the availability of adequate funding. This budget provides for an average mission cadence of every 27 months.

Acquisition Strategy

NASA competitively selects new Discovery missions, releasing AOs when available funding allows.

INDEPENDENT REVIEWS

The Discovery Program's next Program Implementation Review (PIR) will occur in 2021.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
PIR	Standing Review Board (SRB)	Aug 2016	Review implementation of program	Passed	2021

LUCY

Formulation	Development	Operations

FY 2021 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	BTC	Total
Formulation	94.7	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	94.7
Development/Implementation	44.2	165.5	210.7	**153.4**	40.4	0.0	0.0	0.0	0.0	614.2
Operations/Close-out	0.0	0.0	0.0	**0.0**	23.4	16.5	18.6	22.9	190.8	272.2
2020 MPAR LCC Estimate	**138.9**	**165.5**	**210.7**	**153.4**	**63.8**	**16.5**	**18.6**	**22.9**	**190.8**	**981.1**
Total Budget	**138.9**	**165.5**	**210.8**	**153.4**	**63.7**	**16.5**	**18.6**	**22.9**	**190.8**	**981.1**
Change from FY 2020				**-57.4**						
Percentage change from FY 2020				**-27.2%**						

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Lucy will for the first time investigate Trojan asteroids, which are of particular scientific interest because they are leftovers of giant planet formation and provide a fossil record of the early history of the outer Solar System.

PROJECT PURPOSE

Lucy will investigate the "fossils" of planet formation. The mission name honors the primitive Australopithecus human fossil Lucy and the influence it has had in advancing understanding of the history of our species. The Lucy mission supports the goals of advancing the knowledge of our planetary origin and gaining understanding of the formation and evolution of our solar system.

The Lucy mission will investigate six primitive asteroids: one in the main asteroid belt, four Jupiter Trojans orbiting ahead of the planet, and a binary system (two asteroids in orbit around each other) of Trojans orbiting behind Jupiter. Scientists believe Trojans are primitive, volatile, and organic rich bodies that are gravitationally shepherded by Jupiter. These bodies are the leftover building blocks of the giant outer planets. Lucy is the first mission to visit the Jupiter Trojan asteroids. NASA plans to launch no later than November 2021.

LUCY

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

PROJECT PARAMETERS

NASA selected the Lucy mission in December 2016 from the Discovery Program's 2014 Announcement of Opportunity (AO). Lucy, with a launch date no later than November 2021, will reach its first Trojan in 2027, and it will have its final Trojan asteroid encounter in 2033. During its lifetime, Lucy will perform five Trojan encounters, closely studying these fascinating objects (one encounter is of a nearly equal mass binary).

Lucy's 21-day launch window is open from October 16, 2021, to November 5, 2021. Lucy's instrument payload includes a panchromatic and color visible imager (L'Ralph), a high-resolution visible imager (L'LORRI), and a thermal infrared (IR) spectrometer (L'TES). In addition, Lucy will perform Doppler mass determinations using its radio subsystem.

Lucy will have a heliocentric trajectory and perform all its flybys in a period of 11.6 years. Lucy will fly by and extensively study several different taxonomic classes of Jupiter Trojans, plus a main belt asteroid binary. A fortuitous orbital alignment that is unlikely to recur in the near future enables this comprehensive tour.

ACHIEVEMENTS IN FY 2019

Lucy successfully completed its critical design review (CDR) and continued final design and fabrication and risk reduction activities throughout FY 2019.

WORK IN PROGRESS IN FY 2020

Lucy will conduct its System Integration Review (SIR), followed by Key Decision Point-D (KDP-D), and proceed to its system assembly, integration, and test phase (Phase D) in September 2020.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

Lucy will complete its assembly, integration, and test activities in preparation for launch.

LUCY

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2021 PB Request
KDP-C	Nov 2018	Nov 2018
CDR	Oct 2019	Oct 2019
SIR	July 2020	Jul 2020
KDP-D	Aug 2020	Aug 2020
Operations Readiness Review (ORR) / Flight Readiness Review (FRR)	Aug 2021	Aug 2021
Launch	Nov 2021	Nov 2021
Start Phase E	Dec 2021	Dec 2021

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2019	622.2	70%	2020	614.2	-1.3%	Launch Readiness Date (LRD)	Nov 2021	Nov 2021	0

Note: The confidence level (CL) estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

LUCY

Formulation	Development	Operations

Development Cost Details

NASA confirmed Lucy to proceed into implementation in October 2018.

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**622.2**	**614.2**	**-8.0**
Aircraft/Spacecraft	161.3	157.3	-4.0
Payloads	43.2	43.0	-0.2
Systems I&T	30.7	30.7	0
Launch Vehicle	161.2	148.3	-12.9
Ground Systems	17.2	17.2	0
Science/Technology	14.3	13.3	-1.0
Other Direct Project Costs	194.3	204.4	+10.1

Project Management & Commitments

The principal investigator for Lucy is from the Southwest Research Institute (SwRI). Goddard Space Flight Center (GSFC) manages the Lucy mission and will provide systems engineering, safety and mission assurance, project scientists, flight dynamics, payload management, and mission system management.

Element	Description	Provider Details	Change from Baseline
Spacecraft	Spacecraft bus and propulsion system	Provider: Lockheed Martin Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

LUCY

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Panchromatic Visible Imager and IR Spectrometer (L'Ralph = Multi-spectral Visible Imaging Camera + Linear Etalon Imaging Spectral Array)	Provides color and near IR images to discriminate between and map compositional units	Provider: SwRI/GSFC Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
High-Resolution Visible Imager (L'LORRI)	Provides high resolution images to determine shape, geology, and albedo of the Trojans asteroids	Provider: Johns Hopkins University (JHU)/Applied Physics Laboratory (APL) Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Thermal Emission Spectrometer (L'TES)	Provides thermal inertia maps of the Trojans' elemental composition	Provider: Arizona State University (ASU) Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Radio Science	Utilizes the X-band radio telecommunications system to measure the Trojans' mass	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Launch Vehicle	Launch vehicle and related launch services	Provider: United Launch Alliance (ULA) Lead Center: Kennedy Space Center (KSC) Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

LUCY

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: The solar array schedule erodes such that the solar arrays are not delivered by the assembly, test, and launch operations (ATLO) need date, Then: The Lucy environmental test program will need to be reordered and re-planned, resulting in cost and schedule impacts.	Implementing schedule risk mitigation, including working multiple shifts and weekends. Building additional ground support equipment to allow for parallel fabrication and testing. Completing qualification test program on representative coupons (materials used in construction of spacecraft). Completed pathfinder program to inform the fabrication process. Adding personnel to augment existing staff. Project investigating potential ATLO work-arounds.

Acquisition Strategy

NASA competitively selected the Lucy mission through a competitive Discovery 2014 AO and a down-selection in 2017. All major acquisitions are in place. The major elements of the mission and spacecraft are as proposed for the AO. NASA competitively selected the launch vehicle through the NASA Launch Services program.

MAJOR CONTRACTS/AWARDS

NASA selected Lucy through the Discovery Program AO released on November 5, 2014. The Planetary Missions Program Office in Huntsville, AL, provides programmatic oversight of the mission.

Element	Vendor	Location (of work performance)
Spacecraft, System Integration and Test, Launch Operations, Mission Operations	Lockheed Martin	Denver, CO
PI, Co-Is, Science Team, Science Operations, Payload Management	SWRI	Boulder, CO
Project Management, Systems Engineering, SMA, Navigation, L'Ralph Instrument	GSFC	Greenbelt, MD
Launch Vehicle	ULA	Cape Canaveral, FL

LUCY

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board (SRB)	Sep 2018	Preliminary Design Review (PDR)	Successful	Oct 2019
Performance	SRB	Oct 2019	CDR	Successful	Jul 2020
Performance	SRB	Jul 2020	SIR	TBD	Jul 2021
Performance	SRB	Aug 2021	ORR	TBD	

PSYCHE

Formulation	Development	Operations

FY 2021 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	BTC	Total
Formulation	92.3	51.4	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	143.7
Development/Implementation	0.0	122.8	219.3	**187.4**	152.4	0.0	0.0	0.0	0.0	681.9
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	28.7	29.0	32.0	81.1	170.8
2020 MPAR LCC Estimate	**92.3**	**174.2**	**219.3**	**187.4**	**152.4**	**28.7**	**29.0**	**32.0**	**81.1**	**996.4**
Total Budget	**92.3**	**174.2**	**219.3**	**187.4**	**152.4**	**28.7**	**29.0**	**32.0**	**81.1**	**996.4**
Change from FY 2020				**-31.9**						
Percentage change from FY 2020				**-14.5%**						

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Shown here is an artist's impression of the Psyche spacecraft.

PROJECT PURPOSE

The Psyche mission will explore one of the most intriguing targets in the main asteroid belt, a giant metal asteroid known as 16 Psyche. This asteroid measures approximately 140 miles in diameter and, unlike most other asteroids that are rocky or icy bodies, is likely comprised mostly of metallic iron and nickel, similar to Earth's core. Scientists theorize that Psyche may be the exposed core of an early planet that could have been as large as Mars, but which lost its rocky outer layers due to a number of violent collisions billions of years ago. The mission will help scientists understand how planets and other bodies separated into their layers—including cores, mantles, and crusts—early in their histories.

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

PSYCHE

Formulation	Development	Operations

PROJECT PARAMETERS

NASA plans to launch the mission in August 2022 for arrival at 16 Psyche in January 2026, where the spacecraft will spend 21 months in four different orbits. Each orbit will be successively closer to the asteroid to study its shape and magnetic field, topography and spectral characteristics, gravitational field, and elemental compositions, respectively. Each orbit provides knowledge and constraints needed to guide one or more future orbits, and operators have ample time to update the models, plans, and sequences. Psyche's instrument payload includes a multispectral imager, a gamma ray and neutron spectrometer, and a magnetometer. Psyche will use the X-band radio telecommunications system to measure 16 Psyche's gravity field. The mission will aid in our understanding of iron cores and the formation of planets. It will provide insight into terrestrial planets, including Earth, by directly examining what scientists theorized was once the interior of a differentiated body. In addition, it will allow us to explore a world not made of rock or ice, but of metal.

ACHIEVEMENTS IN FY 2019

Psyche conducted its preliminary design review (PDR) in March 2019. The project conducted its Key Decision Point-C (KDP-C) gate review and entered the final design and fabrication phase (Phase C) in May 2019.

WORK IN PROGRESS IN FY 2020

Psyche will continue final design and fabrication and hold its critical design review (CDR) in April 2020.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

Psyche will conduct its KDP-D gate review in January 2021 and will begin the assembly, integration, and testing phase (KDP-D) of the flight hardware in February 2021.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2021 PB Request
KDP-C	May 2019	May 2019
CDR	Apr 2020	Apr 2020
System Integration Review (SIR)	Dec 2020	Dec 2020
KDP-D	Jan 2021	Jan 2021
Operations Readiness Review (ORR)	May 2022	May 2022
Launch	Aug 2022	Aug 2022

PSYCHE

Formulation	Development	Operations

Milestone	Confirmation Baseline Date	FY 2021 PB Request
Phase E Start	Sept 2022	Sept 2022

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2020	681.9	70%	2020	681.9	0	Launch Readiness Date (LRD)	Aug 2022	Aug 2022	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

This is the first report of development costs for this mission.

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**681.9**	**681.9**	**0**
Aircraft/Spacecraft	199.9	223.5	+23.7
Payloads	49.6	53.1	+3.5
Systems I&T	19.2	19.1	-0.1
Launch Vehicle	154.3	154.3	0
Ground Systems	16.1	16.6	+0.5
Science/Technology	9.3	9.1	-0.2

PSYCHE

Formulation	Development	Operations

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
Other Direct Project Costs	233.5	206.1	-27.4

Project Management & Commitments

The Principal Investigator is from Arizona State University (ASU) and leads the management of the mission. The Jet Propulsion Laboratory (JPL) serves as the development Center for the Psyche mission and provides systems engineering; mission assurance; spacecraft design, build, and test; mission and science operations; navigation; and ground data systems.

Element	Description	Provider Details	Change from Baseline
Solar Electric Propulsion Chassis	Spacecraft bus and propulsion system	Provider: Maxar Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Psyche Multispectral Imager	Provides high-resolution images using filters to discriminate between 16 Psyche's metallic and silicate constituents	Provider: ASU Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Magnetometer	Detects and measures the remnant magnetic field of 16 Psyche	Provider: University of California, Los Angeles (UCLA) Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Gamma Ray and Neutron Spectrometer	Detects, measures, and maps 16 Psyche's elemental composition	Provider: APL Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

PSYCHE

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Gravity Science	Utilizes the X-band radio telecommunications system to measure 16 Psyche's gravity field	Provider: Massachusetts Institute of Technology (MIT) Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Launch Vehicle	Launch vehicle and launch services	Provider: TBD Lead Center: Kennedy Space Center (KSC) Performing Center(s): N/A Cost Share Partner(s): N/A	
Deep Space Optical Communications (DSOC)	Demonstrates DSOC technology's capabilities	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): NASA Human Exploration and Operations Mission Directorate (HEOMD)/Space Technology Mission Directorate (STMD)	N/A

Project Risks

Risk Statement	Mitigation
If: The cost of Xenon, used for the ion propulsion engine, exceeds the planned amount due to market fluctuations, Then: Project could incur additional cost.	Perform a market study of options for how and when to purchase Xenon.

Acquisition Strategy

NASA competitively selected the Psyche mission through a competitive Discovery 2014 AO and a down selection in 2017. All major acquisitions are in place. The major elements of the mission and spacecraft are as proposed for the AO. NASA competitively selects the launch vehicle through the NASA Launch Services program.

PSYCHE

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

NASA selected Psyche through the Discovery Program AO released on November 5, 2014. The Planetary Missions Program Office in Huntsville, AL provides programmatic oversight of the mission.

Element	Vendor	Location (of work performance)
Spacecraft	Maxar	Palo Alto, CA
Project Management, Systems Engineering, SMA, Spacecraft Design, Build and Test, Navigation, Operations, Ground Data System	JPL	Pasadena, CA
PI, Co-Is, Imager, Science Data Center	ASU	Tempe, AZ

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board (SRB)	Mar 2019	PDR	Successful	Apr 2020
Performance	SRB	Apr 2020	CDR	TBD	Dec 2020
Performance	SRB	Dec 2020	SIR	TBD	May 2022
Performance	SRB	May 2022	ORR	TBD	TBD

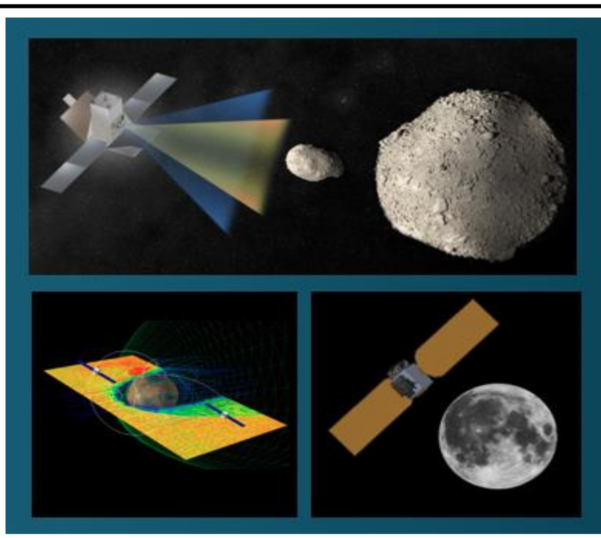
OTHER MISSIONS AND DATA ANALYSIS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
InSight	23.1	--	**11.8**	8.8	8.8	0.0	0.0
Strofio	0.9	--	**1.3**	1.0	0.9	1.0	1.8
International Mission Contributions (IMC)	3.1	--	**11.0**	16.5	16.6	15.9	32.6
Planetary Missions Program Office	13.2	--	**15.0**	16.1	16.2	16.2	16.2
Discovery Future	13.0	--	**67.0**	122.5	307.5	450.4	359.9
Discovery Research	7.7	--	**7.9**	8.8	8.6	8.6	8.6
Dawn	0.2	--	**0.0**	0.0	0.0	0.0	0.0
Planetary SmallSats	4.9	--	**19.7**	28.6	30.0	30.0	30.0
Mars-moon Exploration with GAmma rays and NEutrons (MEGANE)	3.9	--	**9.7**	5.9	1.0	0.6	1.8
Total Budget	**69.8**	**--**	**143.5**	**208.3**	**389.6**	**522.5**	**450.9**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.



In June 2019, NASA selected three finalists among a dozen concepts for future small satellites. The finalists include a 2022 robotic mission to study two asteroid systems (Janus, top image), twin spacecraft to study the effects of energetic particles around Mars (EscaPADE, bottom left), and a lunar orbiter to study water on the Moon (Lunar Trailblazer, bottom right).

Discovery Other Missions and Data Analysis funds research and analysis, management activities, operations of active missions, small projects, and international collaborations. It includes missions of opportunity, operating missions, competed research, funding for future mission selections, and program management activities.

Mission Planning and Other Projects

STROFIO

Strofio (STart from a ROtating FIeld mass spectrOmeter) is a unique mass spectrometer, part of the suite of instruments flown onboard the joint European Space Agency (ESA) and Japanese Aerospace Exploration Agency (JAXA) BepiColombo spacecraft, launched on

OTHER MISSIONS AND DATA ANALYSIS

October 20, 2018. Strofio will determine the chemical composition of Mercury's surface, providing a powerful tool to study the planet's geologic history.

Recent Achievements

The Strofio instrument, onboard the BepiColombo spacecraft, continues in the cruise phase of its nine-year voyage to Mercury. The project has completed the initial near-Earth commissioning phase testing of the Italian Space Agency's instrument suite, which includes NASA's Strofio instrument contribution. This testing included the successful retrieval of Strofio science data packets from the BepiColombo data processing unit.

INTERNATIONAL MISSION CONTRIBUTIONS (IMC)

There are more scientifically interesting destinations across the solar system than any one country's program can quickly undertake. NASA works closely with other space agencies to find opportunities to participate in each other's missions. These opportunities complement NASA-led planetary missions and address additional Decadal Survey priorities when appropriate. Under the International Mission Contributions, NASA funds instruments and scientific investigators and will provide navigation and data relay services in exchange for participation. International missions include the Japanese Space Agency's Hayabusa2 and Akatsuki (Venus Climate Orbiter) missions. The Akatsuki mission is in orbit around Venus and will investigate the planet for at least the next four years. Hayabusa2 arrived at the Ryugu asteroid in June 2018, successfully deployed Japanese and European rovers in 2019, touched down, and collected samples for return to Earth. The spacecraft is currently on its journey back to Earth, with a planned landing in December 2020. In addition, NASA is currently collaborating with ESA on a potential Venus Mission Concept (EnVision) as part of ESA's M5 competition as well as continuing to study a Venus flagship mission concept (Venera-D) with IKI/Roscosmos.

PLANETARY MISSIONS PROGRAM OFFICE

The Planetary Missions Program Office (PMPO) at the Marshall Space Flight Center (MSFC) manages all Planetary Science flight projects that are not part of the Mars Exploration Program, including the competed Discovery and New Frontiers missions, the Jupiter Icy moons Explorer (JUICE), the Double Asteroid Redirection Test (DART), Europa Clipper, the PI-led CubeSats, and SmallSat missions. The PMPO includes support for the day-to-day efforts of the mission managers and business office, as well as standing review boards and external technical support as needed for the projects. It also funds the Science Office for Mission Assessments (SOMA) at Langley Research Center (LaRC) to support the mission selection process, including the development of Announcements of Opportunities (AOs) and the formation and operations of independent review panels to evaluate mission proposals.

DISCOVERY FUTURE

Discovery Future funds new missions selected through the AO process, specific technology investments to enable future missions, and small missions of opportunity. NASA will select missions from the 2019 Discovery AO to develop concept study reports in FY 2020 and plans to receive the reports by October 2020. NASA will then evaluate the concept study reports and down-select up to two missions to proceed into formulation in FY 2021.

OTHER MISSIONS AND DATA ANALYSIS

NASA plans to release the next Discovery AO in 2023 with mission selection planned in 2025.

PLANETARY SMALLSATS

NASA established the Small Innovative Missions for Planetary Exploration (SIMPLEx) program element to develop and operate targeted science investigations that exploit the unique attributes of small spacecraft to conduct compelling science. These small satellite missions take advantage of available launch capacity to reduce the overall costs of launching multiple missions, provide a means to mature technologies for future missions, and serve as additional opportunities to provide flight experience to the workforce.

In June 2019, NASA announced the selection of three small satellite missions under the SIMPLEx Program: Janus, EscaPADE (Escape and Plasma Acceleration and Dynamics Explorers), and Lunar Trailblazer.

Both the Janus and EscaPADE missions are twin-spacecraft missions. NASA plans to launch them with NASA's Psyche mission in 2022. Janus will visit two binary asteroid systems to study the formation of small "rubble pile" asteroids, and EscaPADE will orbit Mars to study how its atmosphere responds to the constant outflow of the solar wind.

NASA plans to launch Lunar Trailblazer with the Interstellar Mapping and Acceleration Probe Heliophysics mission in 2024 and will directly detect and map water on the surface of the Moon to determine how its form, abundance, and location relate to geology.

Recent Achievements

NASA announced the selection of Janus, EscaPADE, and Lunar Trailblazer under the SIMPLEx program element in June 2019.

MEGANE

MEGANE (Mars-moon Exploration with Gamma rays and Neutrons; also Japanese for "eyeglasses") is a gamma-ray and neutron spectrometer instrument currently in development by the Johns Hopkins University Applied Physics Laboratory, as a contribution to JAXA's Martian Moons eXploration (MMX) mission. Planned for launch in 2024, MMX will operate in close proximity to the Martian moons Phobos and Deimos for approximately three years and return a sample from Phobos to Earth in 2029. MEGANE will measure the bulk composition of the near-surface materials on Phobos for a set of eight elements to constrain theories for the origin of the moons. It will also make maps of the near-surface materials on Phobos to enable the study of surface processes and support MMX sample site selection.

Recent Achievements

MEGANE conducted its instrument requirements review and passed its Key Decision Point-B (KDP-B) review in March 2019 to enter its preliminary design and technology completion phase (Phase B).

OTHER MISSIONS AND DATA ANALYSIS

DISCOVERY RESEARCH

Discovery Research funds analysis of archived data from Discovery missions and supports participating scientists for the InSight mission. Discovery Research gives the research community access to samples and data and allows research to continue for many years after mission completion. NASA solicits planetary research proposals from the U.S. planetary science community and evaluates them for selection through competitive peer review. Discovery Research also funds the analysis of samples returned to the Earth by the Stardust and Genesis missions as well as the development of new analysis techniques for samples returned by future missions.

The Discovery Data Analysis Program element (DDAP) has provided support for continued analysis of spacecraft data from the NEAR-Shoemaker, Stardust, Genesis, Deep Impact, MESSENGER, Dawn, and Kepler missions. The supported projects conduct new scientific inquiries and regularly obtain new and unexpected scientific results, using data sets to go beyond the work conducted by the original mission teams. The Rosetta Data Analysis Program element (RDAP) has provided additional support targeted for analysis of data from Rosetta, an ESA-led mission with NASA participation, to explore and land on Comet 67P/Churyumov-Gerasimenko.

Recent Achievements

Various research projects supported by the DDAP have significantly clarified the nature of Mercury's magnetic field and magnetosphere. One such study demonstrated a significant impact of the magnetic reconnection mechanism in controlling global thermal and energetic particle precipitation and produced unequivocal evidence of neutral and/or ionized sodium leaving Mercury’s surface and being injected in the magnetosphere. A related study focused particularly on the "cusp" regions of the magnetosphere. It showed how a small number of low energy ions near the dayside magnetopause could energize on their way to the cusp to the 10 to 100-times higher levels found in the observations. These results are a substantial step in understanding dayside acceleration of planetary ions at Mercury.

A project supported by RDAP used Rosetta data to measure the rates of release of water, oxygen, carbon monoxide, and carbon dioxide from the nucleus of comet 67P in response to the changing solar heating over a span of more than two years. The study found that more than six million tons of volatile compounds were lost from the comet during this period and that the loss rates vary in subtle ways for different compounds over the surface of the comet and over time, indicating the complexities of cometary evolution. Another RDAP study of comet 67P found that the macroscopic roughness of comet 67P varies greatly across the body, from almost perfectly smooth to very rough. These studies provided insight into many areas of the comet that would be hazardous to landing or sample return; therefore, any missions planned to comets that involve these activities should plan on at least two months of on-orbit reconnaissance and site selection.

Operating Missions

INSIGHT

InSight is a robotic lander investigating fundamental issues of terrestrial planet formation and evolution by studying the deep interior of the planet Mars. The mission launched on May 5, 2018 and landed on the

OTHER MISSIONS AND DATA ANALYSIS

surface of Mars at Elysium Planitia on November 26, 2018. The mission is contributing to an understanding of the evolutionary formation of rocky planets, including Earth, by investigating the crust and core of Mars. InSight investigates the dynamics of Martian tectonic activity and meteorite impacts, which could offer clues about such phenomena on Earth. The InSight lander is equipped with two science instruments that are conducting the first “check-up” of Mars in its more than 4.5 billion years, measuring its “pulse,” or internal activity, its temperature, and its “reflexes” (the way the planet wobbles when it is pulled by the Sun and its moons). The science payload comprises two major instruments: the Seismic Experiment for Interior Structure (SEIS) and the Heat Flow and Physical Properties Package (HP3). SEIS is making precise measurements of quakes and other internal activity on Mars to help understand the planet’s history and structure. HP3 is a self-penetrating heat flow probe designed to burrow up to five meters below the surface to measure how much heat is coming from Mars’ core. In addition, the Rotation and Interior Structure Experiment (RISE) is using the spacecraft communication system to provide precise measurements of planetary rotation.

InSight's prime missions are approximately two years, 720 Earth days or 700 “sols” (Martian days), investigating the deep interior of Mars.

Recent Achievements

InSight is different from previous Mars missions in that its science is, by its very nature, slow to reveal itself. Scientists expect to need a full Mars year to acquire sufficient data to be able to answer the key questions that engineers designed InSight to address. However, InSight has produced some important early results. SEIS has detected more than 150 marsquakes, approximately 20 of which are large enough to be useful in studying Mars’ interior. The team's preliminary estimates of the global seismic activity of Mars appear to be close to, and somewhat higher than, pre-landing predictions for quakes smaller than approximately magnitude 4.0. Fewer larger quakes have been detected than expected. Importantly, the InSight project has been able to locate the epicenters of three marsquakes. All are near Cerberus Fossae, a region known from orbital imaging to have geologically recent (a few million years or less) volcanic and tectonic activity.

InSight's pressure and wind sensors are providing surprising new observations of atmospheric dynamics. InSight’s instruments have detected thousands of convective vortices (dust devils), despite the fact that there has not been a single visual sighting with the cameras. Researchers are using this data, along with concurrent data from SEIS, to determine the stiffness of the Martian regolith.

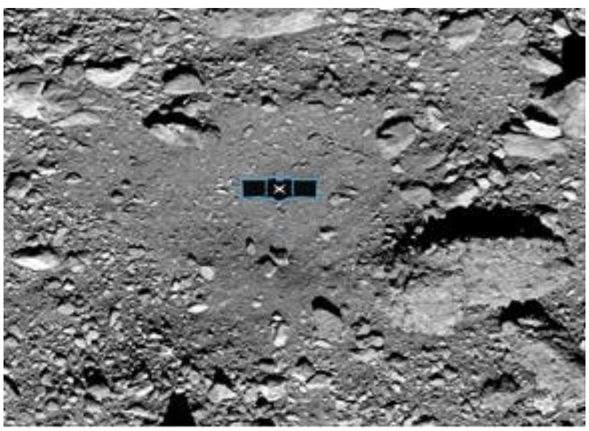
NEW FRONTIERS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Dragonfly	8.0	--	**95.8**	198.8	291.4	288.7	208.9
Other Missions and Data Analysis	85.0	--	**83.2**	115.5	41.4	38.2	76.1
Total Budget	**93.0**	**--**	**179.0**	**314.3**	**332.8**	**326.9**	**285.0**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.



This image shows sample site Nightingale, OSIRIS-REx's primary sample collection site on asteroid Bennu. The image is overlaid with a graphic of the OSIRIS-REx spacecraft to illustrate the scale of the site.

Image Credit: NASA GSFC / University of Arizona

The New Frontiers program explores our solar system with medium-class spacecraft missions. Within the New Frontiers program, possible mission destinations and the science goals for each competitive opportunity are limited to specific science targets announced for the competition aligned with the scientific goals and priorities as described in the Planetary Science Decadal Survey.

The program currently includes three missions in operations: New Horizons, Juno, and OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer) and one in formulation: Dragonfly.

The New Horizons mission is helping us understand worlds at the edge of the solar system. Having completed the first-ever reconnaissance of Pluto and its moons, the spacecraft recently conducted a flyby of 2014 MU69 (now known as Arrokoth), a small world in the Kuiper Belt.

Juno is a mission to Jupiter that is significantly improving our understanding of the origin and evolution of the gas giant planet. Juno is helping us understand the formation of planets and the origins of our solar system.

OSIRIS-REx will return pristine samples from a carbon-rich asteroid (Bennu) to study and analyze on Earth. This mission will increase our understanding of the role that primitive bodies, such as Bennu, played in planet formation and the origin of life. In addition to its science objectives, OSIRIS-REx will improve our knowledge of how to operate human and robotic missions safely near a large Near-Earth Object (NEO). This knowledge will provide significant insight for potential planetary defense strategies.

NEW FRONTIERS

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

ACHIEVEMENTS IN FY 2019

In January 2019, the New Horizons mission successfully completed a flyby of a small Kuiper Belt object designated 2014 MU69 (now known as Arrokoth).

The Juno mission completed additional polar orbits of Jupiter in FY 2019 for a current total of 21 science passes since arriving at Jupiter. Juno has now completed more than half of its prime mission. The OSIRIS-REx mission completed its rendezvous with Bennu. Detailed characterization of the asteroid is nearly complete in preparation of selecting a sampling site.

In June 2019, NASA selected the fourth mission in the New Frontiers program, called Dragonfly. The Dragonfly mission will launch in 2026 and deliver a large flying rotorcraft to Titan, one of Saturn's moons. The mission will sample and examine dozens of sites around this unique world and advance our search for the building blocks of life.

WORK IN PROGRESS IN FY 2020

The New Horizons mission will continue to downlink data as well as collect lightcurve measurements of distant Kuiper Belt objects. The mission is also characterizing the environment of this distant portion of the solar system.

Juno will continue science operations in orbit around Jupiter in FY 2020.

In FY 2020, NASA selected its final two sample collection sites (a primary called Nightingale, located high in a crater in Bennu's northern hemisphere, and a backup called Osprey) and will complete the reconnaissance overflights to confirm the safety and suitability of the sites. OSIRIS-REx will then conduct a series of progressively closer rehearsals in preparation for sample acquisition. In September 2020, once Bennu has moved far enough away from the Sun in its orbit to ensure that the sample will not be compromised by overheating after sample acquisition, OSIRIS-REx will proceed with the Touch-and-Go sample acquisition, confirm acquisition of the sample, and stow the sample in the Sample Return Capsule (SRC) for Earth return. Once the sample is safely stowed in the SRC, OSIRIS-REx will remain near Bennu until the orbital alignment between Bennu and the Earth is favorable for beginning the cruise back to Earth.

Dragonfly will continue its preliminary design, technology completion, and risk reduction activities throughout FY 2020.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

The Juno mission will complete its prime science mission.

OSIRIS-REx will begin its cruise back to Earth in FY 2021.

NEW FRONTIERS

Dragonfly will continue its preliminary design and technology completion activities.

PROGRAM SCHEDULE

Date	Significant Event
2022	Release of New Frontiers 5 announcement of opportunity (AO) solicitation

PROGRAM MANAGEMENT & PLANNED CADENCE

The New Frontiers Program is a multiple-project program, with responsibility for implementation assigned to the Planetary Missions Program Office, located at the Marshall Space Flight Center (MSFC). The New Frontiers Program AO cadence is approximately every five to six years.

ACQUISITION STRATEGY

NASA competitively selects New Frontiers missions, releasing AOs when available funding allows.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Program Implementation Review (PIR)	MSFC	2016	PIR	Completed	2021
PIR	MSFC	2021	PIR	TBD	2026

DRAGONFLY

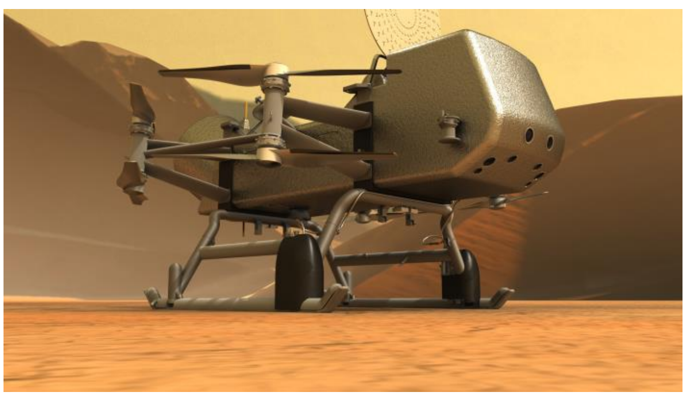
Formulation	Development	Operations

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**8.0**	**--**	**95.8**	**198.8**	**291.4**	**288.7**	**208.9**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.



Artist's impression of Dragonfly on the surface of Titan.

Image Credit: APL

PROJECT PURPOSE

Dragonfly is a mission to study Titan, the largest moon of Saturn and a unique, richly organic world. Using a rotorcraft, it will fly multiple sorties to examine a variety of geologic settings. By taking measurements at diverse locations, Dragonfly will characterize the habitability of Titan's environment; investigate how far pre-biotic chemistry has progressed, and search for chemical signatures indicative of water-based and/or hydrocarbon-based life.

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

PROJECT PRELIMINARY PARAMETERS

Dragonfly will launch in 2026 and arrive at Titan in 2034. The rotorcraft will fly to dozens of locations on Titan, looking for prebiotic chemical processes common on both Titan and Earth. Dragonfly, which has eight rotors and flies like a large drone, marks the first time NASA will fly a multi-rotor vehicle for science on another body. It will take advantage of Titan's dense atmosphere (four times denser than

DRAGONFLY

Formulation	Development	Operations

Earth's) and low gravity (one seventh that on Earth) to become the first vehicle ever to fly its entire science payload to new places for repeatable and targeted access to surface materials.

Titan is an analog to the very early Earth and can provide clues to how life may have begun on our planet. During its 2.7-year baseline mission, Dragonfly will explore diverse environments from organic dunes to the floor of an impact crater where liquid water and complex organic materials, key to life, once existed together, possibly for tens of thousands of years. Its instruments will study how far prebiotic chemistry has progressed. They also will investigate the moon's atmospheric and surface properties and its subsurface ocean and liquid reservoirs. Additionally, instruments will search for chemical evidence of past or extant life. A multi-mission radioisotope thermoelectric generator (MMRTG) will power the Dragonfly rotorcraft.

ACHIEVEMENTS IN FY 2019

NASA selected Dragonfly from the New Frontiers 4 announcement of opportunity (AO) in June 2019. Dragonfly proceeded into its preliminary design, technology completion, and risk reduction activities.

WORK IN PROGRESS IN FY 2020

Dragonfly will continue the preliminary design, technology completion, and risk reduction activities throughout FY 2020.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

Dragonfly will continue the preliminary design, technology completion, and risk reduction activities in preparation for its preliminary design review (PDR).

ESTIMATED PROJECT SCHEDULE

Dragonfly's project schedule is currently under review and based on an April 2026 launch readiness date.

Milestone	Formulation Authorization Document	FY 2021 PB Request
Key Decision Point-C (KDP-C)	TBD	TBD
KDP-D	TBD	TBD
Launch	Apr 2026	Apr 2026

DRAGONFLY

Formulation	Development	Operations

Formulation Estimated Life Cycle Cost Range and Schedule Range Summary

Life cycle cost estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (KDP-C), which follows the PDR.

KDP-B Date	Estimated Life Cycle Cost Range ($)	Key Milestone	Key Milestone Estimated Date Range
Jun 2019	1.8 billion - 2.2 billion	Launch	Apr 2026

Project Management & Commitments

The Principal Investigator is from the Johns Hopkins University Applied Physics Laboratory (APL). APL has project management responsibility for Dragonfly.

Element	Description	Provider Details	Change from Formulation Agreement
Dragonfly Mass Spectrometer	Provides detailed analysis of organic chemistry	Provider: Goddard Space Flight Center (GSFC) Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Dragonfly Gamma-Ray and Neutron Spectrometer	Determines bulk near-surface composition and layering	Provider: APL Lead Center: APL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Dragonfly Geophysics and Meteorology Package	Measures atmospheric conditions, seismicity, and surface/subsurface properties	Provider: APL Lead Center: APL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Dragonfly Camera Suite	Documents landforms and processes, provides context for samples, and performs aerial imaging to scout landing sites	Provider: MSSS Lead Center: APL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

DRAGONFLY

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
Drill for Acquisition of Complex Organics Sampling System	Provides pneumatic transfer system and sample acquisition drill	Provider: Honeybee Robotics Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Multi-Mission Radioisotope Thermoelectric Generator	Provides power to the Dragonfly lander	Provider: Department of Energy Lead Center: Glenn Research Center (GRC) Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Cruise Stage	Propulsion stage to get Dragonfly to Titan	Provider: Lockheed Martin Lead Center: APL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Entry, Descent, and Landing Assembly	Includes aeroshell, parachutes, and support equipment	Provider: Lockheed Martin Lead Center: APL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Dragonfly Lander	Flight system to carry and support the science instruments	Provider: APL Lead Center: APL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

Project Risks

It is too early in the formulation phase to identify significant risks.

Acquisition Strategy

NASA competitively selected the mission through the New Frontiers 4 AO and a down selection in June 2019. The major elements of the mission and spacecraft are as proposed for the AO.

DRAGONFLY

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
PI, Science Co-Is, Mission Management, Lander Development, DraGMet, DraGNS, System I&T, Science Operations, Mission Operations	APL	Laurel, MD
Cruise Stage, Entry, Descent, and Landing (EDL) Assembly, I&T Support	Lockheed Martin	Denver, CO

INDEPENDENT REVIEWS

All dates are preliminary.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Life Cycle	Standing Review Board (SRB)	TBD	PDR	TBD	Critical Design Review (CDR)
Life Cycle	SRB	TBD	CDR	TBD	System Integration Review (SIR)
Life Cycle	SRB	TBD	SIR	TBD	Operations Readiness Review (ORR)
Life Cycle	SRB	TBD	ORR	TBD	Launch Readiness Review (LRR)
Life Cycle	SRB	TBD	LRR	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
New Frontiers Future Missions	2.3	--	**9.7**	70.6	6.0	19.9	46.8
New Frontiers Research	7.9	--	**6.9**	9.2	9.3	9.3	9.3
Origins Spectral Interpretation Resource	50.3	--	**28.8**	16.9	26.1	8.9	20.0
New Horizons	12.7	--	**9.5**	0.0	0.0	0.0	0.0
Juno	11.8	--	**28.4**	18.9	0.0	0.0	0.0
Total Budget	**85.0**	**--**	**83.2**	**115.5**	**41.4**	**38.2**	**76.1**

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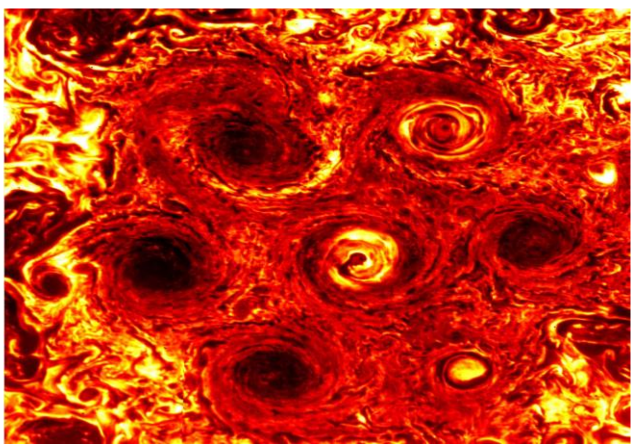

A new, smaller cyclone can be seen at the lower right of this infrared image of Jupiter's south pole taken on November 4, 2019, during the 23rd science pass of the planet by NASA's Juno spacecraft. The image was captured by Juno's Jovian Infrared Auroral Mapper (JIRAM) instrument, which measures heat radiated from the planet at an infrared wavelength of approximately 5 microns.

Image Credit: NASA/JPL-Caltech/SwRI/ASI/INAF/JIRAM

New Frontiers Other Missions and Data Analysis includes three operating missions: New Horizons, Juno, and OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer), analysis of data from those missions, as well as preparation for future missions.

Mission Planning and Other Projects

NEW FRONTIERS FUTURE MISSIONS

New Frontiers Future supports technology development for future missions and provides the funding required for the next announcement of opportunity (AO). NASA recently selected the fourth New Frontiers mission. The New Frontiers program expects to begin the competition to select the fifth mission in 2022.

OTHER MISSIONS AND DATA ANALYSIS

NEW FRONTIERS RESEARCH

New Frontiers Research funds analysis of archived data from New Frontiers missions as well as participating scientists and selected members of the research community, whom augment and enhance the science teams of New Frontiers missions. New Frontiers Research gives the research community access to data, in the future, samples and allows research to continue for many years after mission completion. Participating scientists bring new ideas into mission teams and frequently provide a pathway for early career investigators to gain experience with planetary missions. This arrangement allows the maximum science return from each of the missions. NASA solicits planetary research proposals from the U.S. planetary science community and evaluates them for selection through competitive peer review. NASA will select new research in 2020 using the New Horizons mission data returned from Pluto, 2014 MU69 (now known as Arrokoth) data, Juno mission data returned from Jupiter, and OSIRIS-REx mission data returned from the asteroid Bennu.

Recent Achievements

NASA selected participating scientists for the Juno mission in 2019 along with multiple research investigations.

Operating Missions

NEW HORIZONS

New Horizons is the first scientific investigation to obtain close observations of Pluto and its moons, Charon, Nix, Hydra, Kerberos, and Styx (scientists discovered the last four moons after the spacecraft's launch in 2006). Scientists aimed to find answers to basic questions about the surface properties, geology, interior makeup, and atmospheres of these bodies.

New Horizons launched on January 19, 2006. It successfully encountered Pluto in July 2015 and completed downloading all the primary science observation of the Plutonian System in October 2016.

Recent Achievements

As part of its extended mission, the spacecraft encountered the small Kuiper Belt Object designated Arrokoth (2014 MU69). This object is one of the small and primitive icy bodies in this region approximately two billion miles beyond Pluto’s orbit.

The mission continues gathering data on the plasma environment of the Kuiper Belt as well as obtaining light curves of distant Kuiper Belt Objects.

Scientists analyze data from the Arrokoth (2014 MU69) encounter as they are downlinked. More detailed analysis of data from the Pluto encounter continues to result in new discoveries.

Below are some of the recent findings and research from the New Horizons mission:

OTHER MISSIONS AND DATA ANALYSIS

- Evidence supporting Pluto's surprising geologic activity continues to grow; scientists discovered ammoniated ices near areas showing signs of geologically recent activity, which is significant because these ices are relatively short-lived;
- Laboratory research suggests that the strangely colored regions on Pluto's surface could be due to the presence of complex, prebiotic organic molecules; and
- Images and modeling revealed that Arrokoth (2014 MU69) began as two bodies in very close orbit that eventually merged, created the first "contact binary" ever explored.

New Horizons scientists found evidence for methanol, water ice, and organic molecules on the surface of Arrokoth (2014 MU69), a mixture very different from most icy objects explored previously by spacecraft but expected to be common in the Kuiper Belt.

JUNO

Juno is conducting an in-depth study of Jupiter, the most massive planet in the solar system. Juno launched on August 5, 2011 and entered Jupiter's orbit on July 4, 2016. Juno’s instruments are gathering information from deep in Jupiter’s atmosphere, enabling scientists to understand the fundamental processes of the formation and early evolution of the solar system. During its science operations mission, Juno is sampling Jupiter’s full range of latitudes and longitudes. From its polar perspective, Juno combines remote sensing observations to explore the polar magnetosphere and determine what drives Jupiter’s remarkable auroras. Juno has an onboard camera that is producing images and providing unique opportunities to engage the next generation of scientists.

Recent Achievements

Juno is currently in a 53-day orbit and has successfully completed 21 science flybys of Jupiter, more than half of its planned orbits. The magnetic field mapping indicates multiple possible sources of the interior magnetic field and has discovered a region of enhanced magnetic field that is responsible for minute, but significant, time variations of Jupiter's interior magnetic field. This discovery defies expectations based on experience with other planets' dynamos, including Earth's.

Juno has contributed imaging, gravity, and magnetic field data to a community-wide focus on understanding the shrinking of Jupiter's great red spot, which has diminished in width by one third since the time of the Voyager flybys in 1979.

OSIRIS-REX

OSIRIS-REx will be the first U.S. mission to bring a sample from an asteroid back to Earth. The OSIRIS-REx spacecraft will travel to (101955) Bennu, a near-Earth carbonaceous asteroid formerly designated 1999 RQ36, study the asteroid in detail, and bring back a sample (at least 60 grams or 2.1 ounces) to Earth. Analysis of this sample by current and future generations of scientists will yield insight into planet formation and the origin of life and address questions we have not thought of yet (using laboratory instruments we have not invented yet). The data collected at the asteroid will aid in understanding asteroids that can collide with Earth. This mission will also measure the Yarkovsky effect on a potentially hazardous asteroid and measure the asteroid properties that contribute to this effect. The

OTHER MISSIONS AND DATA ANALYSIS

Yarkovsky effect is a small force on an asteroid caused by the Sun as the asteroid absorbs sunlight and re-emits that energy as heat.

OSIRIS-REx launched on September 8, 2016 and arrived at Bennu on December 3, 2018. The mission is globally mapping the surface from distances of about three miles to less than half a mile. The spacecraft cameras and instruments are photographing the asteroid and measuring its surface topography, composition, and thermal emissions. Radio science is providing mass and gravity field maps. This information will help the mission team select the most promising location to collect a sample of pristine asteroid material.

In 2020, the spacecraft will descend to the surface of the asteroid, gently contact the surface, collect a sample, and back away. To deliver the sample to Earth, OSIRIS-REx has a capsule similar to the one that returned the sample of Comet 81P/Wild on the Stardust spacecraft. The capsule, with its pristine sample from Bennu, will land at the Utah Test and Training Range on September 24, 2023. NASA will transport the capsule containing the sample to JSC for processing, analysis, and curation at a dedicated research facility. Johnson Space Center (JSC) will make subsamples available for research to the worldwide science community.

Recent Achievements

On December 31, 2018, OSIRIS-REx entered an approximately 1.5-kilometer (km) radius (approximately 1.25 km from the surface) orbit around Bennu, with each orbit taking approximately 50 hours, setting a record for closest orbit to a celestial body ever achieved. In June 2019, it broke this record, orbiting only 0.6 km from the surface of Bennu.

In January 2019, OSIRIS-REx unexpectedly discovered that Bennu was an "active asteroid," which regularly ejects small particles into space, which may escape, or orbit briefly as transient satellites before falling back to the surface. Although these particles are not hazardous to the spacecraft, they are a significant scientific discovery.

The OSIRIS-REx team made significant progress towards eventual sample retrieval by identifying four sites that are the best candidates for acquisition of a sample to return to Earth in late 2023. Because of the need to target smaller-than-expected sample sites, a new method of "bullseye TAG" (TAG=Touch-And-Go sample collection) using "natural feature tracking" is being developed to guide the spacecraft down. Reconnaissance observations of the four sites is underway, and NASA selected its final two sample collection sites (a primary, Nightingale, and a backup, Osprey) in December 2019.

MARS EXPLORATION

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Mars Rover 2020	502.6	318.7	**162.3**	97.0	33.0	0.0	0.0
Other Missions and Data Analysis	210.1	--	**366.2**	491.4	638.2	798.7	855.3
Total Budget	**712.7**	**--**	**528.5**	**588.4**	**671.2**	**798.7**	**855.3**

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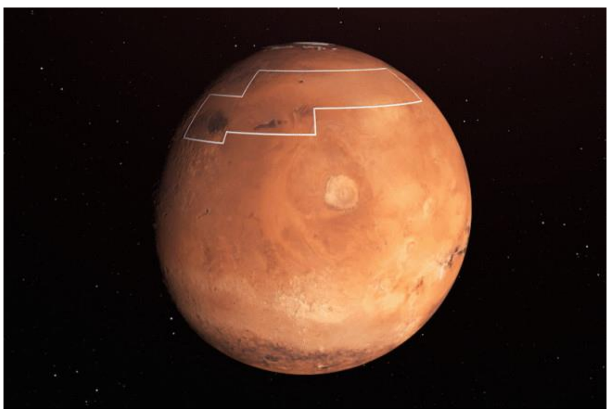
The Mars Exploration Program seeks to understand when Mars may have been habitable, whether Mars is habitable today, or can be a habitable world in the future, and whether it ever supported life. As the most Earth-like planet in the solar system, Mars has a landmass approximately equivalent to the Earth's as well as many of the same geological features, such as riverbeds, past river deltas, and volcanoes. Mars also has many of the same "systems" that characterize Earth, such as air, water, ice, and geology that all interact to produce the Martian environment. Mars also has fundamental differences from Earth including the lack of a global magnetic field and chaotic changes in the orientation of its spin axis over tens of millions of years, which have affected its environment.



The annotated area of Mars in this illustration holds near-surface water ice that would be easily accessible for astronauts to dig up. The water ice was identified as part of a map using data from multiple NASA orbiters, including the Mars Reconnaissance Orbiter, Mars Odyssey and the Mars Global Surveyor.

Image Credit: NASA/JPL-Caltech

The four broad, overarching goals for Mars Exploration are to:

- Determine if life ever arose on Mars;
- Characterize the climate of Mars;
- Characterize the geology of Mars; and,
- Prepare for human exploration.

Today, our robotic scientific explorers are paving the way. Together, humans and robots will pioneer Mars and the solar system.

MARS EXPLORATION

EXPLANATION OF MAJOR CHANGES IN FY 2021

This budget, through funding in the Mars Future project, supports the development of the Mars Sample Return campaign as early as 2026 and begins planning for a Mars Ice Mapper mission that will study and profile the near-surface (3-15 meters) water ice.

The Mars rover 2020 mission has experienced cost growth due to technical issues with the Planetary Instrument for X-ray Lithochemistry (PIXL) and Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals (SHERLOC) instruments and the Sample Caching System.

MARS ROVER 2020

Formulation	Development	Operations

FY 2021 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	BTC	Total
Formulation	397.6	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	397.6
Development/Implementation	1186.4	515.3	300.3	**34.3**	0.0	0.0	0.0	0.0	0.0	2036.2
Operations/Close-out	0.0	0.0	22.7	**133.6**	100.5	35.1	0.0	0.0	0.0	292.0
2020 MPAR LCC Estimate	**1584.0**	**515.3**	**323.0**	**167.9**	**100.5**	**35.1**	**0.0**	**0.0**	**0.0**	**2725.8**
Total Budget	**1488.9**	**502.6**	**318.7**	**162.3**	**97.0**	**33.0**	**0.0**	**0.0**	**0.0**	**2602.5**
Change from FY 2020				**-156.4**						
Percentage change from FY 2020				**-49.1%**						
Total NASA Budget	**1584.0**	**515.3**	**323.0**	**167.9**	**100.5**	**35.1**	**0.0**	**0.0**	**0.0**	**2725.8**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

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An engineer working on NASA's Mars 2020 mission uses a solar intensity probe to measure and compare the amount of artificial sunlight that reaches different portions of the rover. The data collected during this test is used to confirm thermal models regarding how the Sun's rays will interact with the 2020 rover while on the surface of Mars.

Image Credit: NASA/JPL-Caltech

PROJECT PURPOSE

NASA's Mars 2020 science rover is a mission, currently in development, that will advance the scientific priorities detailed in the Planetary Science Decadal Survey, entitled “Vision and Voyages for Planetary Science in the Decade 2013-2022.” In addition, the mission provides an opportunity for payload elements that align with human exploration and technology demonstration objectives.

Mars 2020 will build upon many discoveries from the Mars Science Laboratory Curiosity rover and the two Mars Exploration Rovers, Spirit and Opportunity, by taking the next key steps in our understanding of Mars’ potential as a habitat for past or present life. The Mars 2020 rover will seek signs of past life on Mars, collect and store a set of samples for potential return to

MARS ROVER 2020

Formulation	Development	Operations

Earth in the future, and test new technology to benefit future robotic and human exploration of Mars. The mission will also deploy new capabilities developed through investments by NASA's Space Technology Mission Directorate, Human Exploration and Operations Mission Directorate, and contributions from international partners.

EXPLANATION OF MAJOR CHANGES IN FY 2021

Recent technical issues with the Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals (SHERLOC) instruments and the Sample Caching System have resulted in mission cost growth in the Mars 2020 project. NASA addressed these changes in the December 2019 Breach Report to Congress.

PROJECT PARAMETERS

The Mars 2020 mission is planned to launch in July 2020, landing on Mars in February 2021, and spending at least one Mars year (two Earth years) exploring the landing site region. The mission uses much of the design of the highly successful Mars Science Laboratory (MSL) “Curiosity” rover, which has been exploring Mars since 2012. The Mars 2020 rover body and other major hardware (such as the cruise stage, aeroshell, and heat shield) will be near-duplicates of the systems of MSL and will take maximum advantage of engineering heritage. The new rover will carry more sophisticated, upgraded hardware and new instruments to conduct geological assessments of the rover's landing site, determine the potential habitability of the environment, and directly search for signs of ancient Martian life. To minimize costs and risks, NASA will use a proven landing system and rover chassis design as much as possible, while still delivering a highly capable rover.

The Mars 2020 rover is carrying a competitively selected science and technology instrument payload of seven instruments. NASA chose five of those instruments to provide the clearest possible measurements for seeking possible signs of ancient life (potential “biosignatures”) on Mars over its long, 4.6 billion-year history. NASA chose the remaining two instruments to assess environmental hazards and resources for future human exploration. The rover also will collect and store samples of rocks and soils in sealed tubes, which will be stored on the surface of Mars for possible return to Earth by a subsequent mission.

The rover’s baseline power source is a Multi-Mission Radioisotope Thermoelectric Generator. It uses the heat from the natural decay of plutonium-238 to generate electricity. NASA and European Space Agency telecommunications relay assets in Mars orbit will support the mission.

ACHIEVEMENTS IN FY 2019

NASA selected Jezero Crater as the landing site for the Mars 2020 mission.

The Project completed flight model delivery of the instrument payload and major subsystems, assembled the rover, cruise stage, descent stage, and aeroshell, and began environmental testing of the spacecraft.

MARS ROVER 2020

Formulation	Development	Operations

WORK IN PROGRESS IN FY 2020

The Mars 2020 project will complete its Operational Readiness Review (ORR) in preparation for launch in July 2020 and formally enter its mission operations phase (Phase E) of implementation.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

The Mars 2020 mission will land on Mars in February 2021 and begin surface operations on Mars.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2021 PB Request
KDP-C	Jun 2016	Jun 2016
CDR	Dec 2016	Feb 2017
KDP-D	Jan 2018	May 2018
Launch Readiness Date	Jul 2020	Jul 2020
Landing	Feb 2021	Feb 2021
End of Prime Mission	Jun 2023	Jun 2023

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2017	SMD 1620.1 NASA 1676.9	70%	2020	SMD 1957.6 NASA 2036.2	SMD 20.8% NASA 21.4%	LRD	Jul 2020	Jul 2020	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

MARS ROVER 2020

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**1676.9**	**2036.2**	**+359.4**
Tech Development	88.4	316.9	+228.5
Aircraft/Spacecraft	527.4	798.1	+270.7
Payloads	155.4	279.8	+124.4
Systems I&T	71.1	78.8	+7.7
Launch Vehicle	342.5	230.4	-112.1
Ground Systems	80.4	62.1	-18.3
Science/Technology	16.5	22.3	+5.8
Other Direct Project Costs	395.1	247.8	-147.3

Project Management & Commitments

The Jet Propulsion Laboratory (JPL) has project management responsibility for Mars 2020.

Element	Description	Provider Details	Change from Baseline
Mastcam-Z	Advanced camera system with panoramic and stereoscopic imaging capability with the ability to zoom	Provider: ASU Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
SuperCam	Instrument that can provide imaging, chemical composition analysis, and mineralogy	Provider: Los Alamos National Laboratory Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): CNES	N/A

MARS ROVER 2020

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
PIXL	An X-ray fluorescence spectrometer that will also contain an imager with high resolution to determine the fine scale elemental composition of Martian surface materials	Provider: JPL Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
SHERLOC	A spectrometer that will provide fine-scale imaging and uses an ultraviolet laser to determine fine-scale mineralogy and detect organic compounds	Provider: JPL Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
RIMFAX	A ground-penetrating radar that will provide centimeter-scale resolution of the geologic structure of the subsurface	Provider: Norwegian Defense Research Establishment, Norway Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): NASA SMD	N/A
MEDA	A set of sensors that will provide measurements of temperature, wind speed and direction, pressure, relative humidity and dust size and shape	Provider: Centro de Astrobiologia, Instituto Nacional de Tecnica Aeroespacial, Spain Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): NASA HEOMD/STMD	N/A
MOXIE	An exploration technology investigation that will produce oxygen from Martian atmospheric carbon dioxide	Provider: Massachusetts Institute of Technology Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): HEOMD/STMD	N/A

MARS ROVER 2020

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
MEDLI-2	A set of engineering sensors embedded in the aeroshell to gather data on the aerothermal conditions, thermal protection system, and aerodynamic performance during atmospheric entry and descent	Provider: NASA Langley Research Center (LaRC) Lead Center: LaRC Performing Center(s): LaRC/JPL Cost Share Partner(s): HEOMD/STMD	N/A

MARS ROVER 2020

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: Any one of a set of mission single point failures associated with rover mechanisms and associated electronics occurs (including mechanisms in the caching system, remote science mast, and mobility system), Then: Functional failure could prevent mission success.	The Flight System is considering one or more or all of the potential mitigation: use of high reliability parts with additional parts screening or testing; comprehensive reliability analyses with rigorous reviews; additional inspection points; additional testing with intra-board test points; board-level and/or box-level stress testing; extended environmental or functional testing; operational rules and practices that reduce hardware stress.
If: One or several of the aggregated Entry, Descent, and Landing residual risks or unknown-unknowns that are inherited from MSL is realized (such as single point failures, environmental factors), Then: Could cause loss of mission.	Remove risks retired by MSL's flight itself and Mars 2020 plans that will correct some testing shortfalls. This reduced 43 previously identified risks to 27. Re-examine aggregated risks to understand if any baseline changes affect them. It is very likely that the Mars 2020 mission will need to accept most, if not all, of the aggregated residual risks.
If: Complexity of the Sampling and Caching Subsystem (SCS) results in new / late issues during final validation and end-to-end testing that require hardware modifications, Then: The schedule at JPL and KSC could be impacted, reducing schedule reserve.	Final SCS flight hardware is proceeding as expected for delivery in Jan/Feb 2020 with sufficient margin. The end-to-end testing has begun under stressing conditions, and Mars ambient pressure and temperature. The project is continuing to apply substantial resources and management attention on this activity.
If: Unanticipated parts issues arise late in the final processing of the flight vehicle at JPL or KSC, Then: Remaining schedule reserve can be consumed.	A number of parts issues have arisen over the last six months, mostly on other projects with common parts. However, none of these issues has threatened the flight launch schedule. The project and institution will continue to monitor for these issues and react if necessary.

Acquisition Strategy

NASA is acquiring the spacecraft and flight systems for the Mars 2020 mission through JPL and the radioisotope power system through the Department of Energy, taking advantage of the previous investment in the MSL project to maximize heritage. NASA is using contracts existing from the MSL

MARS ROVER 2020

Formulation	Development	Operations

project to procure new versions of the as-flown hardware. NASA competitively selected the Mars 2020 investigations payload.

MAJOR CONTRACTS/AWARDS

NASA released an announcement of opportunity for the Mars 2020 rover instruments on September 24, 2013, with selections announced on July 31, 2014. NASA selected seven science instruments and exploration technology investigations for the Mars Rover 2020 payload.

Element	Vendor	Location (of work performance)
Aeroshell	Lockheed Martin	Denver, CO
Actuators	Cobham	Hauppauge, NY
Robotic arm	Motiv	Pasadena, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Oct 2014 / Mar 2015	SRR & MDR	Successful	Feb 2016
Performance	SRB	Feb 2016	PDR	Successful	Feb / Mar 2017
Performance	SRB	Feb / Mar 2017	CDR	Successful	Feb 2018
Performance	SRB	Feb 2018	SIR	Successful	May 2020
Performance	SRB	May 2020	ORR	TBD	

OTHER MISSIONS AND DATA ANALYSIS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Mars Organic Molecule Analyzer (MOMA)	6.9	--	**6.9**	4.0	4.0	3.0	0.0
Aeroscience Ground Test Capabilities	12.5	--	**0.0**	0.0	0.0	0.0	0.0
ExoMars	2.1	--	**2.2**	2.0	2.0	2.0	2.0
Mars Program Management	13.2	--	**12.3**	12.3	12.3	12.3	12.3
Mars Future Missions	30.3	--	**232.6**	405.6	550.8	713.4	775.0
Mars Mission Operations	1.9	--	**5.4**	5.4	5.4	5.4	5.4
Mars Research and Analysis (R&A)	10.0	--	**11.7**	11.7	14.7	14.7	14.7
Mars Technology	20.5	--	**6.7**	4.4	4.4	4.4	4.4
2011 Mars Science Lab	51.1	--	**40.0**	0.0	0.0	0.0	0.0
Mars Reconnaissance Orbiter 2005 (MRO)	26.0	--	**25.5**	25.0	24.5	23.5	23.5
Mars Exploration Rover 2003	3.6	--	**0.0**	0.0	0.0	0.0	0.0
Mars Odyssey 2001	11.5	--	**1.0**	0.0	0.0	0.0	0.0
Mars Express	2.8	--	**0.0**	0.0	0.0	0.0	0.0
Mars Atmosphere & Volatile EvolutioN (MAVEN)	17.9	--	**22.0**	21.0	20.0	20.0	18.0
Total Budget	**210.1**	**--**	**366.2**	**491.4**	**638.2**	**798.7**	**855.3**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

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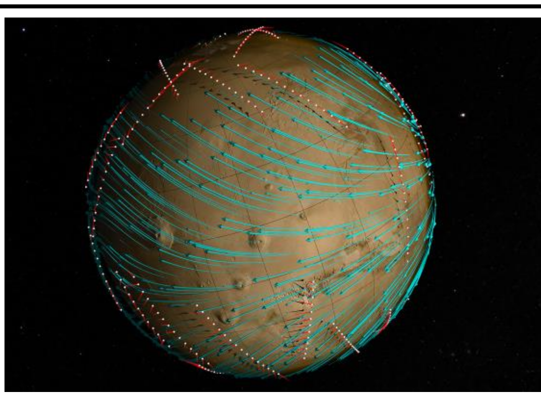

Researchers have created the first map of wind circulation in the upper atmosphere of a planet besides Earth, using data from NASA's MAVEN spacecraft that were collected during the last two years. The new map of Mars winds helps scientists to better understand the workings of the Martian climate, giving them a more accurate picture of its ancient past and its ongoing evolution.

Other Missions and Data Analysis includes mission planning and other projects such as NASA's contribution the Mars Organic Molecule Organizer (MOMA) to the European Space Agency (ESA) Exobiology on Mars (ExoMars) 2020 rover, ExoMars, Mars Program Management, Mars Mission Operations, Mars Research and Analysis, Mars Technology, and Mars Future. In addition are the operating projects, which include Mars Science Laboratory (MSL), Mars Reconnaissance Orbiter 2005 (MRO), Mars Odyssey 2001, Mars Express, and Mars Atmosphere and Volatile Evolution (MAVEN). Also included are the flight operations, NASA-contributed Electra communications radios, and the participation of co-Investigators on two instruments of the 2016 ExoMars Trace Gas Orbiter (TGO).

OTHER MISSIONS AND DATA ANALYSIS

Mission Planning and Other Projects

MARS ORGANIC MOLECULE ANALYZER (MOMA)

MOMA is the core astrobiology instrument on the ESA ExoMars 2020 rover, and it addresses the top ExoMars science goal of seeking signs of past or present life on Mars. The MOMA-Mass Spectrometer (MOMA-MS), the NASA-provided subsystem of MOMA, is in development. It is primarily a dual-source mass spectrometer, including laser desorption capability, to detect a wide range of organic molecules in Martian samples. Organic structure and distribution can be indicators of past or present life.

EXOMARS

The ExoMars program is a series of two missions designed to understand if life ever existed on Mars. The first mission in the ExoMars program is the 2016 ExoMars Trace Gas Orbiter (TGO), which launched in March 2016 and began its science and relay operations phase in March 2018 starting with the observations of the global dust storm. For this mission, NASA contributed two Electra ultra-high frequency (UHF) telecommunication radios, identical to those used successfully on NASA's MRO and MAVEN. The Electra radio acts as a communications relay and navigation aid for surface assets and support navigation, command, and data-return needs for landers and rovers. Furthermore, two instruments, the Stereo Surface Imaging Systems and the Nadir and Occultation for Mars Discovery have significant contributions from U.S. co-Investigators.

Recent Achievements

After completing the global dust storm observation in November 2018, TGO made the first observation of semi-heavy water simultaneously with water vapor, providing key information on the processes that control the amount of hydrogen and deuterium atoms (an isotope of hydrogen often called 'heavy hydrogen') escaping to space. It also means scientists can derive the deuterium-to-hydrogen ratio, which is an important marker for the evolution of the water inventory on Mars. The observations show that water, deuterated or not, is very sensitive to the presence of ice clouds, preventing it from reaching atmospheric layers higher up. During the storm, water reached much higher altitudes. Models theoretically predicted this, but scientists observed it for the first time using the TGO measurements.

MARS PROGRAM MANAGEMENT

Mars Program Management provides for the broad-based implementation and programmatic management of the Mars Exploration program. Mars Program Management also supports independent panel reviews, studies regarding planetary protection, advanced mission studies and program architecture, program science, and telecommunications coordination and integration.

MARS MISSION OPERATIONS

Mars Mission Operations provides management and leadership for the development and operation of Mars multi-mission systems for operations. Mars Mission Operations supports and provides common

OTHER MISSIONS AND DATA ANALYSIS

operational systems and capabilities at a lower cost and risk than having each Mars project produce systems individually.

MARS RESEARCH AND ANALYSIS (R&A)

Mars R&A provides funding for research and analysis of Mars mission data to understand how geologic, climatic, and other processes have worked to shape Mars and its environment over time, as well as how they interact today. Specific investments include:

- Mars Data Analysis that analyzes archived data collected on Mars missions; and
- Critical Data Products that provide data and analyses for the safe arrival, aero-maneuver, entry, descent, and landing at Mars.

Data analysis through Mars R&A enables a much broader and objective analysis of the data and samples. It also allows research to continue for many years after the mission completion. These research projects increase our scientific understanding of Mars' past and present environments, disseminating the results through the scientific publications. By using data collected by spacecraft, researchers are able to make scientific discoveries and test hypotheses about the Martian environment.

Recent Achievements

Recently published papers have provided significant new information on the atmosphere of Mars, the nature and formation mechanisms of active wind-driven deposits, and the potential habitability of Mars.

MARS TECHNOLOGY

Mars Technology focuses on technological investments that lay the groundwork for successful future Mars missions, such as entry, descent, and landing capabilities; Mars ascent vehicle components, sample handling and processing technologies; and surface-to-orbit communications improvements.

MARS FUTURE MISSIONS

Mars Future Missions funds the planning of future robotic missions to Mars that build on scientific discoveries from past missions and incorporate the lessons learned from previous missions. Mars Future supports the development of the Mars Sample Return (MSR) mission that is planning to enter formulation (Phase A) as early as the summer of FY 2020. In FY 2021 MSR formulation activities include concept and technology development, and early design and studies in support of the Sample Return Lander and the Capture/Containment and Return System. Mars Future also supports a study of the facility required for handling of returned samples. In developing concepts for a Mars Sample Return mission, the future budget supports an estimated MSR launch readiness date of 2026. Also included is funding for a potential collaboration with Canada on the Mars Ice Mapper. The Mars Ice Mapper is a remote sensing mission under study intended to map and profile the near-surface (3-15 meters) water ice, particularly that which lies in the mid-latitude regions, in support of future science and exploration missions.

OTHER MISSIONS AND DATA ANALYSIS

Operating Missions

2011 MARS SCIENCE LAB (MSL)

MSL and its Curiosity rover, which successfully landed in August 2012, completed its prime mission exploration activities. The Curiosity rover is exploring and quantitatively assessing regions on Mars as potential past habitats for life, and has determined that Mars, at least at one point in time, was once able to support microbial life. The Curiosity rover is collecting Martian soil and rock samples and analyzing them for organic compounds and environmental conditions that could have supported microbial life, and making measurements of the Martian atmosphere, the radiation environment, and the weather. MSL is the first planetary mission to use precision landing techniques, steering itself toward the Martian surface. This landing method enabled the rover to land in an area less than 12 miles in diameter, about one-sixth the size of previous landing zones on Mars and this successful system is the basis of the system architecture of the Mars 2020 mission.

Curiosity is the first planetary rover to make use of a nuclear power source, which gave the rover the ability to travel up to 12 miles during the two-year primary mission. This international partnership mission uses components provided by the space agencies of Russia, Spain, and Canada.

Recent Achievements

Curiosity has traveled over 13 miles and has been exploring the lower reaches of Mt. Sharp – the prime science target of the mission – and is now in its third extended mission period. Since landing on Mars in 2012, the Curiosity rover has consistently detected low levels of methane in the atmosphere at Gale Crater. The methane concentration varies seasonally and is occasionally punctuated by transient spikes. This year, Curiosity detected the largest spike to-date, which peaked at 30 times above normal. The origin of transient methane on Mars is still unknown, but the science community is aware of both geological and biological processes that could potentially produce them. Repeated observations of this phenomenon will continue to produce insight into Mars' methane climate.

Curiosity is now more than halfway through a region scientists call the "clay-bearing unit" on the side of Mount Sharp, inside of Gale Crater, where the rover has found an array of complex organic compounds. Rock samples that the rover has drilled here have revealed the highest amounts of clay minerals found during the mission. In addition, Curiosity has monitored three plus Mars years of local weather and radiation environments.

MARS RECONNAISSANCE ORBITER 2005 (MRO)

MRO, currently in its fifth extended operations phase, carries the most powerful camera ever flown on a planetary exploration mission: the High-Resolution Imaging Science Experiment (HiRISE). This capability provides a more detailed view of the geology and structure of Mars and is critical in identifying obstacles that could jeopardize the safety of future landers and rovers. A second camera, The Context Camera (CTX), acquires medium-resolution images that provide a broader geological context for the more detailed observations from higher-resolution instruments; it has covered most of the planet and searches for new phenomena, such as new impact craters, revealing subsurface ice. MRO also carries a radar sounder to find subsurface water ice, an important consideration in selecting scientifically worthy landing sites for future exploration.

OTHER MISSIONS AND DATA ANALYSIS

MRO carries a high-resolution imaging spectrometer, the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM), which can map minerals at unprecedented spatial resolution. A wide-angle camera, the Mars Color Imager (MARCI), provides daily global weather maps, and the Mars Climate Sounder (MCS) shows how the Martian atmosphere transports dust and water vapor. MRO will follow up on recent discoveries of an increasingly diverse array of ancient aqueous environments and enough buried carbon dioxide ice that, if released, would double the present atmospheric pressure. MRO will extend mapping of the three-dimensional structure and content of the polar ice deposits, characterize the episodic nature of great dust storms, expand coverage of surface changes, and monitor possible seasonal surface color changes suggestive of liquid water flow on Mars today. MRO characterized the landing sites for the Mars 2020 Rover and the 2020 ESA ExoMars Rover.

As it explores Mars, MRO also serves as a major element of an “interplanetary Internet,” as a relay communications orbiter relaying commands to and data from Curiosity rover and InSight lander to Earth. In FY 2020, MRO will continue to characterize phenomena on the surface of Mars, such as the Recurring Slope Lineae and dust storms.

Recent Achievements

MRO made observations in FY 2019 that provide information on Mars climate change. Climate variations affect how ice is deposited on the surface and these climate variations result in part from orbital oscillations. Mars’ climate has changed significantly throughout history, as its orbit and spin axis change with periods of 51,000 and 120,000 years. These periodic variations result in patterns of icy layers in the polar ice sheets, with repeating climatic cycles resulting in similar types of layers. HiRISE observed the icy polar layers, and through analysis of the resulting stereo-images, MRO scientists connected patterns in the layers to patterns in the climate oscillation, thereby relating spatial changes in the geology, to temporal changes in climate, defining a rough stratigraphy for the ice cap.

A 2019 study using MCS and MARCI instruments found towering dust clouds reaching 70 kilometers (km) altitude in storms well to the east of the Tharsis volcanoes. Past observations showed that towering dust clouds in storms on Mars’ Tharsis volcanoes could bring dust to altitudes of 50-80 km. Researchers attributed towering dust clouds on volcanoes to dust starting at high surface elevation and radially symmetric daytime upslope winds exclusive to volcanoes. Based on this latest data, it appears that towering dust clouds are not limited to volcanic summits and their unusual circulations.

MARS ODYSSEY 2001

Mars Odyssey, currently in its eighth extended mission operations phase, is still in orbit around Mars. It continues to send information to Earth about Martian geology, climate, and mineralogy. Measurements by Odyssey enabled scientists to create maps of minerals and chemical elements and identify regions with buried water ice. Images that measure the surface temperature provided spectacular views of Martian topography. Mars Odyssey will continue critical, long-term longitudinal studies of the Martian climate. Odyssey has served as the primary means of communications for NASA Mars surface explorers over the past decade. Starting in November 2018, Odyssey has provided relay support for the InSight lander.

Recent Achievements

A key question in Martian science is understanding where and when there was water. Chloride salts are a class of minerals (including common table salt) that form in the presence of water. Mars Odyssey was the

OTHER MISSIONS AND DATA ANALYSIS

first to map the geologic context of chloride deposits around the globe in 2010. Now, an improved chloride index from Mars Odyssey's thermal emission imaging system instrument team has been created and enabled the discovery of 704 new chloride deposits. This greatly expanded database has allowed the team to determine that chloride formation stops abruptly near the dramatic climate transition at the end of the Noachian period.

MARS EXPRESS

Mars Express, currently in its sixth extended mission operations phase, is an ESA mission that provides an understanding of Mars as a "coupled" system: from the ionosphere and atmosphere down to the surface and sub-surface. This mission addresses the climatic and geological evolution of Mars as well as the potential for life on the planet. NASA contributed components for the Mars Advanced Radar for Subsurface and Ionospheric Sounding and Analyzer of Space Plasmas and Energetic Atoms instruments aboard Mars Express, and participates in the scientific analysis of mission data.

Recent Achievements

Mars Express has been measuring atmospheric loss and characterizing the Mars ionosphere and its interaction with the solar wind, and conducting a series of radio science investigations to gather data on lower atmosphere dynamics, which will be important to future missions during entry, descent and landing operations.

MARS ATMOSPHERE AND VOLATILE EVOLUTION (MAVEN)

MAVEN, now in its third extended mission, launched in 2013 and successfully completed its primary mission in November 2015. MAVEN is providing a comprehensive picture of the Mars upper atmosphere, ionosphere, solar energetic drivers, and atmospheric losses, to determine how the Mars atmosphere evolved through time. The mission is answering long-standing questions regarding the loss of the Mars atmosphere, climate history, liquid water, and habitability. MAVEN is the first mission devoted to studying Mars' upper atmosphere, with the most comprehensive measurements ever taken to address key scientific questions about Mars' evolution. It is exploring the upper atmosphere, ionosphere, interactions with the Sun and solar wind, and the resulting loss of gas from the atmosphere to space. Scientists are using MAVEN data to determine the role that loss of volatile compounds (e.g., carbon dioxide, water) from the Mars atmosphere to space has played through time, and the importance of this loss in changing the Mars atmosphere and climate through time.

As with all Mars Exploration Program orbiters, MAVEN carries an Electra radio for communications with rovers and landers on the Martian surface. MAVEN has been carrying out relay activities at a low level for the past three years but in FY 2019, the spacecraft positioned to a more relay efficient orbit. This will allow MAVEN to increase its relay support to landed assets.

Recent Achievements

In FY 2019, MAVEN devoted three months to modifying its trajectory to make it a better platform for relaying scientific data from the Mars rovers and landers back to Earth. During this aerobraking period, the spacecraft pushed its closest approach slightly closer to Mars, thereby increasing the atmospheric friction on the spacecraft. The very small increase in atmospheric friction modified MAVEN's orbit so

OTHER MISSIONS AND DATA ANALYSIS

that it would be better for relay. Since the end of aerobraking in March 2019, MAVEN has increased its relay responsibility to up to one data relay pass per day each for the Curiosity rover and the InSight lander. The new orbit will also be optimal for MAVEN to play an important data relay role during Mars 2020 entry, decent, and landing in early 2021. During aerobraking, MAVEN was able to sample deeper in the Martian atmosphere than it had previously. Scientific measurements during the aerobraking campaign have given new information into the way that dust storms affect the upper atmosphere and have provided insight about the interpretation of plasma measurements. This new insight will be highly beneficial to future missions that sample dense ionospheric plasmas.

During FY 2019, MAVEN scientists used data from MAVEN and several other Mars missions to provide the most detailed look to date at the historical amount of carbon dioxide (CO2) at Mars. The study looked at how CO2 has either been lost to space or been trapped on Mars in ice or carbon-bearing materials. Results indicate enough CO2 existed in the past for Mars to have a thick early atmosphere and would have provided substantial greenhouse warming, and contributed significantly to providing an early warm environment.

OUTER PLANETS AND OCEAN WORLDS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Jupiter Europa	732.4	592.6	**403.5**	351.8	224.9	180.8	160.1
Other Missions and Data Analysis	61.2	--	**10.9**	18.9	14.5	11.5	11.7
Total Budget	**793.6**	**--**	**414.4**	**370.7**	**239.4**	**192.3**	**171.7**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Europa, with its probable vast subsurface ocean sandwiched between a potentially active silicate interior and a highly dynamic surface ice shell, offers one of the most promising extraterrestrial habitable environments, and a plausible model for habitable environments beyond our solar system. Vision and Voyages for Planetary Science in the Decade 2013-2022.

The Outer Planets and Ocean Worlds program enables the exploration of worlds in our solar system possessing vast expanses of liquids. These liquid reservoirs provide insight into some of the most fundamental questions about life and the evolution of the solar system. The exploration of ocean worlds has the highest relevance and potential in the search for extant life and its habitable environments beyond Earth, one of NASA’s strategic objectives.

NASA missions have revealed an increasing number of ocean worlds in our solar system while at the same time providing enticing though limited details about these unexpected oceans. Not far underneath its icy crust, Jupiter's moon Europa contains a global liquid water ocean holding twice as much water as all of Earth’s oceans. Recent observations suggest active plumes emanate from the surface of Europa, which could provide another option for future exploration. Scientists detected a similar though smaller global ocean on Enceladus, a small moon orbiting Saturn, also emanating active plumes. Other moons (such as Ganymede, Titan, and perhaps Callisto) also possess oceans deep beneath their surfaces. Unlike Europa and Enceladus, whose oceans have a rocky bottom, these oceans are sandwiched between ice layers. Titan also possesses huge lakes of liquid methane on its surface – the only place beyond Earth with lakes exposed to an atmosphere.

Simultaneously with these discoveries, astrobiology research, along with the exploration of Earth’s oceans, has demonstrated the pervasiveness of life given the proper conditions and environment. Research has increasingly indicated that ocean worlds possess at least some of the conditions necessary for extant life: long-lived oceans providing liquid water and a stable habitat, hydrothermal activity and other chemical sources providing energy, and the basic elements along with organics providing the necessary materials, among others. Thus, ocean worlds are the most likely places to search for currently habitable environments in the solar system and the life forms that could exist in those environments.

OUTER PLANETS AND OCEAN WORLDS

The Outer Planets and Ocean Worlds program enables science investigations spanning the diversity of worlds hosting large liquid bodies in the outer solar system. The strategic missions currently in this portfolio investigate a broad array of science disciplines with more depth than is possible for smaller, tightly focused missions in the Discovery and New Frontiers programs. These missions in turn enable the definition of focused questions that smaller missions in the Discovery and New Frontiers programs can pursue.

EXPLANATION OF MAJOR CHANGES IN FY 2021

The 2020 Budget proposed to launch the Clipper on a commercial launch vehicle in 2023. However, current law meant that NASA was unable to initiate a launch vehicle contract in time for a 2023 launch. Therefore, the 2021 Budget supports the launch of the Europa Clipper as early as 2024 (one year later than previously proposed) on a commercial launch vehicle, which would save over $1.5 billion compared to an SLS rocket, allow additional investment in other NASA missions, and free up an SLS rocket for use on human space exploration missions. A Europa Lander mission, which was not supported by the science community in the Planetary Science decadal midterm report, is not funded.

In 2019, NASA established a baseline cost and schedule for Europa Clipper. NASA's current planning is consistent with current law requiring the Europa Clipper to launch on an SLS rocket. Given that NASA plans to complete development of Europa Clipper in 2023, it would be kept in storage until an SLS launch vehicle is potentially available. Due to ongoing development challenges with the SLS and the Artemis missions, an SLS is not expected to be available until later in the 2020s.

The Budget provides no funding to Icy Satellites Surface Technology in 2021, a congressionally directed project focused on technology development for exploration of the icy moons of Jupiter and Saturn. Researchers will still be able to compete for funding for this type of technology development from other planetary science programs.

EUROPA CLIPPER

Formulation	Development	Operations

FY 2021 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	BTC	Total
Formulation	1023.3	195.7	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	1219.0
Development/Implementation	0.0	349.3	592.6	**530.8**	445.1	255.0	120.0	120.0	0.0	2412.8
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	50.1	50.1	518.0	618.2
2020 MPAR LCC Estimate	**1023.3**	**545.0**	**592.6**	**530.8**	**445.1**	**255.0**	**170.1**	**170.1**	**518.0**	**4250.0**
Total Budget	**1023.3**	**545.0**	**592.6**	**403.5**	**351.8**	**224.9**	**180.8**	**160.1**	**518.0**	**4000.0**
Change from FY 2020				**-189.1**						
Percentage change from FY 2020				**-31.9%**						

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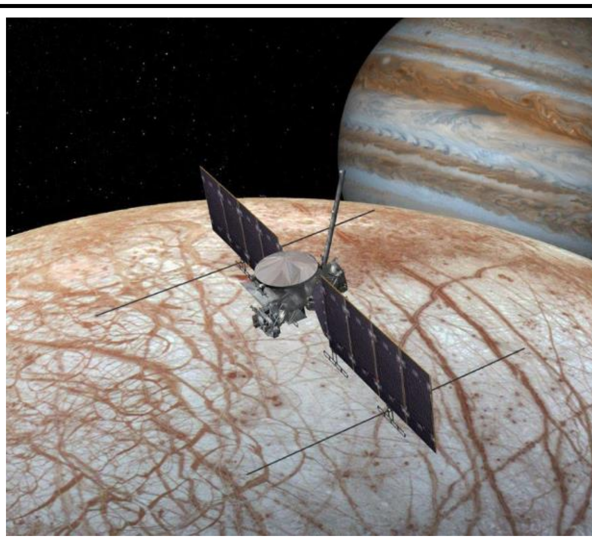

NASA designed the Europa Clipper spacecraft to collect data with four in situ and five remote sensing instruments, thoroughly characterizing Europa's habitability.

PROJECT PURPOSE

Jupiter's moon Europa has the largest known ocean in the solar system, and is one of the most likely places to find current life beyond our Earth. NASA has developed concepts to explore Europa and determine if it is habitable based on characteristics of its vast oceans (twice the size of all of Earth's oceans combined); the ice surface – ocean interface; the chemical composition of the intriguing, irregular brown surface areas; and the current geologic activity providing energy to the system. After thorough investigation of concept options, NASA directed a multiple flyby mission (Europa Clipper) that delivers the most science for the least cost and risk of all the concepts studied. The Europa Clipper mission takes advantage of solar power and requires no new technology development, despite the harsh radiation environment that the spacecraft will encounter during the flybys. The Clipper mission will explore Europa and investigate its habitability.

EUROPA CLIPPER

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2021

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Recognizing the important science objectives, NASA is pursuing a facility instrument, the Europa Clipper Magnetometer (ECM), to replace the terminated ICEMAG instrument. The facility-class instrument will be managed and developed by the Clipper project team and not competed or led by a principal investigator. The ECM will have reduced functionality compared to the concept ICEMAG was striving for, but will maintain capability for the highest priority science observations. In addition, NASA has invited all ICEMAG Co-Investigators to remain on the Europa Clipper science team to support the mission.

PROJECT PARAMETERS

NASA formulated the Europa Clipper mission in response to the planetary science Decadal Survey (Vision and Voyages for Planetary Science in the Decade 2013-2022), which identified a strategic mission to Europa as the second highest priority for planetary science flagship missions. This mission will leverage the competitively selected payload of investigations to characterize the ice shell and any subsurface water, including their heterogeneity, ocean properties, and the nature of the surface-ice ocean exchange. It will also seek to understand the habitability of Europa's ocean through composition and chemistry of the surface and exosphere; understand the formation of surface features, including sites of recent or current activity; and identify and characterize high science interest localities. This will be the first NASA mission explicitly designed to explore an ocean world.

The Europa Clipper mission will spend four years in orbit around Jupiter, conducting its scientific observations by completing approximately 44 close fly-bys of Europa, minimizing the spacecraft's exposure to the harsh radiation environment near Europa.

ACHIEVEMENTS IN FY 2019

The Europa Clipper mission passed its KDP-C gate review in August 2019 and entered the final design and fabrication phase (Phase C) of the project.

EUROPA CLIPPER

Formulation	Development	Operations

WORK IN PROGRESS IN FY 2020

The project will conduct the remaining instrument and subsystem Critical Design Reviews (CDRs). NASA scheduled an Agency Program Management Council for May 2020 to evaluate the status of the launch vehicle options and potential cost implications. The Europa Clipper project will hold its Critical Design Review in August 2020.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

Europa Clipper will conduct its KDP-D gate review in June 2021 after which it will enter the assembly, integration and test phase (Phase D) of the project.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2021 PB Request
KDP-C	Aug 2019	Aug 2019
CDR	Aug 2020	Aug 2020
SIR	Mar 2021	Mar 2021
KDP-D	Jun 2021	Jun 2021
ORR	May 2023	May 2023
Launch Readiness Date*	Sept 2025	Sept 2025
Phase E Start	Nov 2025	Nov 2025

**This launch readiness date assumes the requirement in current law to launch the Europa Clipper no later than 2025. The Budget proposes to launch the Europa Clipper on a commercial launch vehicle as early as 2024.*

EUROPA CLIPPER

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2020	2412.8	69%	2020	2412.8	0	LRD	Sept 2025	Sept* 2025	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

**This launch readiness date assumes the requirement in current law to launch the Europa Clipper no later than 2025. The Budget proposes to launch the Europa Clipper on a commercial launch vehicle as early as 2024.*

Development Cost Details

This report is the first report of development costs for this mission.

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**2412.8**	**2412.8**	**0**
Aircraft/Spacecraft	818.7	828.7	+10.0
Payloads	168.7	168.7	0
Systems I&T	63.2	63.2	0
Launch Vehicle	432.0	432.0	0
Ground Systems	104.8	104.8	0
Science/Technology	24.8	24.8	0
Other Direct Project Costs	800.6	790.6	-10.0

EUROPA CLIPPER

Formulation	Development	Operations

Project Management & Commitments

Responsibility for Europa Clipper project management resides at Jet Propulsion Laboratory (JPL).

Element	Description	Provider Details	Change from Baseline
Spacecraft		Provider: JPL Lead Center: JPL Performing Center(s): JPL, APL, GSFC, MSFC, JSC, KSC Cost Share Partner(s): N/A	
Europa UVS Instrument	Ultraviolet Spectrograph	Provider: SwRI Lead Center: JPL Performing Center(s): SwRI Cost Share Partner(s): N/A	
MASPEX	Time-of-Flight Mass Spectrometer	Provider: SwRI Lead Center: JPL Performing Center(s): SwRI Cost Share Partner(s): N/A	
Europa Imaging System (EIS)	Narrow Angle and Wide Angle cameras	Provider: APL Lead Center: JPL Performing Center(s): APL Cost Share Partner(s): N/A	
SUDA	Dust Analyzer; Mass Spectrometer	Provider: LASP - CU Lead Center: JPL Performing Center(s): LASP - CU Cost Share Partner(s): N/A	
E-THEMIS	Thermal Imager	Provider: ASU Lead Center: JPL Performing Center(s): ASU, BATC Cost Share Partner(s): N/A	
ICEMAG	Magnetometer	Provider: JPL Lead Center: JPL Performing Center(s): JPL, UCLA Cost Share Partner(s): N/A	Terminated

EUROPA CLIPPER

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
ECM	Magnetometer	Provider: JPL Lead Center: JPL Performing Center(s): JPL, UCLA Cost Share Partner(s): N/A	Facility instrument to replace ICEMAG functionality
PIMS	Plasma Instrument - Faraday Cups	Provider: APL Lead Center: JPL Performing Center(s): APL Cost Share Partner(s): N/A	
MISE	Infrared Spectrometer	Provider: JPL Lead Center: JPL Performing Center(s): JPL, APL Cost Share Partner(s): N/A	
REASON	Sounding Radar	Provider: Univ. of Texas Lead Center: JPL Performing Center(s): JPL, UT, U. Iowa Cost Share Partner(s): N/A	

Project Risks

Risk Statement	Mitigation
Launch Vehicle uncertainty due to congressional direction on using an SLS and Administration position on using a commercial launch vehicle	Maintaining compatibility with both commercial launch vehicle and SLS. Assessing information on launch vehicles in development as it becomes available. Regular meetings with SLS on performance, interfaces, and environments. If the Congress were to support the Administration's position, NASA could move forward this year with securing a commercial launch vehicle.
Radiation Effects (including total dose, spacecraft charging, and internal electrostatic discharge)	Early parts testing for radiation tolerance and lot buys of compatible parts made available to subsystems and instruments; development of preferred parts list; early radiation modeling to optimize shielding.

EUROPA CLIPPER

Formulation	Development	Operations

Acquisition Strategy

The Europa Clipper spacecraft is a JPL "in-house" build with each subsystem doing its internal make/buy assessment, with competed industry contracts where appropriate. JPL has entered into a partnership with Applied Physics Laboratory (APL) for this build, leveraging each other's strengths as well as those of other NASA centers. As a result, APL is responsible for propulsion module and the telecom subsystem, and Goddard Space Flight Center will be providing the propulsion subsystem. The Europa Clipper payload comprises nine investigations, each competitively selected via a Science Mission Directorate Announcement of Opportunity.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Telecom and Propulsion Subsystems	APL	Laurel, MD Greenbelt, MD (GSFC)
EIS instrument	APL	Laurel, MD
PIMS instrument	APL	Laurel, MD
REASON instrument	University of Texas JPL University of Iowa	Austin, TX Pasadena, CA Iowa City, IA
MISE instrument	JPL APL	Pasadena, CA Laurel, MD
SUDA instrument	LASP - University of Colorado	Boulder, CO
MASPEX instrument	SWRI	San Antonio, TX
UVS instrument	SWRI	San Antonio, TX
E-THEMIS instrument	ASU Ball Aerospace Raytheon Vision Systems	Tempe, AZ Boulder, CO Goleta, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Jan 2017	Europa SRR and MDR	Successful	Aug 2018

EUROPA CLIPPER

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Aug 2018	PDR	Successful	Jun 2019
Performance	SRB	Jun 2019	Delta-PDR	Successful	Aug 2020
Performance	SRB	Aug 2020	CDR	TBD	Mar 2021
Performance	SRB	Mar 2021	SIR	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Icy Satellites Surface Technology	35.0	--	**0.0**	5.8	2.8	2.5	2.5
JUICE - Jupiter Icy Moons Explorer	15.6	--	**2.7**	4.8	3.4	0.8	0.8
Outer Planets Research	6.7	--	**8.3**	8.3	8.3	8.3	8.3
Cassini	3.9	--	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**61.2**	**--**	**10.9**	**18.9**	**14.5**	**11.5**	**11.7**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Other Missions and Data Analysis includes NASA's contribution to the ESA Jupiter Icy Moons Explorer (JUICE) mission, Icy Satellites Surface Technology, and Outer Planets Research.

Mission Planning and Other Projects

ICY SATELLITES SURFACE TECHNOLOGY

NASA is developing the technologies needed to explore the icy moons of Jupiter and Saturn. These include electronics and computers capable of surviving extremely harsh radiation environments, solar power systems to operate in the cold far from the Sun, actuators, and mechanisms to operate on frigid surfaces, and mobility systems to traverse through thick ice crusts to reach and explore hidden oceans. Advances in autonomous spacecraft operations and sample acquisition will help maximize the science return from future missions. Researchers also need cryogenic containment systems to maintain the integrity of samples returned to Earth.

Recent Achievements

Engineers designed and built two autonomy testbeds, one physical and the other virtual, to evaluate advances in autonomy technology to use in future to robotic exploration of icy worlds.

NASA released a draft solicitation for proposals to develop approaches to perform daily activities of an ocean world sample acquisition in the presence of failures or unexpected interactions with environment.

JUICE - JUPITER ICY MOONS EXPLORER

NASA is collaborating with the European Space Agency (ESA) on this ESA-led mission to Ganymede and the Jupiter system. The JUICE mission provides an opportunity for comparative investigation of three

OTHER MISSIONS AND DATA ANALYSIS

of the ocean worlds in the Jupiter system: Europa, Ganymede, and Callisto. Researchers believe Ganymede and Callisto possess liquid water oceans sandwiched between ice layers deep beneath their surfaces. ESA plans to launch the mission in 2022 for arrival at Jupiter in 2030. The NASA contribution consists of three separate pieces of hardware: one full instrument, Ultra Violet Spectrometer (UVS); two sensors for the Particle Environment Package suite of instruments (PEP-Hi); and the transmitter and receiver hardware for the Radar for Icy Moon Exploration (RIME) instrument.

Recent Achievements

The three NASA JUICE contributions, UVS, PEP-Hi, and RIME completed their NASA Critical Design Reviews (CDR), including the RIME delta CDR in September 2019.

EUROPA LANDER CONCEPT

Public Law 116-93 directed NASA to provide a five-year funding profile for a Europa lander mission. The FY 2021 Budget includes no funding for a Europa Lander mission. With FY 2019 appropriated funding, NASA is conducting pre-formulation (pre-Phase A) technology development and studies - which will continue into FY 2020. Given the early nature of this project, NASA cannot provide a year-by-year funding profile. However, recent estimates for a notional lander concept have been in the range of $3.5-$5.0 billion.

OUTER PLANETS RESEARCH

Outer Planets Research increases the scientific return of current and past NASA outer planets missions and paves the way for future missions (e.g., refining landing sites on Titan, reconsidering the ice shell thickness on Europa).

Recent Achievements

Recent research offers additional evidence about plume activity on Europa, an ocean world orbiting Jupiter and destination for the Europa Clipper mission. In 2012 and 2014, scientists using the Hubble Space Telescope found evidence supporting the existence of large plumes of water sporadically erupting from Europa. When scientists reanalyzed data from the Galileo mission, they found evidence of a similar plume erupting in 2000. Analysis showed distortion of the magnetic field near Europa, which was most likely caused by a plume erupting within a few hundred miles of the spacecraft as it flew by Europa. Independently, a separate team used the Keck telescope on Earth to obtain the first direct detection of water vapor in Europa's atmosphere. The most likely source for this water vapor, only detected once in 17 searches, is an erupting plume. Both of these discoveries provide further strong evidence that plume activity at Europa is persistent and composed of water.

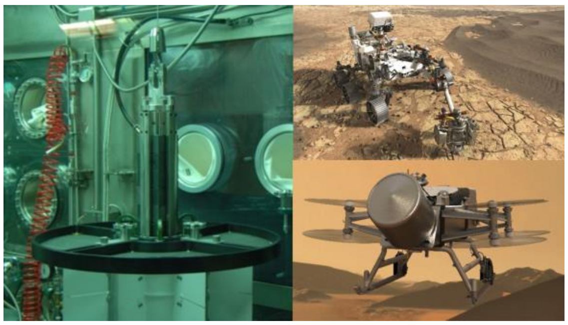
RADIOISOTOPE POWER

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**123.3**	**--**	**146.3**	**150.1**	**162.8**	**165.4**	**169.8**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.



The MMRTG flight unit, being fueled at Idaho National Laboratory (left), will provide power for the Mars 2020 rover (upper right). Another MMRTG is baselined for the Dragonfly mission to Titan (lower right).

Planetary Science missions demand advances in technology to enable successful trips to distant solar system destinations, harsh environments, and missions with highly challenging trajectories and operations. To meet these needs, Planetary Science supports the development of advanced multi-mission capabilities through technology investment in key spacecraft systems, such as radioisotope power. The Radioisotope Power Systems (RPS) Program managed by Glenn Research Center includes technology and system development, in partnership with the U.S. Department of Energy (DOE) to ensure continuing plutonium-238 production and PU-238 production operations infrastructure. The program also supports nuclear launch approval activities.

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

ACHIEVEMENTS IN FY 2019

RPS facilitated the selection of the F2 MMRTG (Multi-Mission Radioisotope Thermoelectric Generator) unit for the Mars 2020 mission and, in partnership with DOE, completed fueling of the unit in support of its upcoming launch. In addition, RPS supported technical information exchanges for the New Frontiers 4 selection process and provided input to the 2019 Discovery announcement of opportunity, wherein up to two MMRTG units and/or dozens of radioisotope heater units were offered to be included in mission proposals.

RADIOISOTOPE POWER

RPS supported NASA and interagency nuclear launch approval process studies; culminating in a new National Security Presidential Memorandum-20, regarding Launch of Spacecraft Containing Space Nuclear Systems (NSPM-20), that NASA will apply to future RPS and fission-based spaceflight missions.

The Next-Gen RTG activity, through a partnership with DOE/Idaho National Lab (INL), competitively selected two aerospace contractors to perform concept studies for a potential future modular vacuum-based RPS. Technology maturation of thermoelectric and dynamic energy conversion hardware continued, including a Gate 2 review of the enhanced MMRTG effort and successful Gate 1 reviews of three Dynamic RPS convertor technology contracts, which enabled initiation of technology hardware fabrication. Heritage dynamic convertors of similar configuration to those under contract continued to undergo long-duration testing, with two variants surpassing 9 and 13 years of maintenance free normal operation.

DOE fully integrated the plutonium supply activity into production operations activities, bringing together all the supply chain activities for Constant Rate Production (CRP). Within CRP, ongoing facility maintenance and upgrades continued, including operation of an automated target fabrication capability at Oak Ridge National Laboratory and installation of a new hot press glovebox at Los Alamos National Laboratory. The new hot press provides redundant heat source manufacturing capability in support of CRP.

WORK IN PROGRESS IN FY 2020

Energy conversion technologies will result in delivery of three Dynamic RPS (DRPS) technology demonstration convertors and performance data from the industry teams. These efforts will culminate in a DRPS activity Gate 2 review in FY 2020. The program plans a DRPS systems development effort, including seeking industry input via a DOE Sources Sought Notice for a potential lunar surface RPS solution in providing long-lived power for scientific exploration. The next generation RTG technology effort will complete its first Gate review once the two contractor-led concept study phase efforts are complete.

NASA will continue to develop processes and decision-making steps applicable to RPS usage on NASA missions. Implementing the first step within these areas is the planned FY 2020 issuance of a Radioisotope Heater Unit (RHU) programmatic environmental assessment and development of a RHU documented safety analysis by DOE.

NASA will ensure DOE continues processing of the MMRTG for Mars 2020, completing its acceptance testing, with anticipated delivery of the power system to KSC to support mission integration in early 2020.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

In FY 2021, NASA will continue to support utilization of RPS on missions, specifically providing a liaison between DOE and the Dragonfly mission on system integration and engaging with potential Discovery AO mission teams as required. NASA will acquire via DOE existing and emerging RPS generators and will provide services to enable the baselined MMRTG for Dragonfly.

RADIOISOTOPE POWER

Program Elements

RADIOISOTOPE POWER SYSTEM (RPS)

The Radioisotope Power System project will continue to ensure the availability of RPS for the exploration of the solar system in environments where conventional solar or chemical power generation is impractical or impossible. Working with DOE to provide fueled RPS to missions and to support mission design and integration activities will achieve this goal. The project will continue to reduce costs to the missions and increase system performance. RPS will continue energy conversion research and development to advance state-of-the-art performance in heat to electrical energy conversion.

DOE OPERATIONS AND ANALYSIS

NASA funds DOE national laboratory personnel and infrastructure required to maintain the capability to develop and fuel radioisotope power systems for deep space spacecraft missions. DOE resumed domestic production of Plutonium-238 for the first time since the 1980's. NASA funds the effort and the DOE Oak Ridge National Laboratory leads the effort and irradiates targets at its High Flux Isotope Reactor. The DOE Idaho National Laboratory (INL) participates in the development of targets for future irradiation at the Advanced Test Reactor, which is required to meet Pu-238 production rates. DOE continues to increase annual production, producing approximately 200-300 grams per year. As the process is refined and automated over the next several years, it is expected to ramp up to a full operational capability of 1.5 kilograms per year. DOE Los Alamos National Laboratory (LANL) manages the existing Pu-238 inventories and manufactures fuel, resulting in continual annual fueled clad manufacturing by LANL and delivery to INL at a rate of 10-15 clads per year. INL integrates the fueled clads with generator systems and manages the transportation and launch operations activities in support of NASA missions.

Program Management & Commitments

Glenn Research Center manages the Radioisotope Power Systems (RPS) Program.

Program Element	Provider
RPS	Provider: GRC Lead Center: GRC Performing Center(s): GRC, JPL, GSFC, KSC, DOE Cost Share Partner(s): N/A
DOE Operations and Analysis	Provider: DOE Lead Center: GRC Performing Center(s): GRC, DOE Cost Share Partner(s): N/A

RADIOISOTOPE POWER

Acquisition Strategy

DOE provides radioisotope power systems and production operations on a reimbursable basis. Maturity of the technologies determines the acquisition of technologies and new systems. NASA or DOE laboratory competed acquisitions can be used to mature technology before system development begins. NASA-led DOE laboratory acquisitions procure unfueled designs and flight qualified hardware when initiating a system development.

The program acquires content via existing Agency contracts with JPL and APL. The program will use in-house or competitive procurements as needed.

JAMES WEBB SPACE TELESCOPE

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**305.1**	**423.0**	**414.7**	**175.4**	**172.0**	**172.0**	**172.0**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

James Webb Space Telescope

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

FY 2021 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	BTC	Total
Formulation	1800.1	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	1800.1
Development/Implementation	5913.7	305.1	423.0	**357.4**	3.4	0.0	0.0	0.0	0.0	7002.6
Operations/Close-out	0.0	0.0	0.0	**57.3**	172.0	172.0	172.0	172.0	114.7	860.1
2020 MPAR LCC Estimate	**7713.8**	**305.1**	**423.0**	**414.7**	**175.4**	**172.0**	**172.0**	**172.0**	**114.7**	**9662.7**
Total Budget	**7713.8**	**305.1**	**423.0**	**414.7**	**175.4**	**172.0**	**172.0**	**172.0**	**114.7**	**9662.7**
Change from FY 2020				**-8.3**						
Percentage change from FY 2020				**-2.0%**						

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Image depicting the deployment and tension of the five-layer sunshield, which will protect the James Webb Space Telescope once it is in orbit.

PROJECT PURPOSE

The James Webb Space Telescope (Webb) is a large, space-based astronomical observatory. The mission is in many ways a successor to the Hubble Space Telescope, extending Hubble's discoveries by looking into the infrared spectrum. Webb will observe the highly red-shifted early universe and study relatively cool objects like protostars and protoplanetary disks, which emit infrared light strongly where dust obscures shorter wavelengths. With more light-collecting area than Hubble and with near-to mid-infrared-optimized instruments, Webb will observe objects farther away and further back in time.

The four main science goals are to:

- Search for the first galaxies or luminous objects formed after the Big Bang;
- Determine how galaxies evolved from their formation until now;
- Observe the formation of stars from the first stages to the formation of planetary systems; and
- Measure the physical and chemical properties of planetary systems and investigate the potential for life in those systems.

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

While Hubble greatly improved knowledge about distant objects, its infrared coverage is limited. Light from distant galaxies is red-shifted out of the visible part of the spectrum and into the infrared by the expansion of the universe. Webb will explore the poorly understood epoch when the first luminous objects in the universe came into being after the Big Bang.

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

PROJECT PARAMETERS

Webb is an infrared-optimized observatory that will conduct imaging and spectrographic observations in the 0.6- to 28-micrometer wavelength range. Webb will be roughly 100 times more capable than Hubble because its mirror is seven times larger. It will spend about twice as much time observing targets since the Earth will not be in the way. Its detectors cover larger regions of the sky and are always on (i.e., are always running in parallel), and its multi-object spectroscopic capabilities greatly expands the number of spectra per field.

The 6.5-meter primary mirror consists of 18 actively controlled segments. A multilayer sunshield the size of a tennis court passively cools the mirror, telescope optics, and instruments to about 40 Kelvin. Webb will launch in 2021 from Kourou, French Guiana on an Ariane 5 rocket contributed by the European Space Agency (ESA). Webb will operate in deep space about 1 million miles from Earth.

Webb's instruments include the Near-Infrared Camera, Near-Infrared Spectrograph, Mid-Infrared Instrument, and the Fine Guidance Sensor/Near-Infrared Imager and Slitless Spectrograph.

The Near-Infrared Camera takes images with a large field of view and high-resolution, over the wavelength range of 0.6 to 5 micrometers. The Near-Infrared Camera also aligns and focuses the optical telescope. The Near-Infrared Camera detects light from the earliest stars and galaxies in the process of formation, stars in nearby galaxies, young stars in the Milky Way, and solar system Kuiper Belt objects. The Near-Infrared Camera is equipped with coronagraphs, which allow astronomers to view dimmer objects near stars. With the coronagraphs, astronomers hope to determine the characteristics of planets orbiting nearby stars.

A spectrograph disperses light from an object into a spectrum. The atoms and molecules in the object imprint lines on its spectrum that uniquely fingerprint each chemical element present. Analyzing the spectrum of an object provides information on its physical properties, including temperature, mass, chemical composition, and motion.

The Near-Infrared Spectrograph can obtain simultaneous spectra of more than 100 objects in a single exposure, over the wavelength range of 0.6 to 5 micrometers.

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

The Mid-Infrared Instrument takes wide-field images and narrow-field spectra, over the wavelength range of 5 to 28 micrometers. The Mid-Infrared Instrument operates at about seven degrees Kelvin, which an onboard cooling system makes possible.

The Fine Guidance Sensor is a camera that provides fine pointing control and locks the telescope onto its target. The sensor operates over a wavelength range of 1 to 5 micrometers. The Near-Infrared Imager and Slitless Spectrograph instrument provide unique imaging and spectroscopic modes to investigate the distant universe, as well as exoplanets.

For more information, go to: http://www.jwst.nasa.gov

ACHIEVEMENTS IN FY 2019

NASA made significant progress in the integration and testing of the Webb system. The project also completed significant and technically challenging developments and tests successfully. The project:

- Completed Spacecraft Element (SCE) environmental testing, including acoustics, vibration and thermal vacuum testing;
- Conducted System Integration Review (SIR) Part 1 to support the integration of the Optical Telescope and Integrated Science Instrument Module (OTIS) to the spacecraft; and
- Completed mechanical and electrical integration of spacecraft and the OTIS, including full deployment of the telescope.

WORK IN PROGRESS IN FY 2020

In FY 2020, the project will:

- Conduct post-SCE environmental sunshield deployment, fold and stow activities;
- Complete SIR Part 2;
- Complete Key Decision Point D (KDP-D) program management council with entrance into the assembly, integration and test phase of the mission;
- Perform sunshield upgrades;
- Conduct observatory acoustics and vibration testing; and
- Initiate post observatory environmental sunshield deployment.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

The President's FY 2021 budget request provides the full level of funding required to keep Webb on schedule for a 2021 launch. In FY 2021, the project plans to:

- Complete post-environmental sunshield deploy, stow, and fold activities for launch configuration;
- Conduct testing of the Webb flight operations system and science processing system;
- Transport Webb to the launch site in Kourou, French Guiana; and
- Launch the observatory.

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

NASA plans to launch Webb in March 2021 to begin a five-year prime mission. Per the Agency KDP-D review in November 2019, NASA plans to reassess the launch date in the spring of 2020. The following timeline shows the development agreement schedule per the Agency re-plan from June 2018.

Milestone	Confirmation Baseline Date	FY 2021 PB Request
Rebaseline	Feb 2019	Feb 2019
System Integration Review (SIR) Part 1	Aug 2019	Jul 2019
System Integration Review (SIR) Part 2	N/A	Oct 2019
KDP-D	Sep 2019	Nov 2019
KDP-E	Jan 2021	Jan 2021
Launch	Mar 2021	Mar 2021
Begin Phase E	Sep 2021	Sep 2021
End of Prime Mission	Sep 2026	Sep 2026

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2019	7,002.6	N/A	2020	7,002.6	0%	LRD	Mar 2021	Mar 2021	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost. NASA originally baselined Webb in 2009, re-baselined Webb in 2012, and conducted a re-plan in 2018 which became a new reporting baseline in Public Law 116-6, Consolidated Appropriations Act, 2019. The original baseline provided in the Supporting Data section.

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**7,002.6**	**7,002.6**	**+0.0**
Aircraft/Spacecraft	3,818.5	3,954.5	+136.0
Payloads	776.2	827.1	+50.9
Systems Integration & Test (I&T)	441.2	503.4	+62.2
Launch Vehicle	10.4	1.2	-9.2
Ground Systems	801.6	917.3	+115.7
Science/Technology	34.3	46.9	+12.6
Other Direct Project Costs	1,120.4	752.2	-368.2

Project Management & Commitments

NASA Headquarters is responsible for Webb program management and GSFC is responsible for Webb project management.

Element	Description	Provider Details	Change from Baseline
Observatory	Includes Optical Telescope Element (OTE), spacecraft, sunshield, observatory assembly integration and testing, and commissioning. Designed for at least a five-year lifetime. Northrop Grumman Aerospace Systems (NGAS) has the lead for the OTE, sunshield, spacecraft bus, and selected assembly, integration, and testing activities	Provider: NGAS and GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Mission management and system engineering	Includes management of all technical aspects of mission development and system engineering of all components	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A

JAMES WEBB SPACE TELESCOPE

Formulation	**Development**	Operations

Element	Description	Provider Details	Change from Baseline
ISIM	Contains the science instruments and Fine Guidance Sensor. Provides structural, thermal, power, command, and data handling resources to the science instruments and Fine Guidance Sensor	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
NIRCam	Operates over the wavelength range of 0.6 to 5 micrometers and is optimized for finding first light sources	Provider: University of Arizona, Lockheed Martin Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
NIRSpec	Operates over the wavelength range of 0.6 to 5 micrometers with three observing modes	Provider: ESA Lead Center: ESA Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
MIRI	Operates over the wavelength range of 5 to 28 micrometers and provides imaging, coronagraphy, and spectroscopy	Provider: ESA, University of Arizona, JPL Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Fine Guidance	Provides scientific target pointing information to the observatory's attitude control sub-system	Provider: Canadian Space Agency (CSA) Lead Center: CSA Performing Center(s): N/A Cost Share Partner(s): CSA	N/A
Launch vehicle and launch operations	Ariane 5	Provider: ESA Lead Center: ESA Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Ground control system and science operations and control center	Includes mission operations and science operations center	Provider: Space Telescope Science Institute (STScI) Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: Major issues arise during observatory integration and testing, Then: This may delay completion of testing, adding risk to achieve the March 2021 launch.	The project has established an environmental testing plan that includes testing at lower levels of assembly prior to integration and testing at higher levels of assembly, to reduce risk to testing at higher levels of assembly.

Acquisition Strategy

The project has awarded all major contracts.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Science and Operations Center	STScI	Baltimore, MD
NIRCam	University of Arizona; Lockheed Martin	Tucson, AZ Palo Alto, CA
Observatory	NGAS Ball Aerospace ITT/Exelis/Harris Alliant Techsystems	Redondo Beach, CA Boulder, CO Rochester, NY Edina, MN
Near-Infrared Detectors	Teledyne Imaging Systems	Camarillo, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board (SRB)	Apr 2010	CDR	Determined mission design is mature and recommended a more in-depth review of the integration and testing plan	N/A

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	Test Assessment Team	Aug 2010	Evaluate plans for integration and testing	The team recommended several changes to the test plan	N/A
Other	Independent Comprehensive Review Panel	Oct 2010	Determine the causes of cost growth and schedule delay on Webb, and estimate the launch date and budget, including adequate reserves	The report made 22 recommendations, covering several areas of management and performance	N/A
Other	The Aerospace Corporation	Apr 2011	Analysis of alternatives	Determined that Webb design was still the best value to achieve the primary scientific objectives of the mission	N/A
Other	SRB	May 2011	Review technical, cost, and schedule plans	The SRB proposed rebaselined project technical, cost, and schedule plans and made recommendations to the Agency	N/A
Performance	NASA Headquarters Office of Evaluation	Jun 2012	Replan assessment review	A review assessed progress against replan	N/A
Performance	SRB	Apr 2016	OTE/Integrated Science SIR	Completed	N/A
Performance	SRB	Aug 2016	OTE/Integrated Science Pre-Environmental Review	Completed	N/A
Other	SRB	Mar 2018	Schedule risk assessment	SRB recommended new launch date	N/A
Other	IRB	Apr 2018	Conduct assessment of mission development for schedule & mission success	The IRB recommended to Agency re-baseline of schedule, cost, and launch date	N/A
Other	SRB	Apr 2019	Interim review schedule risk	Completed; validated Mar 2021 LRD is achievable	N/A

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Part 1 Jul 2019 Part 2 Oct 2019	Observatory SIR	Completed; confirmed project was ready to proceed to observatory integration	N/A
Performance	SRB	Jan 2021	ORR	TBD	TBD

ASTROPHYSICS

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Astrophysics Research	222.8	--	**269.7**	279.1	327.2	314.9	331.1
Cosmic Origins	222.8	--	**124.0**	123.2	120.0	122.4	122.4
Physics of the Cosmos	151.2	--	**143.9**	160.8	155.3	169.8	154.1
Exoplanet Exploration	367.9	--	**47.2**	50.4	47.6	51.6	52.2
Astrophysics Explorer	226.5	--	**246.2**	277.7	350.8	301.0	315.6
Total Budget	**1191.1**	**1306.2**	**831.0**	**891.2**	**1000.9**	**959.7**	**975.5**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Astrophysics

ASTROPHYSICS RESEARCH

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Astrophysics Research and Analysis	83.4	--	**90.2**	92.2	94.2	94.2	94.2
Balloon Project	40.2	--	**44.8**	45.8	45.7	46.3	46.3
Science Activation	45.0	--	**45.6**	45.6	45.6	45.6	45.6
Other Missions and Data Analysis	54.2	--	**89.1**	95.5	141.7	128.8	145.0
Total Budget	**222.8**	--	**269.7**	**279.1**	**327.2**	**314.9**	**331.1**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

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Balloon launch of the Picture-C payload (pictured) demonstrating technologies for direct imaging of exoplanets from Fort Sumner, NM on September 25, 2019.

The Astrophysics Research program develops innovative technologies for future missions to explore and understand the cosmos, from the nature of planets circling other stars to the birth of distant galaxies and the earliest cosmic history. High-altitude balloon and sounding rocket flights test new types of instruments. These flights also allow a quick response to unexpected events, such as the appearance of a new supernova.

The program provides basic research awards for scientists to test their theories and to understand how they can best use data from NASA missions to gain new knowledge from the cosmos. Awardees analyze the data from Astrophysics missions to understand astronomical events, such as the explosion of a star or the fingerprints of early cosmic history in the microwave background. The Science Activation project delivers SMD’s unique science content and expertise to learners of all ages through networks of local and national partners.

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

ACHIEVEMENTS IN FY 2019

In FY 2019, NASA launched two sounding rocket payloads. The Dual-Channel Extreme Ultraviolet Continuum Experiment (DEUCE) payload from the University of Colorado launched on December 18,

ASTROPHYSICS RESEARCH

2018, from White Sands Missile Range in New Mexico. The DEUCE mission measured extreme ultraviolet light produced by young and luminous stars in our own galaxy. This experiment addresses questions of how and when galaxies first formed and how the formation of these stars affect their environments.

On August 11, the Suborbital Imaging Spectrograph for Transition region Irradiance from Nearby Exoplanet (SISTINE) Rocket mission from the University of Colorado launched from White Sands Missile Range in New Mexico. SISTINE enables studies of the ultraviolet radiation (UV) environment around low-mass stars and the effects of that UV on potential exoplanet atmospheres.

NASA conducted two balloon campaigns in 2019, specifically the Antarctica campaign in December 2018-January 2019, and the Fort Sumner, New Mexico, campaign in August - October 2019. The Antarctica campaign focused on astrophysics missions, while the Fort Sumner campaign included heliophysics, Earth atmospheric science, astrophysics, student experiments, and engineering test missions. Two other campaigns that were cancelled included the New Zealand campaign (cancelled because of the partial U.S. Government shutdown from December to January), and the Palestine, Texas campaign (cancelled because of a balloon engineering/safety study ongoing at that time).

The Science Activation project accomplishments include:

- 4,600 libraries celebrated the "Summer of Space" reading lists including Apollo 50th anniversary materials;
- 350 science centers and museums received hands-on toolkits that were also available digitally to all users;
- 421 subject matter experts provided science content across the four disciplines; and
- Over 1.9 million educators accessed online science materials tailored to state-based education standards, organized by grade-level.

WORK IN PROGRESS IN FY 2020

NASA scheduled seven Astrophysics sounding rockets for launch in FY 2020. The first four will fly from the White Sands Missile Range. NASA will launch the other three from Equatorial Launch Australia, a commercial launch site in Australia's Northern Territory. The first sounding rocket, launched on October 7, 2019, is the DUST (Determining Unknown yet Significant Traits) mission from Goddard Space Flight Center. This experiment is studying the formation of dust grains in microgravity. The second sounding rocket mission, FORTIS (Far-ultraviolet Off Rowland-Circle for Imaging and Spectroscopy), from Johns Hopkins University will demonstrate multi-object spectroscopy over wide angular fields in the far-UV. The third mission, CIBER-2 (Cosmic Infrared Background Experiment), from Rochester Institute of Technology will measure the cosmic near-infrared extragalactic background light. The fourth sounding rocket mission, Micro-X, from Northwestern University will advance the critical technology of transition edge sensors of X-ray astronomy. The three sounding rocket launches from Australia will have access to celestial targets in the Southern Hemisphere including the center of the Milky Way. The first two sounding rocket payloads are the annual launches of the above mentioned SISTINE and DEUCE missions. The third mission is the X-ray Quantum calorimeter from the University of Wisconsin obtaining high spectral resolution x-ray observation of diffuse hot gas.

ASTROPHYSICS RESEARCH

NASA has planned four balloon campaigns in 2020; the Antarctica long-duration balloon campaign, the New Zealand campaign to launch test flight of the super-pressure balloon with a science mission of opportunity, the Palestine, Texas, campaign, and the Fort Sumner, New Mexico campaign.

HaloSat is the first Astrophysics CubeSat launched on May 2018 and is currently in orbit collecting good data on the structure of the X-ray emission from the Galactic Halo. During FY 2020 it will continue to collect data until its predicted reentry in September 2020. Currently, Astrophysics has five other CubeSats in development. CUTE, built in Boulder, Colorado, measures UV spectra of planets transitioning in front of stars. BurstCube, built at NASA GSFC in Maryland, detects sudden gamma-ray bursts that occur when neutron stars collide. Star-Planet Activity Research CubeSat (SPARCS), built at Arizona State University, measures the UV flares from red dwarf stars to determine which flares are a hazard to life on planets orbiting such stars. SPRITE, built at University of Colorado in Boulder, observes UV spectra of star forming regions in numerous nearby galaxies, to trace the history of star formation. During FY 2020, NASA will fund a new CubeSat called BlackCat, built at Penn State University, that will discover transient X-ray sources.

NASA completed 9 six-month long studies of possible smallsat missions to do high priority astrophysics science at a lower cost than a typical Small Explorer Mission. Several of these proposed to the Astrophysics Explorer Mission of Opportunity and are currently under review for possible selection. Based on the success of these studies, NASA initiated a second set of such studies with proposals due in December 2019.

The National Academies of Science, Engineering, and Mathematics (NASEM) assessed the Science Activation (SciAct) project and released its report in November 2019. The report found the project to be of considerable value and suggested a few ideas for improvement. By the end of 2020, the Science Activation project aims to enable active learners in all 50 states; continue to support the Federal CoSTEM Education Five-Year Strategic Plan goals; strengthen the number of experts supporting the project, and increase the number of strategic partners, as appropriate, to enhance the overall effort consistent with the NASEM conclusions. The budget includes funding for citizen science training and implementation. This will allow NASA to coordinate and amplify citizen science in every discipline.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

NASA will continue a competed Astrophysics Research program with emphasis on suborbital payloads and on development of key technologies for use in future missions. Theoretical work will provide the foundation to develop science requirements for new missions. Data analysis will multiply the science yield from NASA's astrophysics missions.

The Balloon project plans to support the annual Antarctic long-duration balloon campaign. It will also support a super-pressure balloon campaign from New Zealand, and two domestic campaigns with conventional flights from Palestine, Texas, and Fort Sumner, New Mexico.

The Sounding Rocket project is planning a campaign in Alaska at the Poker Flat Research Range. Three missions: LAMP, INCAA, and Beam-PE will observe high altitude plasma and the Northern Lights to understand their physical processes.

The Science Activation project will modify its plans based on the findings and recommendations of the NASEM assessment, new administration guidance, and other stakeholder inputs. These could include new opportunities for competition through NASA's annual Research Opportunities in Space and Earth Sciences (ROSES) announcements. These new awards would respond to gaps identified in the NASEM assessment as well as new priorities not envisioned in 2016.

Program Elements

RESEARCH AND ANALYSIS

This project supports basic research, solicited through NASA's annual Research Opportunities in Space and Earth Sciences (ROSES) announcements. NASA solicits investigations relevant to Astrophysics over the entire range of photon energies, gravitational waves, and particles of cosmic origin. Scientists and technologists from a mix of disciplines review proposals and provide findings that underlie NASA's merit-based selections.

Astrophysics Research and Analysis solicits technology development for detectors and instruments for potential use on future space flight missions and science and technology investigations using sounding rockets, high-altitude balloons, and similar platforms. A new type of scientific instrument often flies first on a stratospheric balloon mission or on a sounding rocket flight, which takes it briefly outside Earth's atmosphere. Instruments for balloons and sounding rockets are less expensive than orbital missions and experimenters can build them quickly to respond to unexpected opportunities, such as a newly discovered supernova. The experimenter usually retrieves the equipment after the flight so that new instruments can be tested, improved, and flown again. Suborbital flights are important for training the next generation of scientists and engineers to maintain U.S. leadership in STEM. The project also supports small experiments flown on the ISS, laboratory astrophysics, and limited ground-based observations.

The Astrophysics Theory program element solicits basic theory investigations needed to interpret data from NASA's space astrophysics missions and develop the scientific basis for future missions. Astrophysics Theory topics include the formation of stars and planets, supernova explosions and gamma-ray bursts, the birth of galaxies, dark matter, dark energy, and the cosmic microwave background.

The Exoplanet Research program element solicits observations to detect and characterize planets around other stars and to understand their origins.

The Nancy Grace Roman Technology Fellowship develops early career researchers, who could lead future flight instruments and missions. Initially, NASA identifies promising early career researchers and supports their investigations. NASA then selects a subset of fellows for additional funding to start a laboratory or develop a research group at the Fellow's institution.

BALLOON PROJECT

The Balloon project offers inexpensive, high-altitude flight opportunities for scientists to conduct research and test new technologies before space flight application. Balloon experiments cover a wide range of disciplines in astrophysics, solar physics, heliospheric physics, and Earth upper-atmosphere chemistry as well as selected planetary science, such as comet observations. Observations from balloons have detected echoes of the Big Bang and probed the earliest galaxies. The Balloon project continues to increase

ASTROPHYSICS RESEARCH

balloon size and enhance capabilities, including an accurate pointing system to allow high-quality astronomical imaging and a super-pressure balloon that maintains the balloon's integrity at a high altitude to allow much longer flights at mid-latitudes that include nighttime viewing of astronomical objects.

SCIENCE ACTIVATION

The FY 2021 budget will continue to support multi-year Science Activation awards made in 2016. The peer-evaluated, competitive project includes 24 awards that deliver SMD's unique content and expertise more efficiently and effectively into the learning environment for learners of all ages. Based on recommendations from the National Academies and other stakeholders, the awardees of these cooperative agreements work collaboratively with each other, with internal NASA organizations, and with local and national partners to achieve a multiplier effect utilizing NASA and SMD investments. All awards include independent evaluators that assess the individual projects' measures of success. In FY 2020, the National Academies completed an overarching assessment of the project.

By the end of FY 2021, the project plans better connections between subject matter experts in both strategic and competed arenas and the community-based networks established to date. New processes will ensure cohesion across the collective set of awards and stronger linkage between objectives and measures of success. In addition, new citizen science efforts will be highlighted and reported.

Program Schedule

The program issues solicitations every year. A Senior Review process assesses all missions in the extended operations phase every three years and all data archives every three or four years.

Date	Significant Event
Feb 2020	ROSES-2021 NRA solicitation release
May 2020	Astrophysics Archives Programmatic Review
Q1 FY 2021	ROSES-2021 selection within six to nine months of receipt of proposals
Feb 2021	ROSES- 2022 NRA solicitation release
Q1 FY 2022	ROSES-2022 selection within six to nine months of receipt of proposals
Feb 2022	ROSES- 2023 NRA solicitation release
Mar 2022	Senior Review of Operating Missions
Q1 FY 2023	ROSES-2023 selection within six to nine months of receipt of proposals
Feb 2023	ROSES-2024 NRA solicitation release
Mar 2024	Astrophysics Archives Programmatic Review

ASTROPHYSICS RESEARCH

Program Management & Commitments

Program Element	Provider
Research and Analysis Project	Provider: All NASA Centers Lead Center: Headquarters (HQ) Performing Center(s): All Cost Share Partner(s): None
Balloon Project	Provider: Wallops Flight Facility (WFF) Lead Center: WFF Performing Center(s): WFF Cost Share Partner(s): None

Acquisition Strategy

NASA issues solicitations for competed research awards each February through ROSES. Panels of scientists conduct peer reviews on all proposals. NASA will issue the solicitation no later than March because of the partial government shutdown from December to January. A Senior Review panel reviews all missions in extended operations phase every three years, and all data archives every three or four years.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Balloon Management	Operation of the Columbia Scientific Balloon Facility in Palestine, TX NGIS	Palestine, TX and other balloon launch sites

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	Astrophysics Archives Programmatic Review	2015	Review of Astrophysics data archives	Recommended improvements in archives	May 2020
Quality	Astrophysics Advisory Committee	2019	Review to assess program against strategic objectives of Astrophysics science	Recommendation was to maintain a strong program consistent with the decadal survey	2020

ASTROPHYSICS RESEARCH

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	Senior Review of Operating Missions	2019	Review of Astrophysics operating missions	Recommendations on mission extensions	2022, 2025
Quality	National Academies Independent Assessment of Science Activation Committee	2019	Validation of approach and logic model	Informs next phase of project ending in 2026	One-Time
Quality	Astrophysics Advisory Committee	2020	Review to assess program against strategic objectives of Astrophysics science	TBD	2021

OTHER MISSIONS AND DATA ANALYSIS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Astrophysics Directed R&T	4.5	--	**25.7**	29.4	23.3	9.0	25.5
Contract Administration, Audit and Quality Assurance Services	12.7	--	**17.3**	17.3	17.3	17.3	17.3
Astrophysics Senior Review	0.0	--	**0.0**	0.0	51.2	50.4	49.9
Astrophysics Data Program	19.1	--	**21.6**	22.6	23.6	23.6	23.6
Astrophysics Data Curation and Archival	17.9	--	**24.5**	26.3	26.4	28.5	28.7
Total Budget	**54.2**	**--**	**89.1**	**95.5**	**141.7**	**128.8**	**145.0**

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The CHESS-4 mission launched from Roi Namur, Kwajalein Atoll, Marshall Islands on April 16, 2018 (pictured). CHESS studies the interstellar medium in the ultraviolet, answering questions on star and planet formation.

Astrophysics Research Other Missions and Data Analysis funds Astrophysics senior review, data program, data curation and archival, support for contract administration, contract audits and contract quality assurance for the Science Mission Directorate and the Astrophysics directed research and technology project.

Mission Planning and Other Projects

DIRECTED RESEARCH AND TECHNOLOGY

This project funds the civil service staff that will work on emerging Astrophysics projects, instruments, and research.

CONTRACT ADMINISTRATION, AUDIT, AND QUALITY ASSURANCE SERVICES

This project provides critical safety and mission product inspections and contract audit services from the Defense Contract Management Agency and Defense Contract Audit Agency, respectively. It also provides for contract assurance audits, assessments, and surveillance by the NASA Contract Assurance Services Program.

OTHER MISSIONS AND DATA ANALYSIS

ASTROPHYSICS SENIOR REVIEW

Every three years, the Astrophysics division conducts a Senior Review to perform evaluations of missions that have successfully completed or are about to complete their prime mission operation phase. The Senior Review findings help NASA prioritize which missions will receive funding for extended operations. The 2019 Senior Review found that NASA's fleet of operating astrophysics missions constitute a "portfolio of extraordinary power" and recommended that NASA continue their operations. The next Senior Review will take place in spring 2022.

ASTROPHYSICS DATA ANALYSIS PROGRAM (ADAP)

ADAP solicits research that emphasizes the analysis of NASA space astrophysics data archived in the public domain at one of NASA’s Astrophysics Data Centers. NASA's archival astronomical data holdings continue to grow with the ongoing successful operation of a portfolio of missions. The missions range from modest Explorer-class like NuSTAR and TESS to the great observatories Hubble and Chandra. Investigations funded under the ADAP ensure that data holdings continue to be the subject of vigorous scientific research, thereby maximizing the scientific return on NASA mission investments.

The ADAP portfolio includes focused investigations that involve the analysis of archival data from a single mission, as well as broader investigations that combine data from multiple missions and span a wide wavelength range. Such multi-mission, multi-wavelength studies are a unique and exciting aspect of the program. The combinations of data collected by different missions operating in different regions of the spectrum often yield scientific insights that are unobtainable through analysis of the individual data sets alone.

Recent Achievements

During FY 2019, the ADAP supported more than 160 science investigators at academic institutions, NASA centers, and other Federal laboratories across the country. The scope of the investigations is as vast as the universe itself. It includes studies of every aspect of the Milky Way Galaxy including the physics and chemistry of the Interstellar Medium, the formation and evolution of stars and exoplanetary systems, the detection and characterization of exoplanets, and the structure of stars and the processes by which they age and die. It also includes the physics of supernovae explosions and the exotic neutron stars and black holes they produce.

Beyond our galaxy, ADAP-supported researchers are studying the fundamental nature of galaxies and the mechanism by which the very first proto-galaxies formed after the big bang grew and evolved into the diverse population of galaxies we observe today. They are also studying active galaxies, the hearts of which contain supermassive black holes that produce enormous amounts of energy and drive furious bursts of star formation. There are ADAP investigations that peered further back into the history of our universe, back to a time before the first stars and the first galaxies, and searched for clues into the nature of the Big Bang and insight into the fate of our universe.

OTHER MISSIONS AND DATA ANALYSIS

ASTROPHYSICS DATA CURATION AND ARCHIVAL RESEARCH (ADCAR)

The Astrophysics Data Centers constitute an ensemble of archives receiving processed data from individual missions and making them accessible to the scientific community. After the completion of a mission, the relevant, active, multi-mission archive takes over all data archiving activities. ADCAR covers the activities of the Astrophysics Data Centers and the NASA Astronomical Virtual Observatories (NAVO).

Recent Achievements

The Astrophysics Data System (ADS) produced a new cloud-based service to replace the capabilities of its aging bibliographic database. The transition to the new platform provides researchers an opportunity to discover capabilities previously unavailable or unexplored. The paradigm of iterative searches championed by traditional digital library systems expands to allow workflows that include searching, refining, and exploring.

The Mikulski Archive for Space Telescopes (MAST) has expanded to include the TESS mission. MAST provided TESS data to the exoplanet community at a greater volume and a faster rate than for other previous missions. Researchers produce publications at triple the rate from 10 years ago. MAST's new ExoMAST interface joined z.MAST, an interface designed specifically for deep-field studies of the universe based on MAST holdings.

The High Energy Astrophysics Science Archive Center (HEASARC) now hosts a complete copy of the Monitor of All-sky X-ray Image data from the ISS instrument. HEASARC supported preparations for the Japanese/U.S. XRISM mission, and ingested the first 3.5 years of space weather data from the CALET ISS instrument. HEASARC is working with IceCube, VERITAS, and HaloSat teams on future data releases. It released numerous new capabilities in its web services, released updates to the calibration database for active and archival missions, and responded to an estimated 20 million user queries.

The NASA/IPAC Infrared Science Archive (IRSA) responded to over 47 million queries during FY 2019, deployed a new Stratospheric Observatory for Infrared Astronomy (SOFIA) archive serving data from three instruments; and released 13 new science datasets, including Near Earth Objects Wide-field Infrared Survey Explorer (NEOWISE).

The NASA/IPAC Extragalactic Database (NED) responded to 172 million web server queries and added data for 440 million new objects, most of which came from the AllWISE source catalog. In FY 2019, 723 refereed journal articles and 100 astronomical telegrams acknowledged using NED. NED released a new service that helps astronomers find the host galaxies of gravitational wave events.

In FY 2019, the NAVO archives supported about 45 million requests for data using VO protocols. NAVO continues to lead NASA's VO efforts within the United States and world communities. Python is now a standard scripting language for astronomical data processing; NAVO began work with the active AstroPy community to establish the PyVO library as the Python standard library for VO data access within AstroPy. NAVO began to develop and apply benchmarking standards to NASA data interfaces to ensure appropriate responsiveness in the oncoming era of big data.

COSMIC ORIGINS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Hubble Space Telescope Operations	98.3	--	**88.3**	98.3	98.3	98.3	98.3
Stratospheric Observatory for Infrared Astronomy (SOFIA)	85.2	--	**12.0**	0.0	0.0	0.0	0.0
Other Missions and Data Analysis	39.3	--	**23.7**	24.9	21.7	24.1	24.1
Total Budget	**222.8**	--	**124.0**	**123.2**	**120.0**	**122.4**	**122.4**

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To understand galaxies throughout the universe, astronomers start by studying our home galaxy, the Milky Way. The center of our galaxy is a crowded place: millions of stars whipping around it at breakneck speeds surround a black hole weighing 4 million times as much as our Sun. This is extreme environment bathed in intense ultraviolet light and X-ray radiation.

Image Credit: NASA, JPL-Caltech, Susan Stolovy (SSC/Caltech) et al., October 9, 2019

"How did we get here?" This simple but fundamental question drives the broad science objectives of NASA's Cosmic Origins program. Our search for answers raises underlying questions and topic areas, such as, how and when did the first stars and galaxies form? When did the universe first create the elements critical for life? How did galaxies evolve from the very first systems to the types we observe "in the here and now," such as the Milky Way in which we live? How do stars and planetary systems form and change over time?

No individual space observatory or airborne observatory can completely address all of these questions, but in partnership, they can begin to unravel the answers. Currently operating facilities in the Cosmic Origins program are the Hubble Space Telescope and the Stratospheric Observatory for Infrared Astronomy (SOFIA).

For more information, go to: http://cor.gsfc.nasa.gov/

EXPLANATION OF MAJOR CHANGES IN FY 2021

This budget proposes termination of the SOFIA mission, as discussed in the SOFIA section below.

HUBBLE SPACE TELESCOPE OPERATIONS

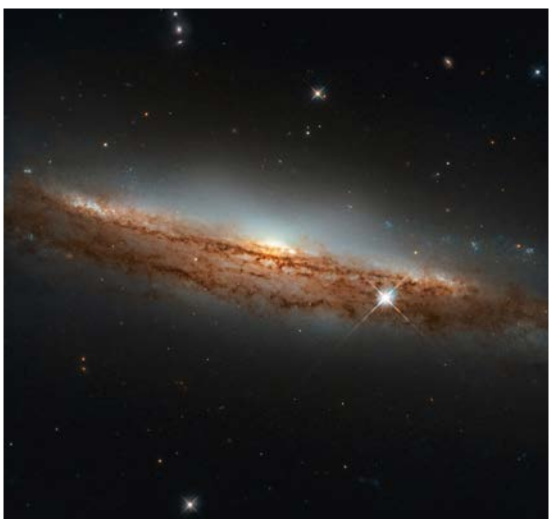
Formulation	Development	Operations

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**98.3**	**--**	**88.3**	**98.3**	**98.3**	**98.3**	**98.3**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.



The NASA/ESA HST sees galaxies of all shapes, sizes, brightness, and orientations in the cosmos. Sometimes, the telescope gazes at a galaxy oriented sideways as shown here. This is NGC3717, a spiral galaxy located 60 million light-years away in the constellation Hydra (The Sea Serpent).

One of NASA's most successful and long-lasting science missions, the Hubble Space Telescope, has beamed over 1 million images back to Earth, helping resolve many of the great mysteries of astronomy. The telescope helped scientists determine the age of the universe, the identity of quasars, and the existence of dark energy. Hubble launched in 1990 and is currently in an extended operations phase. The fifth servicing mission, in 2009, the last visit by a Space Shuttle crew, added new batteries, gyroscopes, and instruments to extend Hubble's life even further into the future.

April 24, 2020 will mark the start of Hubble's 30th year in orbit. The observatory is currently in its most scientifically productive period.

EXPLANATION OF MAJOR CHANGES IN FY 2021

This budget reflects efficiencies realized by the project's excellent cost performance. The change is consistent with operations that are more efficient and aligned with the observatory scientific program. Due to program efficiencies and appropriation of funds above the request for the past few years, the Hubble mission is carrying excess funding. This budget reflects use of excess funds from prior years, resulting in fewer resources requested in FY 2021. NASA does not expect this adjustment to affect the workforce or science generated from the mission.

HUBBLE SPACE TELESCOPE OPERATIONS

Formulation	Development	Operations

ACHIEVEMENTS IN FY 2019

The 2019 Senior Review of Operating Missions recommended continuing Hubble operations as long as the observatory remains highly capable scientifically and recommended extending mission operations for FY 2020 and beyond. This budget supports that recommendation.

On October 5, 2018, one of Hubble's remaining four operational gyros failed. Hubble had four functional gyros (three in operation and one as a backup). The Hubble operations team turned on the backup gyro to replace the failed gyro, but it exhibited anomalous behavior. The team was able to restore this gyro to a nominal state after three weeks of sustained effort, and Hubble restarted standard science operations using three gyros on October 27, 2018. These three gyros should allow science operations to continue well into the mid-2020s, allowing overlap with Webb science operations. Hubble currently has three functional gyros and no backups. Hubble does have plans and built software that will allow for both two and one-gyro modes of operations. The science observations in the two and one-gyro modes of operations will be more limited.

NASA announced the Cycle 27 selections in June 2019.

WORK IN PROGRESS IN FY 2020

In FY 2020 and beyond, NASA will support mission operations, systems engineering, software maintenance, ground systems support, and guest-observer science grants. Work continues on mission life extension initiatives, such as optimizing the use of Hubble’s gyroscopes and extending the lifetime of Hubble's instruments. NASA will select Cycle 28 for observations in mid FY 2020 and will release Cycle 29 call for proposals late in FY 2020.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

The Space Telescope Science Institute (STScI), which manages Hubble’s science program, will select Cycle 29 science observations. Similar to other recent competitions for Hubble observing time, NASA expects requested observational orbits to outnumber the available orbits by a factor of six to one, indicating that Hubble remains one of the world’s preeminent astronomical observatories.

HUBBLE SPACE TELESCOPE OPERATIONS

Formulation	Development	Operations

Project Schedule

Date	Significant Event
Mar 2020	Deadline for Cycle 28 Proposal Submissions
Jun 2020	Approximate date for Announcement of Cycle 28 selections
Nov 2020	Release of Cycle 29 Call for Proposals
Mar 2021	Deadline for Cycle 29 Proposal Submissions
Jun 2021	Approximate date for Announcement of Cycle 29 selections
Nov 2021	Release of Cycle 30 Call for Proposals
Mar 2022	Deadline for Cycle 30 Proposal Submissions
Jun 2022	Approximate date for Announcement of Cycle 30 selections

Project Management & Commitments

Element	Description	Provider Details	Change from Formulation Agreement
Observatory Operation	Provides safe and efficient control and utilization of Hubble, maintenance and operation of its facilities and equipment, as well as creation, maintenance, and utilization of Hubble operations processes and procedures	Provider: Lockheed Martin Lead Center: Goddard Space Flight Center (GSFC) Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Science Management	Evaluates proposals for telescope time and manages the science program	Provider: STScI/Association of Universities for Research in Astronomy (AURA) Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): European Space Agency (ESA)	N/A

HUBBLE SPACE TELESCOPE OPERATIONS

Formulation	Development	Operations

Acquisition Strategy

NASA competes all new Hubble research opportunities.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Observatory Operation	Lockheed Martin	Littleton, CO
Science Management	STScI/AURA	Baltimore, MD

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Senior Review	2019	Evaluate efficiency and productivity of Hubble operations	Maximize Hubble science return and reliability within available resources	2022, 2025, 2028

STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY (SOFIA)

Formulation	Development	Operations

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**85.2**	**--**	**12.0**	**0.0**	**0.0**	**0.0**	**0.0**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

The Center of our Milky Way shown above. The streamlines showing magnetic fields layered over a color image of the dusty ring around the Milky Way's massive black hole. The Y-shaped structure is warm material falling toward the black hole, which is located near where the two arms of the Y-intersect. The streamlines reveal that the magnetic field closely follows the shape of the dusty structure. Each of the blue arms has its own field that is distinct from the ring, shown in pink.

SOFIA is an airborne astronomical observatory that provides the international research community with access to infrared data unattainable from ground-based telescopes. SOFIA investigates the cycle of material in the universe by peering through veils of dust to reveal physical phenomena hidden at other wavelengths.

SOFIA officially entered the extended mission operations phase following its five-year prime mission in October 2019.

EXPLANATION OF MAJOR CHANGES IN FY 2021

The budget proposes termination of SOFIA, which has annual operating costs of over $80 million. SOFIA's annual operations budget is the second most expensive operating mission in the Astrophysics Division (after the Hubble Space Telescope), yet the science productivity of the mission is not on par with other large science missions. Dramatic improvement in SOFIA's scientific productivity is not expected. The nature of the program, which relies on observations using an expensive platform with expensive consumables results in low cost efficiency compared to most observatories. Additionally, the James Webb Space Telescope, planned to launch in 2021, will provide data at mid-infrared wavelengths, partially mitigating the absence of SOFIA.

STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY (SOFIA)

Formulation	Development	Operations

ACHIEVEMENTS IN FY 2019

SOFIA offered 400 hours of observing time to the U.S. community in Cycle 7. In November 2018, the SOFIA Director selected 84 proposals (48 of which are in high priority category, including two proposals from the newly introduced "Legacy" science category) from the 199 proposals received in response. Observations for Cycle 7 began in April 2019 and will be completed in April 2020. SOFIA planned 148 flights for the cycle, including an extended deployment of nine weeks to New Zealand, to observe astronomical objects in the southern skies that are not visible from Northern Hemisphere base in Palmdale.

WORK IN PROGRESS IN FY 2020

SOFIA is in the middle of completing Cycle 7 observations, with the start of Cycle 8 observations planned to commence in spring 2020. The development phase for the third-generation science instrument, the High Resolution Mid-Infrared Spectrometer (HIRMES) is continuing in FY 2020; working around a variety of technical challenges.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

NASA will place the aircraft into storage and disposition the project's inventory during FY 2021.

Project Schedule

Date	Significant Event
Oct 2019	SOFIA begins implementing recommendations from the two reviews at the end of its five-year prime mission.
Apr 2020	Cycle 8 begins
Apr 2021	Cycle 9 begins

STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY (SOFIA)

Formulation	Development	Operations

Project Management & Commitments

The Ames Research Center (ARC) manages SOFIA.

Element	Description	Provider Details	Change from Formulation Agreement
Science Operations Center	Science Operations Center will solicit and select new investigations, schedule observations, and manage data acquisition and processing	Provider: ARC/ USRA Lead Center: ARC Performing Center(s): ARC Cost Share Partner(s): German Aerospace Center (DLR)/Deutsches SOFIA Institute (DSI)	None
Flight Operations	Flight crew, maintenance, and fuel	Provider: Armstrong Flight Research Center (AFRC)/Computer Sciences Corporation (CSC) DynCorp Lead Center: AFRC Performing Center(s): AFRC Cost Share Partner(s): DLR/DSI	None
SOFIA Project Management	Project management of flight and science	Lead Center: ARC	Yes
HIRMES	HIRMES will enable unique spectroscopic capability, providing a higher sensitivity and a higher spectral resolving power, from the 25 to 112 micrometer wavelength range, over any existing observatory	Provider: GSFC Lead Center: ARC Performing Center(s): GSFC Cost Share Partner(s): None	None

Acquisition Strategy

The project has awarded all major contracts. SOFIA awarded a new primary contract for its Science Mission Operations to the Universities Space Research Association (USRA) in March 2017.

STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY (SOFIA)

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Science & Mission Operations	USRA	Moffett Field, CA and Palmdale, CA
Platform	L3 Communications	Palmdale, CA
Cavity Door Drive System	Woodward MPC	Skokie, IL
Aircraft Maintenance Support	L3 Vertex Aerospace (under AFRC shared service contract)	Palmdale, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	Aircraft Operations & Maintenance Efficiency Review	Oct 2018-Feb 2019	Evaluate aircraft operations and maintenance efficiency and explore alternative models of operations and maintenance for improved efficiency	Adjustments to FY 2020 aircraft operations are being implemented	N/A
Quality	Five Year Flagship Review	Feb 2018-Apr 2019	Evaluate science center operations and mission operations efficiency for increased science impact and improved efficiency	Recommendations for optimization of the science output of SOFIA	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Astrophysics Strategic Mission Progam Managemt	0.4	--	**1.6**	1.9	1.7	1.9	2.0
Cosmic Origins Strategic Research and Technology (SR&T)	24.8	--	**18.4**	18.4	18.4	18.4	18.4
Cosmic Origins Future Missions	0.8	--	**2.7**	4.6	1.6	3.8	3.8
SIRTF/Spitzer	13.2	--	**1.0**	0.0	0.0	0.0	0.0
Total Budget	**39.3**	--	**23.7**	**24.9**	**21.7**	**24.1**	**24.1**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

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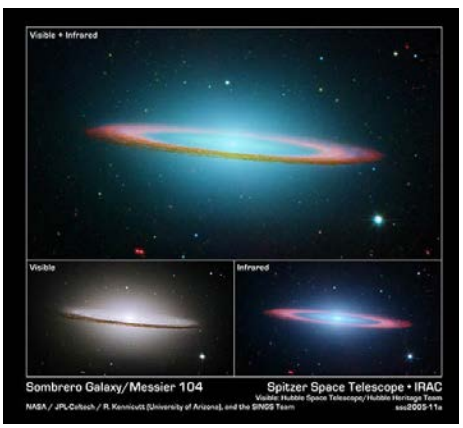

NASA launched its Spitzer Space Telescope into orbit around the Sun on Aug. 25, 2003. Since then, the observatory has lifted the veil on the wonders of the cosmos. Spitzer's primary mission lasted five-and-a-half years and ended when it ran out of the liquid helium coolant necessary to operate two of its three instruments. Its passive-cooling design has allowed part of its third instrument to continue operating for more than 10 additional years. Mission operations ended on January 30, 2020.

Cosmic Origins Other Missions and Data Analysis funds the Spitzer Space Telescope, program management, supporting research and technology, and early studies of potential future Cosmic Origins missions.

Mission Planning and Other Projects

ASTROPHYSICS STRATEGIC MISSION PROGRAM MANAGEMENT

Astrophysics Strategic Mission Program Management (ASMPM) provides programmatic, technical, business management, and program science leadership for all strategic Astrophysics missions throughout definition, design, development, launch, and operations, facilitating science investigations derived from those missions.

COSMIC ORIGINS STRATEGIC RESEARCH AND TECHNOLOGY (SR&T)

Cosmic Origins Strategic Research and Technology (COR SR&T) supports program-specific research and advanced technology development efforts, such as the Strategic Astrophysics Technology solicitation issued in FY 2018. In addition, funding supports the study of future NASA space observatories.

OTHER MISSIONS AND DATA ANALYSIS

The scientific community is actively working to mature mission concept studies and identify technology developments that have provided input to the 2020 Astronomy and Astrophysics Decadal Survey. The four mission concept studies are the Large Ultraviolet/Visible/Infrared Surveyor, Origins Space Telescope, Habitable Exoplanet Imaging Mission, and Lynx X-ray Surveyor. These four mission concept studies and the science case and notional telescope design and instrument studies began in FY 2016. These missions provided an interim report in early 2018. An ad-hoc panel of experts reviewed the report and provided feedback to these teams. These mission concepts issued their final reports at the end of FY 2019. Similarly, the community also studied ten Probe class mission concepts and the completed reports are available to the public.

This budget request supports a solicitation for industry for an on-going segmented-aperture Mirror Technology Development program element. The first one-year study completed in 2019, which included an end-to-end integrated telescope/coronagraph system-level engineering design, modeling studies, and associated testbed demonstrations. A follow-up solicitation to industry addressing and retiring technology gaps, identified by the large mission concepts, has resulted in contract awards to two industry teams, and this technology maturation work is under way.

Recent Achievements

During 2019, the technologists from PCOS/COR and Exoplanet Exploration Program Offices produced a single streamlined and consolidated technology report for astrophysics assessing technology gaps and priorities across the three astrophysics sciences, namely, Cosmic Origins, Physics of the Cosmos, and Exoplanet Exploration. In the past, these gaps and priorities were included in separate technology reports. With the collaboration of the science community through the Astrophysics Program Analysis Groups, the authors achieved coordination and integration as presented in the inaugural Astrophysics Biennial Technology Report.

COSMIC ORIGINS FUTURE MISSIONS

Cosmic Origins Future Missions funding supports studies of future mission concepts.

Recent Achievements

The COR scientific community is engaged in identifying meritorious and compelling science drivers that could lead to diverse mission concept studies and technology development that will inform the 2020 Astronomy and Astrophysics Decadal Survey.

Operating Missions

SPITZER

The Spitzer Space Telescope, launched in 2003 as the final element of NASA's series of Great Observatories, continues in extended operations. Spitzer is an infrared telescope that uses two channels of the Infrared Array Camera instrument to study exoplanet atmospheres, early clusters of galaxies, near-Earth asteroids, and a broad range of other phenomena. Spitzer completed its cryogenic mission in

OTHER MISSIONS AND DATA ANALYSIS

FY 2009 and extended warm operations through FY 2019. Spitzer ended operations on January 30, 2020, with full closeout by the end of FY 2021.

Recent Achievements

Spitzer continues to collect unique data that is revealing new results for exoplanets and other cosmic phenomena. During 2019, in celebration of Spitzer's 16 years in space, NASA released several images displaying Spitzer's accomplishments. One of the images is of a cloud of gas and dust full of bubbles, inflated by wind and radiation from massive young stars. As the project heads toward the end of operations, NASA is releasing monthly images and other newsworthy data such as the temperature, location, and wavelength coverage of the instrument. One of Spitzer's incredible discoveries is of a black hole's event horizon, the area beyond which light cannot escape the immense gravity of the black hole.

PHYSICS OF THE COSMOS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Other Missions and Data Analysis	151.2	--	**143.9**	160.8	155.3	169.8	154.1
Total Budget	**151.2**	**--**	**143.9**	**160.8**	**155.3**	**169.8**	**154.1**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

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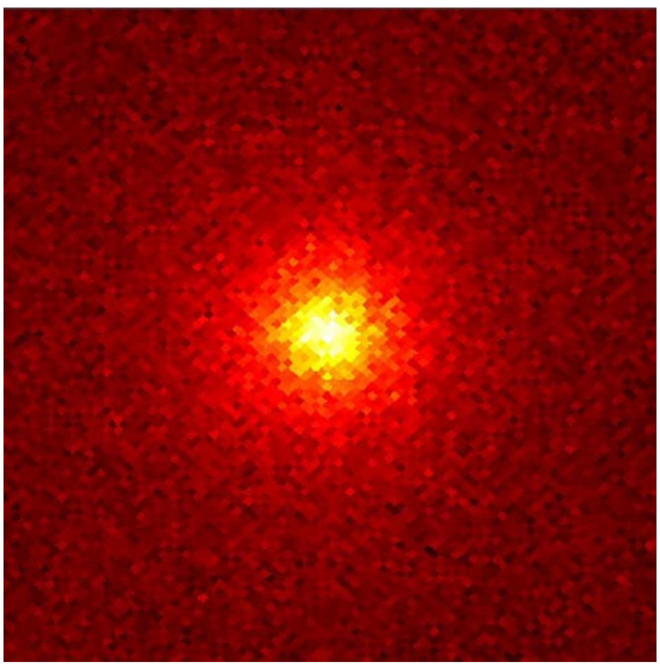

NASA's Fermi Gamma-Ray Space Telescope provides this dramatic image of the Earth's Moon. The image shows gamma-rays with energies greater than 31 million electron volts, or tens of millions of times that of visible light. In these images, the Moon is actually brighter than the Sun.

The universe enables scientists to study the most profound questions at the intersection of physics and astronomy. How do matter, energy, space, and time behave under extreme gravity? What is the nature of dark energy and dark matter? How did the universe grow from the Big Bang to its present size? The Physics of the Cosmos (PCOS) program incorporates cosmology, high-energy astrophysics, and fundamental physics projects that address central questions about the nature of complex astrophysical phenomena, such as black holes, neutron stars, dark matter and dark energy, cosmic microwave background, and gravitational waves.

The operating missions within the PCOS program continue to provide answers to these fundamental questions and more. For example, as NASA sets its sights on sending humans to the Moon by 2024 through the Artemis program, with the eventual goal of sending astronauts to Mars, understanding various aspects of the lunar environment take on new importance. New observations with NASA's Fermi Gamma-Ray Space Telescope provide an important reminder of the cosmic radiation that impacts the lunar surface, as well as fresh insights into the nature of the lunar regolith.

Other PCOS missions, such as the Chandra X-ray Observatory, continue to help astronomers progress in their understanding of some of the most mysterious phenomena, such as the condition of matter near supermassive black holes.

PHYSICS OF THE COSMOS

PCOS includes a vigorous program to develop the technologies necessary for the next generation of space missions to address the science questions of this program.

For more information, go to: https://science.nasa.gov/about-us/smd-programs/physics-of-the-cosmos

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

OTHER MISSIONS AND DATA ANALYSIS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Physics of the Cosmos SR&T	45.7	--	**45.9**	61.2	75.2	87.0	72.1
Euclid	17.2	--	**11.0**	8.9	9.9	10.3	9.5
PCOS/COR Technology Office Management	5.6	--	**5.9**	6.0	5.4	6.0	6.0
Physics of the Cosmos Future Missions	0.0	--	**1.6**	4.6	2.0	3.7	3.7
Fermi Gamma-ray Space Telescope	16.5	--	**13.8**	13.9	0.0	0.0	0.0
Chandra X-Ray Observatory	61.7	--	**62.3**	62.8	62.8	62.8	62.8
X-ray Multi-Mirror Mission (XMM)	4.5	--	**3.5**	3.5	0.0	0.0	0.0
Total Budget	**151.2**	--	**143.9**	**160.8**	**155.3**	**169.8**	**154.1**

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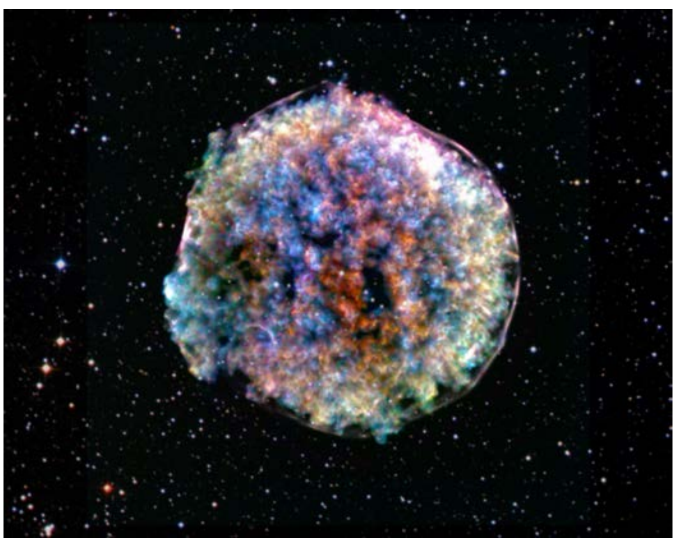

A deep Chandra X-ray image of the Tycho supernova remnant, the debris from an exploding white dwarf star first observed by the Dutch astronomer, Tycho Brahe in 1572. This image is color coded to highlight the approaching (blue) and receding (red) silicon emission amongst the remaining debris (green). New models suggest that the clumpiness in the debris is generated during the explosion rather than because of instabilities in the expanding debris.

Other Missions and Data Analysis supports PCOS SR&T, PCOS/COR Technology Management Office, PCOS Future Missions, Euclid, Fermi, Chandra, and XMM.

Mission Planning and Other Projects

PCOS SUPPORTING RESEARCH AND TECHNOLOGY

PCOS Supporting Research and Technology leads strategic technology development efforts, to prepare for the next generation of PCOS space missions, including program-specific research and advanced technology development efforts, such as the Strategic Astrophysics Technology (SAT) program element.

NASA and the European Space Agency

OTHER MISSIONS AND DATA ANALYSIS

(ESA) are continuing defining the partnership for NASA's contribution to ESA's Athena mission, an X-ray observatory dedicated to high-resolution spectroscopy, and ESA's LISA mission, a space-based gravitational wave observatory. This project supports the technology development and pre-formulation activities necessary to contribute to the ESA missions.

Recent Achievements

In October 2019, the first report was released which integrated PCOS, COR, and Exoplanet Programs' technology gaps solicitation, prioritization, and reporting processes into an Astrophysics Biennial Technology Report for all three astrophysics science themes, namely, Cosmic Origins, Physics of the Cosmos and Exoplanet Exploration.

EUCLID

NASA is collaborating on Euclid, an ESA mission, selected as part of ESA's Cosmic Visions program in June 2012 and scheduled for launch in 2022. Euclid seeks to investigate the accelerated expansion of the universe, the so-called "dark energy," using a Visible Instrument and a Near Infrared Spectrometer and Photometer instrument, as well as ground-based data. The Euclid Consortium, comprised of over 1,200 scientists and engineers from over 50 institutes in Europe, the United States, and Canada, is responsible for development of the two instruments and the Science Data Centers. NASA contributes flight detector subsystems for the Near Infrared Spectrometer and Photometer instrument and a NASA Euclid Science Center that forms part of the Euclid Science Ground System. In exchange, NASA receives membership in the Euclid Science Team and Consortium and competed science opportunities for U.S. investigators.

Recent Achievements

NASA completed the delivery of all 20 Sensor Chip Electronics (SCE) units to ESA in September 2019. The Near Infrared Spectrometer and Photometer instrument in France has all the detectors, cables and SCEs fully integrated. The instrument is going through its thermal vacuum testing and will be ready for shipment to ESA by early 2020.

PCOS/COR TECHNOLOGY OFFICE MANAGEMENT

The PCOS/COR Technology Office Management project provides programmatic, technical, and business management, as well as program science leadership.

Recent Achievements

The technology office is leading the management of NASA's contribution to the ESA-led Athena, an X-ray observatory dedicated to high-resolution spectroscopy. NASA is providing the microcalorimeter and software elements of the Wide Field Imager.

It is also leading the management of NASA's contribution to ESA on the LISA mission, a low-frequency gravitational wave observatory, and it is contributing elements of the payload. NASA established a LISA study office to manage the LISA technology development.

OTHER MISSIONS AND DATA ANALYSIS

PCOS FUTURE MISSIONS

PCOS Future Missions funding supports concept studies of future missions.

Recent Achievements

The PCOS program is continuing its work with the scientific community for design studies and technology development to inform the 2020 Astronomy and Astrophysics Decadal Survey.

Operating Missions

FERMI

The Fermi Gamma-ray Space Telescope explores extreme environments in the universe, from black holes on all scales to ultra-dense neutron stars spinning thousands of times per second, to expand knowledge of their high-energy properties. Fermi observations are answering long-standing questions across a broad range of topics, including solar flares, the origin of cosmic rays, and the nature of dark matter. NASA's Fermi mission launched in June 2008 with contribution from the Department of Energy and international partners. Fermi entered extended mission operations in August 2013. The 2019 Senior Review of Operating Missions recommended continuing Fermi operations through FY 2022.

Recent Achievements

Because Fermi sees the entire high-energy sky, it remains the premier monitor for extreme phenomena in the universe; including gamma-ray bursts, flaring stars and galaxies, and counterparts of gravitational wave events detected by the National Science Foundation's Laser Interferometer Gravitational-Wave Observatory and neutrinos detected by the IceCube neutrino observatory. Recently, Fermi provided a trigger that enabled the detection of the most energetic light ever seen from an exploding star, seen as a gamma-ray burst. Using over 10 years of all-sky collection of data, Fermi scientists were able to deduce the history of star formation in the universe, providing guidance for future observations with the James Webb Space Telescope. Combining Fermi data with radio observations enabled the discovery of a pulsar (a rotating neutron star that seems to blink) hurtling through space at nearly 2.5 million miles an hour, earning it the nickname "cannonball pulsar."

CHANDRA

Launched in 1999, Chandra is transforming our view of the universe with its high-quality X-ray images, providing unique insights into violent events and extreme conditions such as explosions of stars, collisions of galaxies, and matter around black holes. Chandra enables observations of clusters of galaxies that provide direct evidence of the existence of dark matter and greatly strengthens the case for the existence of dark energy. Chandra observations of the remains of exploded stars, or supernovas, have advanced our understanding of the behavior of matter and energy under extreme conditions. Chandra has also discovered and studied thousands of supermassive black holes in the centers of distant galaxies. The 2019 Senior Review of Operating Missions recommended continuing Chandra operations as long as the observatory remains highly capable scientifically. The 2022 Senior Review of Operating Missions will review Chandra extended mission operations for FY 2023 and beyond.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

Chandra's exquisite spatial resolution enables it to pinpoint binary super massive black holes (SMBH) in the nuclei of galaxies, which are in the process of merging. Research has shown strong evidence for a very rare, triple SMBH system, all less than 30,000 light years apart, in the center of three colliding galaxies known as SDSS J0849+1114. The three X-ray sources detected by Chandra demonstrate the presence of three SMBHs vigorously accreting material. Binary and triple SMBH systems will eventually merge to form a single, much more massive SMBH, with the triple systems expected to do so on much shorter timescales than the binaries. While they are rare, triple systems are likely to play a critical role in the growth of the most massive SMBHs in the universe.

X-RAY MULTI-MIRROR MISSION (XMM)

XMM is an ESA-led mission with substantial NASA contributions. The telescope launched in December 1999 and provides unique data for studies of the fundamental processes of black holes and neutron stars. XMM studies the evolution of chemical elements in galaxy clusters and the distribution of dark matter in galaxy clusters and elliptical galaxies. The 2019 Senior Review of Operating Missions recommended continuing operations through FY 2022. The 2022 Senior Review of Operating Missions will consider a proposal for extended mission operations beyond FY 2022.

Recent Achievements

Data from ESA/NASA's XMM-Newton X-ray space observatory have been crucial to scientific achievements in 2019. Astronomers have used it to detect synchronized pulses of optical and X-ray radiation from a pulsar, indicating that a new physical mechanism may be necessary to explain the behavior in these types of objects never seen before.

XMM has also detected unexpected flashes from the active black hole at the center of a distant galaxy. These flares are caused when material in the black hole's accretion disk interact with another body, another black hole, or the remnant of a star previously torn apart by the black hole. Alternatively, instabilities in the flow of the accretion disk near the black hole cause the flares.

XMM observations of a black hole at the nucleus of a different active galaxy show how powerful winds from the accretion disk, very near the black hole, interact with the interstellar matter in the center of the galaxy. These interactions, known about for years but never explained, show how an active central black hole affects the evolution of its host galaxy.

An investigation using XMM observations of active galactic nuclei has shown that there is a discrepancy between the observed evolution of the Universe and the standard cosmological model. This discrepancy suggests that the standard cosmological model may require additional parameters to reconcile the theory with the data. One possible solution is to invoke an evolving dark energy, with a density that increases over time. This solution has the additional benefit that it would also solve another problem that has lately vexed cosmologists: the different values Hubble found when considering data from supernovae and the cosmic microwave background.

EXOPLANET EXPLORATION

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Other Missions and Data Analysis	367.9	--	**47.2**	50.4	47.6	51.6	52.2
Total Budget	**367.9**	**--**	**47.2**	**50.4**	**47.6**	**51.6**	**52.2**

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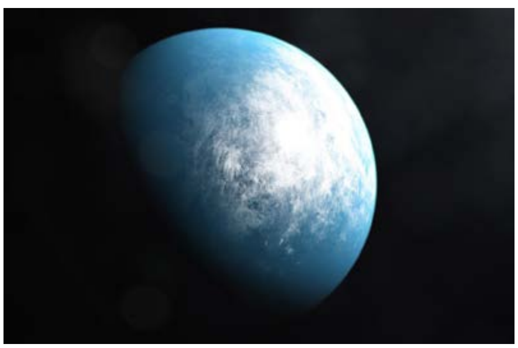

Artist's concept of the planet HD 21749c, the first Earth-sized planet discovered by NASA's Transiting Exoplanet Survey Satellite (TESS). HD21749c is about 89 percent the diameter of the Earth and lies 53 light years away in orbit around a star that is somewhat smaller and cooler than the Sun.

Humankind is gaining insight into timeless questions: Are we alone? Is Earth unique, or are planets like ours common? One of the most exciting new fields of research within the NASA Astrophysics portfolio is the search for planets, particularly Earth-like planets, around other stars.

Since the discovery of the first exoplanets in the mid-1990s, astronomers have confirmed over 4,000 planets orbiting stars of all shapes and sizes in our galaxy. At first, most of the planets discovered were so-called "Hot Jupiters"— gas giants similar in size to the planet Jupiter, but orbiting much closer to their parent stars. However, analysis of the complete Kepler data set suggests that smaller planets — with sizes in the Earth-to-Neptune range — are actually more common. Rocky planets in the habitable zone of their parent stars also appear to be common. The Transiting Exoplanet Survey Satellite (TESS) mission is now discovering many more of these smaller planets orbiting bright stars.

NASA's Exoplanet Exploration Program is advancing along a path of discovery leading to a point where scientists can directly study the atmospheres and surface features of habitable, rocky planets like Earth around other stars in the solar neighborhood. In the future, NASA aims to develop systems that will allow scientists to take the pivotal step from identifying an exoplanet as Earth-sized to determining whether it is truly Earth-like, and possibly even detecting if it bears the fingerprints of life. Such an ambitious goal includes significant technological challenges. An important component of the Exoplanet Exploration effort is a robust technology development program with the goal of enabling a future direct detection and characterization mission.

For more information, go to: https://exoplanets.nasa.gov/

Exoplanet Exploration

Explanation of Major Changes in FY 2021

The Budget proposes termination of the WFIRST mission due to its significant cost and higher priorities within NASA, including successfully launching and deploying the James Webb Space Telescope. WFIRST was originally proposed as a less-than-$2 billion space telescope in the Decadal Survey. The current WFIRST architecture, which was supported by two National Academy studies, differs from that discussed in the 2010 Decadal Survey and exceeds $3 billion.

OTHER MISSIONS AND DATA ANALYSIS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
WFIRST	312.2	--	**0.0**	0.0	0.0	0.0	0.0
Exoplanet Exploration Strategic Research and Technology	32.1	--	**31.5**	32.0	31.3	30.5	31.2
Exoplanet Exploration Technoloy Off Management	7.5	--	**7.1**	7.8	7.4	8.2	8.1
Exoplanet Exploration Future Missions	0.7	--	**1.7**	3.5	1.6	5.4	5.4
Keck Operations	6.5	--	**6.9**	7.0	7.2	7.4	7.4
Kepler	8.9	--	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**367.9**	**--**	**47.2**	**50.4**	**47.6**	**51.6**	**52.2**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Astronomers have discovered a third planet in the Kepler-47 system, securing the system's title as the most interesting of the binary-star worlds. A team of researchers, led by astronomers at San Diego State University, detected the new Neptune-to-Saturn-size planet orbiting between two previously known planets. With its three planets orbiting two suns, Kepler-47 is the only known multi-planet circumbinary system. Circumbinary planets are those that orbit two stars.

Mission Planning and Other Projects

Exoplanet Exploration Other Missions and Data Analysis includes funding for Exoplanet Exploration SR&T, Exoplanet Exploration Technology Office Management, Keck and funding for future mission selections.

EXOPLANET EXPLORATION STRATEGIC RESEARCH AND TECHNOLOGY

Exoplanet Exploration Strategic Research and Technology supports program-specific strategic research and technology development activities to enable future NASA space missions to discover and understand distant worlds.

NASA currently supports 14 competitively selected exoplanet technology development projects involving researchers across the nation. The selected projects focus on advancing technologies to separate the feeble reflected light of an exoplanet from the overwhelming glare of its parent star. Those technologies will one day enable a mission capable of the ultimate goal of NASA's Exoplanet Exploration Program in imaging and measuring the spectra of habitable, Earth-like exoplanets orbiting Sun-like stars in our solar neighborhood.

NASA also supports a range of exoplanet science investigations through its investments in the Keck Observatory in Hawaii and the WIYN Telescope in Arizona. Those science investigations include ground-based follow up observing programs that support the Agency's TESS mission as well as programs that support the operational planning and design of future missions.

Recent Achievements

Coronagraphs and starshades are enabling technologies for the direct imaging and spectroscopy of exoplanets around stars. They block the light from the stars and, thus, make possible the detection of planets orbiting the parent star. NASA could use these technologies in possible future missions to directly image these distant worlds and search for evidence of biosignature gases in their atmospheres. NASA is assessing new coronagraph techniques for their application to the segmented optics of future large telescopes via modeling and laboratory demonstrations. In addition, the NASA starshade team, with membership from government, academia, and industry, has defined and is executing a detailed plan for ground-based demonstration of its five critical technology elements by the early 2020's. One of the starshade technology elements, position sensing for starshade formation flying, has demonstrated its critical technology.

The NASA and NSF partnership, NASA-NSF Exoplanet Observational Research NN-EXPLORE, to develop a new precision radial velocity instrument for the WIYN telescope is progressing well, with commissioning of the new instrument on schedule for early CY 2020. The partnership provides observing time for U.S. astronomers on telescopes with radial velocity (RV) spectrographs in the southern hemisphere for the follow up of exoplanet candidates from TESS.

The project supports high-resolution imaging with speckle instruments on three telescopes, WIYN and Gemini North and South, for follow up exoplanet validation and characterization.

EXOPLANET EXPLORATION TECHNOLOGY OFFICE MANAGEMENT

Exoplanet Exploration Technology Office Management provides scientific and technical leadership as well as business management for the program's portfolio of projects. It coordinates, supports, and tracks the progress of the program’s numerous technology development tasks, actively engages science community stakeholders, and provides effective public and professional communication of exoplanet science discovery and enabling technologies.

Recent Achievements

Scientists have confirmed more than 4,000 exoplanets among the several thousand candidates currently catalogued. Current estimates indicate that perhaps one in four stars host rocky planets that exist in orbits where water may flow freely upon their surface. The project is managing design studies of mission opportunities. The project is also engaging with the scientific community on design studies and technology development that will eventually provide inputs to the 2020 Astronomy and Astrophysics Decadal Survey.

OTHER MISSIONS AND DATA ANALYSIS

EXOPLANET EXPLORATION FUTURE MISSIONS

Exoplanet Exploration Future Missions funding supports the execution of the exoplanet mission science and technology definition teams, and ultimately the formulation, development, and implementation of a future Exoplanet Exploration flight mission.

Recent Achievements

Community-based science and technology teams completed mission concepts and technology development plans in support of the 2020 Astrophysics Decadal Survey. To prepare for the next decade, NASA is studying the scientific merits of exoplanet missions in both the probe (medium) and large classes. The project provided independent review for the concept studies including the establishment of the standards definition and evaluation team, which provided a consistent and independent measure of the exoplanet science yields for the large mission concepts.

Operating Missions

KECK OPERATIONS

Keck Operations is the NASA portion of the Keck Observatory partnership. NASA is a partner for one-sixth of the observing nights on the two 10-meter telescopes of the W.M. Keck Observatory (WMKO), the largest optical telescope pair in the world. NASA uses its share of observing time in support of its Astrophysics and Planetary Science programs. The project allocates observing time for NASA astrophysics science goals, as well as for solar system objects and direct space mission support. Supported missions in recent years include Kepler, TESS, and EUCLID for astrophysics as well as Juno, New Horizons, and Cassini for planetary science. All observing time proposal requests are competed, peer-reviewed, selected, and managed by the NASA Exoplanet Science Institute. The Keck Observatory Archive (KOA), managed by the NASA Exoplanet Science Institute, ingests and curates existing and new data from the Keck Observatory.

Recent Achievements

The large number of proposals submitted continues to demonstrate strong demand for NASA observing nights. NASA reserved 13 nights in semester 2020A for on-going, high priority key strategic mission support programs. Scientists at institutions around the US submitted 84 proposals requesting 124.8 nights for the remaining 35.5 nights, yielding an overall oversubscription rate of 3.5 for both Keck telescopes. The over-subscription varies between three and five times as many requests for time on the telescopes than is available from semester to semester depending on the telescope, instrument, and season. The astronomical community actively uses the KOA with approximately 25 percent of WMKO publications citing the archive as the source of their data. The annual growth is attributed to the availability of more than 10 instruments in KOA covering 25 years of the "Keck Sky."

ASTROPHYSICS EXPLORER

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Other Missions and Data Analysis	226.5	--	**246.2**	277.7	350.8	301.0	315.6
Total Budget	**226.5**	**--**	**246.2**	**277.7**	**350.8**	**301.0**	**315.6**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

The NASA Explorers NuSTAR mission discovered new high-energy X-ray sources within the galaxy NGC6946 (pictured).

The Astrophysics Explorer program provides frequent flight opportunities for world-class astrophysics investigations using innovative and streamlined management approaches for spacecraft development and operations. The program is highly responsive to new knowledge, new technology, and updated scientific priorities by launching smaller missions conceived and executed in a relatively short development cycle. NASA selects new missions based on an open competition of concepts solicited from the scientific community. The program emphasizes the accomplishments of missions under the control of the scientific research community within constrained mission life-cycle costs.

The most recent Astrophysics Medium-Class Explorers (MIDEX) missions cost up to $400 million in total, including launch services. Small Explorers (SMEX) may cost up to $200 million including launch services. The most recent Explorer missions of opportunity (MO) have a total NASA cost of under $75 million, excluding the launch, and may be of several types. Partner MOs are those that will fly on a non-NASA space mission. NASA conducts these missions on a no-exchange-of-funds basis with the organization providing the spacecraft for the mission. Other possible types are new science missions using existing spacecraft and small complete missions. NASA intends to solicit proposals for MOs in conjunction with each AO issued for MIDEX and SMEX investigations.

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

ASTROPHYSICS EXPLORER

ACHIEVEMENTS IN FY 2019

Imaging X-ray Polarimetry Explorer (IXPE) completed its design phase, passed its mission critical design review at the end of June 2019 and entered into the fabrication and testing phase of all its major components.

Galactic/Extragalactic Ultralong duration balloon Spectroscopic Terahertz Observatory (GUSTO) will transition into Phase C and will continue payload development leading up to the critical design review in October 2019.

NASA completed fabrication and testing of the X-Ray Imagining and Spectroscopy (XRISM) Calorimeter Spectrometer Insert (CSI) hardware for Resolve in FY 2019.

NASA selected The Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ices Explorer (SPHEREx) in February 2019 as a new MIDEX investigation, to proceed into Phase B formulation.

In April 2019, NASA released an Announcement of Opportunity (AO) for Astrophysics Small Explorers and Missions of Opportunity (MOs).

WORK IN PROGRESS IN FY 2020

All major components of IXPE continue to be constructed and tested. The systems integration review planned for June 2020 is followed a month later by a Key Decision Point D milestone decision.

GUSTO will continue in development after successful completion of the mission critical design review in October 2019.

NASA plans to deliver the Resolve and the X-ray Mirror Assembly to JAXA for the XRISM mission. The project team will aid JAXA with payload integration and testing. NASA expects to pass its Key Decision Point D (KDP-D), and the JAXA XRISM project will undergo JAXA integrated systems critical design review.

SPHEREx will continue in Phase B formulation. The project successfully passed its project mission systems review in October 2019. The SPHEREx preliminary design review (PDR) planned for April 2020 is followed by the Key Decision Point (KDP-C) currently planned for June 2020.

In November 2019, NASA selected Contribution to ARIEL Spectroscopy of Exoplanets (CASE) as a Partner Mission of Opportunity with ESA's M4 Atmospheric Remote-sensing Infrared Exoplanet Large-survey (ARIEL) mission. CASE will continue Phase B formulation in FY 2020.

NASA will select SMEX and MO missions for the AO19 proposals, and these selected investigations will initiate competitive Phase A mission concept studies.

ASTROPHYSICS EXPLORER

KEY ACHIEVEMENTS PLANNED FOR FY 2021

XRISM will undergo spacecraft-level integration and test led by JAXA, with assistance from NASA project members. NASA will select, through peer review, investigators from the US scientific community to participate in the analysis of data from the performance verification phase of XRISM operations after post-launch commissioning.

SPHEREx will continue development as it prepares for its critical design review planned for April 2021.

CASE will continue formulation as it prepares for its preliminary design review currently planned for early FY 2022.

IXPE will undergo observatory integration and testing of the payload and spacecraft, with a planned launch in October 2021.

GUSTO will integrate the payload into the gondola in FY 2021, in preparation for launch on a high-altitude stratospheric super-pressure balloon from McMurdo, Antarctica, in December 2021 for approximately 75 days.

Program Schedule

Date	Significant Event
Mar 2020	Select SMEX and Explorer MO proposals for competitive Phase A mission concept studies
Aug 2021	Downselect one SMEX and one MO mission for implementation
Sep 2021	AO announcement for MIDEX and MO opportunity to propose
Aug 2022	Select MIDEX and Explorer MO proposals for competitive Phase A mission concept studies
Mar 2024	AO announcement for SMEX and MO opportunity to propose
Jan 2025	Select SMEX and Explorer MO proposals for competitive Phase A mission concept studies

Program Management & Planned Cadence

The Astrophysics and Heliophysics Explorer Programs are both coordinated sets of uncoupled missions, where each mission is independent and has unique science. The Programs share a common program office at GSFC and a common management structure. The Explorer program manager resides at GSFC, reporting functionally to the Center Director and programmatically through the Astrophysics and Heliophysics Division Directors to the Associate Administrator for SMD.

This budget brings the Astrophysics Explorer Program into alignment with the Decadal Survey's recommendation of a two- to three-year mission cadence.

ASTROPHYSICS EXPLORER

Acquisition Strategy

NASA selects all Explorer missions through competitive AOs.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Program Independent Review	SRB	2019	Assess performance of program	Successful	2024

OTHER MISSIONS AND DATA ANALYSIS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Contribution to ARIEL Spectroscopy of Ex	0.0	--	**11.9**	10.2	10.0	6.4	1.0
Universe Explorer Prior Hist Projects	70.0	--	**0.0**	0.0	0.0	0.0	0.0
ASTRO-H (SXS)	0.0	--	**0.0**	0.0	0.0	0.0	0.0
Astrophysics Explorer Future Missions	2.3	--	**10.6**	58.0	219.2	241.5	278.1
Astrophysics Explorer Program Management	4.9	--	**20.7**	18.0	10.7	8.3	9.1
Neutron Star Interior Composition Explorer (NICER)	3.8	--	**4.8**	4.4	0.0	0.0	0.0
Neil Gehrels Swift Observatory	7.0	--	**5.8**	5.8	0.0	0.0	0.0
Nuclear Spectroscopic Telescope Array (NuSTAR)	8.5	--	**8.6**	8.6	0.0	0.0	0.0
Transiting Exoplanet Survey Satellite (TESS)	7.7	--	**14.7**	14.1	0.0	0.0	0.0
Galactic/Extragalactic ULDB Spectroscopi	19.9	--	**7.8**	5.8	1.0	0.0	0.0
Imaging X-Ray Polarimetry Explorer	57.0	--	**45.3**	7.4	4.5	0.5	0.0
X-Ray Imaging and Spectroscopy Mission	23.2	--	**25.1**	36.3	17.7	15.9	14.4
Spectro-Photometer for the History of th	22.2	--	**90.8**	109.1	87.7	28.4	13.0
Total Budget	**226.5**	--	**246.2**	**277.7**	**350.8**	**301.0**	**315.6**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

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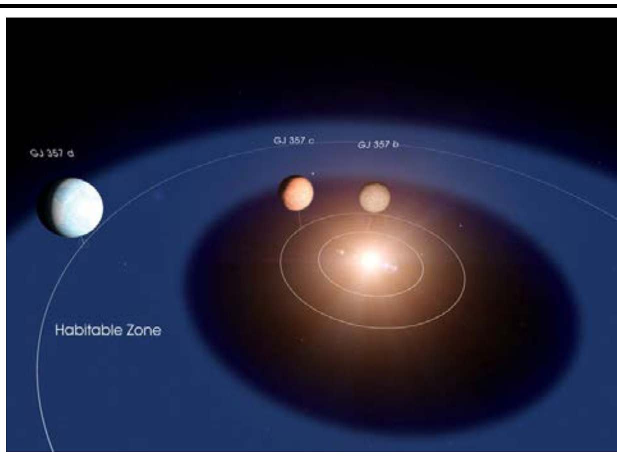

The NASA Explorers TESS mission discovered three exoplanets orbiting a red dwarf star that is 31 light years away (illustrated above).

Mission Planning and Other Projects

Astrophysics Explorers Other Missions and Data Analysis includes funding for small missions in formulation and development (CASE, SPHEREx, GUSTO, IXPE, XRISM), operating missions (TESS, NICER, NuSTAR, Neil Gehrels Swift Observatory), and funding for future mission selections and program management functions Mission Planning and Other Projects.

OTHER MISSIONS AND DATA ANALYSIS

GALACTIC/EXTRAGALACTIC ULDB SPECTROSCOPIC TERAHERTZ OBSERVATORY (GUSTO)

In March 2017, NASA's Astrophysics Explorers Program selected the GUSTO balloon payload as a Mission of Opportunity. GUSTO will launch on a high-altitude stratospheric super-pressure balloon from McMurdo, Antarctica, in December 2021 for approximately 75 days. GUSTO's telescope with its Terahertz heterodyne array receivers will provide the spectral and spatial resolution needed to study the interstellar medium. The GUSTO mission will provide the first complete study of all phases of the stellar life cycle, from the formation of molecular clouds, through star birth and evolution, to the formation of gas clouds and the restart of the cycle. During flight, the GUSTO payload will conduct its scientific observation while tracking the prevailing stratospheric winds at the float altitude of 33.5 km.

SPECTRO-PHOTOMETER FOR THE HISTORY OF THE UNIVERSE, EPOCH OF RE-IONIZATION, AND ICES EXPLORER (SPHEREX)

In February 2019, NASA selected SPHEREx to proceed to Phase B as a Class C Explorer mission. SPHEREx will launch in the second quarter of FY 2024 for a two-year prime mission. SPHEREx will be the first all-sky near-infrared spectral survey that will include near-infrared (0.75 - 5.0 millimeters) images and spectra of an estimated 500 million celestial objects. The project will provide the astronomical community with an unprecedented near-infrared spectral dataset.

Recent Achievements

SPHEREx completed a project mission systems review in October 2019. The project has scheduled the preliminary design review for April 2020 and the Key Decision Point (KDP-C) gate review in June 2020.

THE IMAGING X-RAY POLARIMETRY EXPLORER (IXPE)

NASA selected IXPE, a Small Explorer-class (SMEX) mission, to continue into Phase B formulation in January 2017. Due to the hundred-fold improvement in the sensitivity of X-ray polarimeters during the past two decades, IXPE will enable astrophysicists to open an important, new field of investigation into some of the most extremely unusual objects found in the universe. IXPE will examine polarized X-ray emissions from both galactic and extragalactic X-ray sources, such as active galactic nuclei, quasars, pulsars, pulsar wind nebulae, magnetars, accreting X-ray binaries, supernova remnants, and the Galactic Center. These observations will allow the investigation of general relativistic and quantum effects in the extreme environment associated with these sources and will significantly improve our understanding of fundamental physics. IXPE will launch into a low Earth orbit at a low inclination angle for a two-year mission beginning in October 2021.

Recent Achievements

IXPE entered its final design and fabrication phase (Phase C) in November 2018, after completing the Key Decision Point-C (KDP-C). The project passed its critical design review in June 2019 and entered into the fabrication and testing phase for all of its major components.

OTHER MISSIONS AND DATA ANALYSIS

THE X-RAY IMAGING AND SPECTROSCOPY MISSION (XRISM)

The X-ray Imaging and Spectroscopy Mission (XRISM), previously named XARM, is a joint NASA and JAXA mission that will recover the soft X-ray spectroscopic capability lost with the Hitomi mission that ended in March 2016. JAXA is planning to launch XRISM in early 2022. The key scientific objective of XRISM is to pioneer a new horizon of the Universe with unprecedented high-resolution X-ray spectroscopy. XRISM will provide breakthrough science in a number of areas, including structure and formation of the Universe, the evolution of clusters of galaxies, and the transport and circulation of energy in the cosmos. NASA is developing key components of the main instrument, the Resolve Soft X-ray Spectrometer that will supply the X-ray mirror assemblies for the observatory.

Recent Achievements

The project completed and tested the Calorimeter Spectrometer Insert (CSI) on schedule and delivered it to JAXA in November 2019 as the first of three planned deliveries. The fabrication and testing of the components for the remaining two deliveries are on schedule for delivery to JAXA in 2020. Key Decision Point-D (KDP-D) for the NASA contribution to the XRISM mission is in November 2019, and JAXA critical design review will take place in January 2020. An open call for proposals for guest scientists from the U.S. science community to participate in the analysis of data acquired in the six-month performance verification phase of the mission following post-launch commissioning will occur in 2020.

CONTRIBUTION TO ARIEL SPECTROSCOPY OF EXOPLANETS (CASE)

ARIEL is a joint ESA/NASA mission planned for launch in 2028 that will observe hundreds of warm transiting gas giants, Neptunes, and super-Earths, using spectroscopy (AIRS, 1.2 – 7.8 micrometers) and photometry (CASE extension, 0.5 – 1.2 micrometers). The mission responds to high-priority science from the last Decadal Survey of Astronomy and Astrophysics by addressing the question: "What are the characteristics of planetary systems orbiting other stars and do they harbor life?”

ARIEL’s main science goals include measuring the composition and structure of planetary atmospheres, determining the vertical and horizontal temperature structure, and identifying chemical processes at work (thermochemistry, photochemistry, transport quenching). A mission designed and optimized for transiting exoplanet spectroscopy will address a key gap in NASA’s exoplanet exploration mission portfolio. CASE will fill that gap and ensure the full participation of the United States community in ESA’s ARIEL mission.

ASTROPHYSICS EXPLORERS FUTURE MISSIONS

Astrophysics Explorers Future Missions funding supports future astrophysics Explorers missions and MOs through concept studies and selections. Astrophysics Explorers Future Missions funding will support initiation of an Astrophysics Probe mission as early as 2022, conditional on Decadal Survey recommendations.

ASTROPHYSICS EXPLORERS PROGRAM MANAGEMENT

Astrophysics Explorers program management provides programmatic, technical, and business management of ongoing missions in formulation and development.

OTHER MISSIONS AND DATA ANALYSIS

Operating Missions

NEUTRON STAR INTERIOR COMPOSITION EXPLORER (NICER)

The NICER instrument launched on June 3, 2017, to an external logistics carrier on the International Space Station (ISS) for an 18-month prime mission. Its main goal is spectroscopic X-ray observations of neutron stars with high time resolution, to measure their masses and radii precisely and thus to test models of how matter behaves at extreme densities: a neutron star squeezes up to twice the mass of the Sun into a city-size volume, so the density and pressure are higher than in atomic nuclei. NICER measures fluctuating X-rays from other sources, such as disks of hot gas pouring onto a black hole or neutron star from a stellar companion, or the gas around very massive black holes at the centers of galaxies. The 2019 Senior Review of Operating Missions approved extended mission operations through FY 2022 to include additional cycles of the NICER Guest Observer program element. NICER demonstrated achievement of its prime-mission science goals in a June 2018 review, with public release of key science results in October 2019.

Recent Achievements

NICER measurements have revealed how the inner edge of a black hole's accretion disk – and the corona above it – change in size and shape as a black hole consumes material from a companion star. Through a technique called "reverberation mapping," NICER measured the delay of X-ray light echoes that originate from the corona and then reflect off the accretion disk, to measure how close the disk is to the black-hole event horizon as well as how far off the disk the corona extends. Published as the cover story in the January 2019 issue of the prestigious journal Nature, the NICER team's report showed that the corona contracted from 100 miles to 10 miles high above the disk. NICER featured prominently in the cover story ("The Inner Lives of Neutron Stars") of the March 2019 issue of Scientific American magazine.

NICER discovered red- and blue-shifted spectral lines in X-ray bursts resulting from thermonuclear explosions on the surface of a neutron star. Originally detected in bursts observed in 2017, researchers confirmed the lines in additional bursts from the same star system observed in 2019. These measurements probe the chemical composition and extreme physical conditions of the neutron star's surface as it accretes matter from an orbiting companion.

NICER continues to deliver unprecedented high-precision X-ray of rapidly spinning (hundreds of times each second) neutron stars, with data spanning the entire mission to date and continuing into the extended mission. These timing data are immune to the deviations that plague similar measurements with radio telescopes, caused by the interstellar medium through which the radio waves travel. Scientists use timing measurements in searches for long-wavelength gravitational radiation from distant super-massive black holes.

NICER's operational flexibility on the ISS has allowed it to play the role of X-ray sensor for dozens of multi-wavelength campaigns of a large variety of sources through coordinated observations with telescopes around the world and in space.

OTHER MISSIONS AND DATA ANALYSIS

NEIL GEHRELS SWIFT OBSERVATORY

The Neil Gehrels Swift Observatory is a multi-wavelength space-based observatory that is uniquely equipped to make rapid-response observations to fast-breaking events. The observatory measures the position, brightness, and physical properties of gamma-ray bursts, and is revolutionary in allowing scientists to solve the mystery of their origin in the birth-cries of stellar-mass black holes. The observatory continues to target gamma-ray burst science, while also using its capabilities to increase our understanding of the entire transient universe, ranging in distance from the solar system to high-redshift quasars, and in time from the present to the epoch of reionization. Neil Gehrels Swift Observatory is a MIDEX class mission that launched in 2004 and is currently in, extended mission operations. The 2019 Senior Review of Operating Missions recommended continuing operations through FY 2022.

Recent Achievements

On January 14, 2019, the burst alert telescope triggered and located gamma ray burst 190114C, detected in TeV wavelengths by the major atmospheric gamma imaging cherenkov telescopes, the first time a gamma ray burst was observed at such high energies.

In September 2019, the results of 67 kiloseconds of X-ray telescope (XRT) observations of the nearby galaxy cluster CL2015 were published showing that this cluster displays a very low pressure for its mass, likely due to a low concentration of matter near the center. In February 2019, the ultraviolet optical telescope took the earliest series of UV observations ever taken of a tidal disruption event (TDE), ASASSN-19bt. These observations uncovered a new feature, a drop in the temperature from around 40,000 to 20,000 degrees over a few days, and the TDE occurred in the southern continuous viewing zone of TESS.

NUCLEAR SPECTROSCOPIC TELESCOPE ARRAY (NUSTAR)

Launched in June 2012, NuSTAR completed its prime mission in July 2014 and is now in extended mission operations. NuSTAR enables scientists to locate supermassive black holes in other galaxies, locate and examine the remnants of collapsed stars in our galaxy and the nearby universe, observe selected gamma-ray sources, and observe any new supernovae in the local group of galaxies. NuSTAR’s key science products are sensitive X-ray maps of the celestial sky at a higher energy band than any other focusing X-ray satellite. NuSTAR offers opportunities for a broad range of science investigations, ranging from probing cosmic ray origins and studying the extreme physics around collapsed stars to mapping microflares on the surface of the Sun. NuSTAR performs key follow-up observations of sources found by Chandra, Spitzer, and WISE satellites. The NuSTAR mission implemented a Guest Observer program in 2015. Scientists are now implementing the observations selected under Cycle 5 of the Guest Observer program. Some NuSTAR observations are coordinated with other missions, including Neil Gehrels Swift Observatory, Chandra, INTEGRAL, XMM-Newton, and NICER. Such observations take advantage of NuSTAR' s unique access to high-energy X-rays with synergistic lower-energy X-ray capabilities of these other missions, such as NICER's exquisite X-ray timing, Chandra's high-spatial resolution imaging, and Swift's agility for rapidly slewing across the sky to monitor variable sources.

The 2019 Senior Review of Operating Missions recommended continuing NuSTAR operations through FY 2022. Additionally, NuSTAR most likely will participate in the FY 2022 Astrophysics Senior Review for possible extended operations beyond 2022.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

NuSTAR continues to provide insights into the high-energy Universe and some of the most powerful and mysterious objects in it. During the seven years of successful operations, the number of NuSTAR science publications has been increasing every year, shedding light on objects ranging from quasars billions of light years away, to energetic sources within our own galaxy, to objects in our Solar System, such as the Sun and Jupiter.

At the very center of our own Milky Way galaxy resides a supermassive black-hole with a mass of over 4 million times the mass of our Sun. Named Sagittarius A* (pronounced Sagittarius A-Star), this gravitational monster has, for the most part, been quiet compared to farther away galaxies that can display jetting active cores. However, over the last year our galactic center has awakened with material falling into the black hole and giving off high-energy radiation. NuSTAR, along with several other space-based and ground-based observatories has been measuring these local events to develop a better picture of the central engine of our galaxy. One of the very exciting program elements that NuSTAR has participated in over the past few years has been exploration of ultra-luminous pulsars. Ultra-luminous pulsars are a new class of object, first discovered by NuSTAR in 2014, and are subset of the very bright "ultra-luminous X-ray sources", or ULXs, commonly found in star-forming galaxies. The extreme luminosities of ULXs led early researchers to suggest they were black holes with masses thousands of times greater than the Sun residing in the disks of galaxies. Other researchers suggested they might be black holes with more modest masses, approximately 10 times that of the Sun, undergoing extreme accretion. NuSTAR' s discovery that some of these sources pulsate definitively proved that at least some ULXs are instead pulsating neutron stars, or pulsars, undergoing extreme accretion. Since neutron stars cannot have masses greater than two to three times that of the Sun, this discovery implies ULX pulsars are incredibly luminous and likely in a transient, unstable state. NuSTAR has opened a window on the extreme universe.

TRANSITING EXOPLANET SURVEY SATELLITE (TESS)

The Transiting Exoplanet Survey Satellite (TESS) mission launched on April 18, 2018. TESS is performing an all-sky survey to search for planets transiting nearby stars. The primary goal of TESS is to discover planets smaller than Neptune that transit stars bright enough to enable follow-up spectroscopic observations that can provide planet masses and atmospheric compositions. In its two-year prime mission, TESS will monitor about 200,000 main-sequence dwarf stars with four wide-field optical CCD cameras to detect periodic drops in brightness caused by planetary transits. Photometry of these pre-selected targets record every two minutes. TESS also obtains full-frame images of the entire field-of-view (24 x 96 degrees) at a cadence of 30 minutes to facilitate additional science.

The TESS Mission is designed to survey over 85 percent of the sky (an area of sky 400 times larger than covered by Kepler) to search for planets around nearby stars (within approximately 200 parsecs). TESS stars are typically 30-100 times brighter than those surveyed by the Kepler satellite. Planets detected around these stars will therefore be far easier to characterize with follow-up observations, resulting in refined measurements of planet masses, sizes, densities, and atmospheric properties.

Recent Achievements

As of October 2019, TESS completed two-thirds of the data collection for its exoplanet survey, identifying over 1,100 candidate planets and confirming 29. TESS discovered new Earth-size planets,

OTHER MISSIONS AND DATA ANALYSIS

planets within the habitable zones of their host stars, multi-planet systems, and planets within binary star systems.

TESS's unique observing strategy of continuously surveying millions of objects within a large patch of the sky enables a large array of additional discoveries of astrophysical transients. Nearly 50 percent of refereed TESS science papers are unrelated to the exoplanet survey. General astrophysics highlights include catching the onset of dozens of distant supernova explosions, monitoring the tidal disruption of a star by a supermassive black hole, an extremely rare event that occurs only once every ten thousand to hundred thousand years in a galaxy, and observations of near-earth objects.

The 2019 Senior Review of Operating Missions considered a proposal for an extended TESS mission through FY 2020-22. NASA will continue to operate TESS over this time to expand the survey to new fields, smaller planets, and wider orbits, as well as an ongoing astrophysics program covering topics ranging from solar system objects to high-redshift galaxies.

HELIOPHYSICS

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Heliophysics Research	248.9	--	**230.5**	218.7	225.2	224.0	224.5
Living with a Star	135.3	--	**127.9**	134.5	246.4	225.5	233.3
Solar Terrestrial Probes	180.5	--	**126.3**	262.2	202.6	195.6	115.5
Heliophysics Explorer Program	147.9	--	**148.4**	192.4	167.6	189.0	230.8
Total Budget	**712.7**	**724.5**	**633.1**	**807.8**	**841.8**	**834.1**	**804.1**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Heliophysics

HELIOPHYSICS RESEARCH

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Heliophysics Research and Analysis	71.2	--	**58.6**	58.6	58.6	58.6	58.6
Sounding Rockets	61.1	--	**71.6**	60.1	65.1	65.1	65.1
Research Range	30.0	--	**27.4**	26.4	26.8	26.9	26.9
Other Missions and Data Analysis	86.7	--	**73.0**	73.5	74.7	73.4	73.9
Total Budget	**248.9**	--	**230.5**	**218.7**	**225.2**	**224.0**	**224.5**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

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This time-lapse photograph shows the first stages of the VISION-2 Black Brant X rockets as they leave the launch pad from Svalbard in Norway.

The Sun, a typical medium star midway through its life, governs the solar system. The Sun wields its influence through its gravity, radiation, solar wind, and magnetic fields, all of which spread out through the heliosphere, interacting with other planets, the Earth, and its space environments to produce space weather, which can affect human technological infrastructure and activities. Heliophysics seeks to understand the Sun, heliosphere, and planetary space environments as a single connected system to answer these fundamental questions:

- How and why does the Sun vary?
- How do Earth and the heliosphere respond to the Sun’s changes?
- How do the Sun and the solar system interact with the interstellar medium?
- How do these processes affect human activities?

Heliophysics Research improves our understanding of fundamental physical processes throughout the solar system, utilizing our flight mission data to push the boundaries of knowledge, employing theory and modeling including artificial intelligence (AI) and machine learning for new interpretations and large-scale vision, developing new technologies and flight testing them by launching sounding rockets and CubeSats, and thereby facilitating future missions. Heliophysics Research enables us to understand how the Sun, as the major driver of the energy throughout the solar system, affects our technological society. The scope of Heliophysics ranges from the Sun's interior to Earth's upper atmosphere, and beyond, through interplanetary space to the end of the region of the Sun's influence, far beyond the outer planets.

For more information, go to https://science.nasa.gov/heliophysics/programs/research

EXPLANATION OF MAJOR CHANGES IN FY 2021

Heliophysics is augmenting the Sounding Rocket project to complete the Grand Challenges Initiative-CUSP campaign, an international collaboration to explore the region where Earth meets space. It is an ongoing three-year international research effort involving launches from Andoya and Svalbard in Norway. NASA is also increasing support to the Solar Data Archive Center to allow for long-term archiving of Solar Dynamics Observatory (SDO) science data. Additionally, the Community Coordinated Modeling Center is receiving additional funds to maintain and modernize NASA's modelling capability, to help address increasing data security requirements and increasing demands for heliophysics modelling.

ACHIEVEMENTS IN FY 2019

A robust competed research and analysis program enjoyed an increase in selection rates across its various elements by fully implementing the DRIVE initiative specified in the 2013 National Research Council Decadal Strategy for Solar and Space Physics report, Solar and Space Physics: A Science for a Technological Society (see: http://www.nap.edu/catalog.php?record_id=13060). NASA continued a competed Heliophysics Supporting Research program with emphasis on synergy of data analysis with key enhancement from numerical simulations, theory, or modeling. The theory, modeling, and simulation program element encouraged new theoretical development stretching existing knowledge as well as utilizing AI and machine learning to investigate extensive data repositories seeking new insights.

Technology and Instrument Development for Science (H-TIDeS) will continue to focus on the development of key technologies for use in future missions. The current technology development focuses on reducing sensor size, weight, and power. Future missions will benefit from an increase in sensor density as well as the new option of constellations and swarms of in-situ measurements in a sensor web matched to the temporal and spatial scales of energetic space plasma phenomena.

This year, NASA launched 19 sounding rockets and one reimbursable mission with campaigns in remote areas. The Sounding Rockets project executed an early FY 2019 campaign in Norway, called the Grand Challenge. This involved fabrication, testing, and ground support set-up for six missions from two launch sites (Andoya and Svalbard). In December 2018, VISIONS-2 launched from Svalbard to investigate the process whereby Earth is slowly leaking its atmospheric oxygen into space. NASA launched G-chaser, an educational mission with experiments developed by university students from the United States, Norway, and Japan, from Andoya in January 2019. Another remote campaign at Kwajalein Atoll in the Marshal Islands launched Too-WINDY to study Earth's atmosphere by forming artificial nighttime clouds.

In addition, Heliophysics launched four CubeSats in FY 2019. The Compact Radiation Belt Explorer studied what energizes electrons and causes their escape from the radiation belts. The Electron Losses and Fields Investigation studied dominant wave-loss mechanisms of relativistic electrons. The Solar Cycle Studies for the Miniature X-ray Solar Spectrometer is now in space observing a particular class of X-ray light from the Sun rarely studied. The Tandem Beacon Explorer studies tropical weather in relationship to ionospheric bubbles.

WORK IN PROGRESS IN FY 2020

In FY 2020, the Heliophysics Research program anticipates science results from the analysis of data from the 18 active space missions (26 individual spacecraft) that comprise the Heliophysics System Observatory. Researchers are also analyzing and collaborating with data collected by Ramaty High Energy Solar Spectroscopic Imager (RHESSI) and the Two Wide-angle Imaging Neutral-atom Spectrometers (TWINS) projects, even though both projects have retired and are in closeout. The Van Allen Probes project deactivated both spacecraft and will close over the next year but will continue to analyze and archive data. Heliophysics Research will continue to distribute and archive all other data from the Heliophysics Observatory to promote access and use in the pursuit of superior science. Competitive high-quality research investigations funded by ROSES awards will likewise contribute to heliophysics science advancements.

The current sounding rockets mission manifest features 19 missions in FY 2020 from various locations. The program will go to Norway in the winter for two missions, to White Sands Proving Ground in New Mexico in the fall and spring for eight missions, and to Australia, which will feature several missions investigating celestial targets of interest in the Southern sky.

NASA plans to launch four CubeSats in FY 2020. Science will continue to collaborate with the Human Exploration and Operations Mission Directorate to enable the CubeSat mission to Understand Solar Particles over Earth's Poles (CUSPP) on the first flight using the Space Launch System (SLS), Exploration Mission-1 (EM-1), along with The Cusp Plasma Imaging Detector (CuPID) CubeSat (EM-1/Artemis RideShare). Scintillation observations and response of the ionosphere to electrodynamics will study space weather sources of wave-like plasma perturbations in the ionosphere. The scintillation prediction observations research task and the low-latitude ionosphere/thermosphere enhancements in density CubeSat missions round out the launches.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

In FY 2021, the Heliophysics Research program anticipates significant science results from the analysis of data from the Solar Orbiter Collaboration mission, as well as results from the 18 already active space missions (26 individual spacecraft) that comprise the Heliophysics System Observatory. The anticipated awards of additional research investigations will also contribute to heliophysics science advancements.

The current sounding rockets mission manifest features 19 missions in FY 2021 from various locations in the United States, Norway, and Australia.

HELIOPHYSICS RESEARCH

Program Elements

RESEARCH RANGE

The Research Range project provides operations support, maintenance, and engineering for the Wallops Launch Range and Instrumentation. The range and instrumentation support suborbital, orbital, and aircraft missions conducted on behalf of NASA and the Department of Defense at Wallops Flight Field and at remote sites around the world. New work includes support for NASA technology missions, unmanned aerial vehicle flights, and commercial launch and flight projects.

The range instrumentation includes meteorological, telemetry, radar, command, launch and range control centers, and optical systems. Research Range mobile assets provide range services at other ranges and remote locations around the world.

SOUNDING ROCKETS

The Sounding Rockets Project supports the NASA strategic vision and goals for Earth Science, Heliophysics, Planetary Science, and Astrophysics. The missions flown annually by the project provide researchers with unparalleled opportunities to build, test, and fly new instrument and sensor design concepts while simultaneously conducting world-class scientific research. Coupled with a hands-on approach to instrument design, integration, and flight, the short mission life cycle helps ensure that the next generation of space scientists receives the training and experience necessary to move on to NASA’s larger, more complex space science missions.

With the capability to fly higher than many low Earth orbiting satellites and the ability to launch on demand, sounding rockets often offer the only means to study specific scientific phenomena of interest to many researchers. Unlike instruments on board most orbital spacecraft or in ground-based observatories, sounding rockets can place instruments directly into regions where and when the science is occurring to enable direct, in-situ measurements. The mobile nature of the project enables researchers to conduct missions from strategic vantage points worldwide. Telescopes and spectrometers to study solar and astrophysics phenomena fly on sounding rockets to collect unique science data and test prototype instruments for future satellite missions.

HELIOPHYSICS RESEARCH AND ANALYSIS

This project supports basic research, solicited through NASA’s annual Research Opportunities in Space and Earth Science (ROSES) announcements. These research activities address our understanding of the Sun and planetary space environments, including the origin, evolution, and interactions of space plasmas and electromagnetic fields throughout the heliosphere and in connection with the galaxy. Understanding the origin and nature of solar activity and its interaction with the space environment of the Earth is a particular focus. This project supports the research program element, the theory, modeling and simulation program element, DRIVE science centers, instrument development, Low Cost Access to Space (LCAS) investigations, and Heliophysics Flight Opportunities for Research and Technology (H-FORT), all necessary research directly linked to Heliophysics science questions.

HELIOPHYSICS RESEARCH

Heliophysics supporting research and theory, modeling, and simulation are the foundations of the Heliophysics Research and Analysis project. They lead the way to new understanding of previous investigations and drive science concepts for future missions. They are essential in fully exploiting Heliophysics mission research data collected between the outer edge of the Earth's atmosphere and the interaction of the Sun and solar wind with the local galactic environment currently explored by Voyager. The DRIVE centers program element supports large principal investigator proposed team efforts that require a critical mass of expertise to make significant progress in understanding complex physical processes with broad importance. They employ a variety of fundamental research techniques (e.g., theory, numerical simulation, and modeling), analysis, and interpretation of space data.

LCAS and HFORT investigations use spaceflight of experimental instrumentation to achieve scientific goals and proof-test new technology that may ultimately find application in larger or strategic Heliophysics space missions. These investigations may use a range of flight opportunities, including suborbital rockets, suborbital reusable launch vehicles, ISS payloads, CubeSats, and balloon flights.

Instrument development investigations develop technology with promise for use in scientific investigations on future Heliophysics science missions. These investigations may include the development of laboratory instrument prototypes, but not of flight hardware. The goal is to define and develop scientific instruments and/or components of such instruments to the point where complete instruments are ready for future announcements of opportunity or missions of opportunity without significant additional technology development.

Heliophysics Systems Observatory

The Heliophysics Systems Observatory is comprised of the 18 active space missions (26 individual spacecraft) below:

- Advanced Compositional Explorer (ACE);
- Aeronomy of Ice in the Mesosphere (AIM);
- Geotail;
- Global-scale Observations of the Limb and Disk (GOLD);
- Hinode;
- Interface Region Imaging Spectrograph (IRIS);
- Interstellar Boundary Explorer (IBEX);
- Ionospheric Connection explorer (ICON);
- Magnetospheric Multiscale Satellites (MMS) (four spacecraft);
- Parker Solar Probe;
- Solar and Heliospheric Observatory (SOHO);
- Solar Dynamics Observatory (SDO);
- Solar Terrestrial Relations Observatory (STEREO);
- Space Environment Testbeds (SET);
- Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED);
- Time History of Events and Macroscale Interactions during Substorms (THEMIS) (five spacecraft);
- Voyager (two spacecraft); and
- Wind.

HELIOPHYSICS RESEARCH

Program Schedule

NASA implements the Heliophysics Research program via a competitively selected process. NASA releases research solicitations each year through the Research Opportunities in Space and Earth Science (ROSES) NASA Research Announcements (NRA), aiming to initiate research for about one-third of the program, given the selected investigations are typically three-year awards. NASA will allocate FY 2021 funds to ROSES-2020, ROSES-2019, and ROSES-2018 selections.

Date	Significant Event
Q1 FY 2020	ROSES-2019 selection within six to nine months of receipt of proposals
Q2 FY 2020	ROSES-2020 solicitation: Mar 2020
Q3/Q4 FY 2020	Review of proposals submitted to Heliophysics ROSES-2020 elements
Q1 FY 2021	ROSES-2020 selection within six to nine months of receipt of proposals
Q2 FY 2021	ROSES-2021 solicitation: Feb 2021
Q3/Q4 FY 2021	Review of proposals submitted to Heliophysics ROSES-2021 elements
Q1 FY 2022	ROSES-2021 selection within six to nine months of receipt of proposals
Q2 FY 2022	ROSES-2022 solicitation: Feb 2022
Q3/Q4 FY 2022	Review of proposals submitted to Heliophysics ROSES-2022 elements

Program Management & Commitments

Program Element	Provider
Research and Analysis	Provider: Headquarters (HQ) Lead Center: HQ Performing Centers: Goddard Space Flight Center (GSFC), Marshall Space Flight Center (MSFC), Jet Propulsion Laboratory (JPL), Langley Research Center (LaRC), Johnson Space Center (JSC) Cost Share Partners: None
Sounding Rockets and Research Range	Provider: GSFC Lead Center: HQ Performing Center: GSFC Cost Share Partners: None
Heliophysics Operating Missions	Provider: GSFC, JPL, MSFC Lead Center: HQ Performing Center: GSFC, JPL, MSFC Cost Share Partners: None

HELIOPHYSICS RESEARCH

Acquisition Strategy

NASA issues solicitations for competed research awards each February in the ROSES NRAs. To the widest extent possible, NASA fully and openly competes all new acquisitions. Proposals are peer-reviewed and selected from the annual ROSES announcement. Universities, government research laboratories, and industry partners throughout the United States participate in research projects. NASA previously selected the Heliophysics operating missions and instrument teams via NASA AOs. NASA evaluates the allocation of funding among the operating missions through the Heliophysics Senior Review process.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Sounding Rocket Operations	Orbital ATK, Dulles, VA	Various

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	Mission Senior Review Panel	Oct 2017	A comparative evaluation of Heliophysics operating missions	The report, released in Nov 2017, assessed missions individually and as part of a system observatory	Apr 2020
Relevance	Heliophysics Advisory Committee	2018	To review progress towards Heliophysics objectives in the NASA Strategic Plan	All areas were rated green as documented in the FY 2018 Agency Financial Report	2019
Relevance	Heliophysics Advisory Committee	2019	To review progress towards Heliophysics objectives in the NASA Strategic Plan	All areas were rated green as documented in the FY 2019 Agency Financial Report	2020
Relevance	Heliophysics Advisory Committee	2020	To review progress towards Heliophysics objectives in the NASA Strategic Plan	To be determined	2021

OTHER MISSIONS AND DATA ANALYSIS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Science Planning and Research Support	6.7	--	**6.7**	6.7	6.7	6.7	6.7
CubeSat	22.0	--	**10.0**	10.0	10.0	10.0	10.0
Solar Data Center	1.3	--	**2.5**	1.2	1.2	1.2	1.2
Data & Modeling Services	3.0	--	**3.0**	3.0	3.0	3.0	3.0
Space Physics Data Archive	2.3	--	**2.3**	2.3	2.3	2.3	2.3
Guest Investigator Program	26.5	--	**21.5**	23.0	24.5	23.0	23.0
Community Coordinated Modeling Center	2.7	--	**4.6**	4.9	5.1	5.4	5.6
Space Science Mission Ops Services	11.5	--	**11.9**	11.9	11.9	11.9	11.9
Voyager	5.8	--	**5.5**	5.5	5.0	5.0	5.2
Solar and Heliospheric Observatory (SOHO)	2.3	--	**2.3**	2.4	2.2	2.2	2.2
Wind	2.2	--	**2.2**	2.2	2.3	2.3	2.3
Geotail	0.4	--	**0.4**	0.4	0.5	0.5	0.5
Total Budget	**86.7**	**--**	**73.0**	**73.5**	**74.7**	**73.4**	**73.9**

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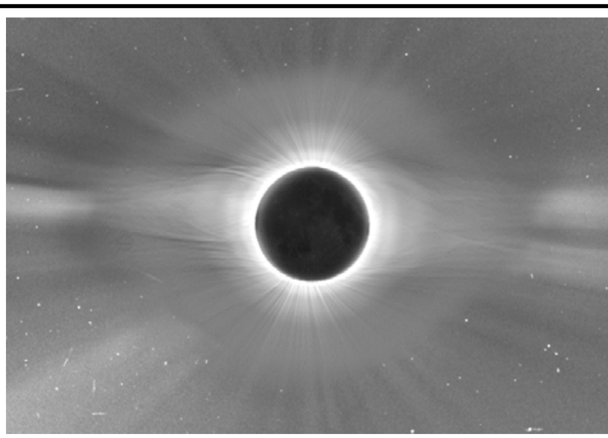

SOHO captured this composite image of the sun in early July 2019 at approximately the same time as the South American solar eclipse. The LASCO imager on SOHO was able to provide the image of the corona, looping above the surface of the sun and streaming into space.

NASA accumulates, archives, and distributes data collected by the Heliophysics System Observatory, a fleet of operating spacecraft. Combining the measurements from all of these observing platforms enables interdisciplinary, connected systems science across the vast spatial scales of our solar system. This collective asset enables the data, expertise, and research results to contribute directly to fundamental research on solar and space plasma physics and to the national goal of real-time space weather prediction. NASA teams support day-to-day mission operations for NASA spacecraft and data analysis to advance the state of space science and space weather modeling. NASA conducts science community-based projects to evaluate research models containing space weather information that is of value to industry and government agencies. Heliophysics data centers archive and distribute the science data from operating missions in the Living With a Star (LWS), Solar Terrestrial Probes (STP), Research, and Explorer programs.

Mission Planning and Other Projects

SCIENCE PLANNING AND RESEARCH SUPPORT

This project supports NASA's participation in proposal reviews by peer review panels, decadal surveys, and National Academies' studies.

DIRECTED RESEARCH AND TECHNOLOGY

This project funds the civil service staff that work on emerging flight projects, instruments, and research.

CUBESAT

Heliophysics implemented a CubeSat project in response to the 2013 Decadal Survey DRIVE initiative recommendation. The aim of the project is to explore the viability of this lower-cost option for enabling scientific discovery.

CubeSats are small spacecraft, built to a standardized form-factor of size and mass, which can launch as secondary or ride-share payloads. With development costs between $1 million and $6 million per investigation and with rapid development cycles, CubeSats can provide frequent science and technology flight opportunities.

This approach is similar to the traditional NASA suborbital programs that use sounding rockets, balloons, and aircraft, but it extends the range of opportunities. CubeSats have significant potential to leverage exploratory and systematic science observations at minimal additional cost.

The CubeSat project initially encompassed all Science themes and disciplines. From 2014 to 2018, the CubeSat project initiated 21 investigations in an exploration of management and implementation required for a new kind of flight program. Beginning in 2018, the science divisions conducted CubeSat investigations independently, using the lessons learned from the cross-discipline project.

The Heliophysics CubeSat project is continuing work on the cross-discipline investigations already underway. In response to the capabilities demonstrated by CubeSat investigations in the initial pathfinder stage, the CubeSat project expanded in 2019 to take advantage of new science achievable via investigations in the $2 million to $10 million range. The larger investigations will enable the development of remote sensing investigations with more sophisticated CubeSats as well as small constellations of in-situ CubeSat investigations. Out of the 2019 competition, panels selected three new CubeSat investigations with total mission costs ranging from $3.5 million to $6.8 million each. The program expects a similar level of selections again in 2020.

OTHER MISSIONS AND DATA ANALYSIS

SOLAR DATA CENTER

The Solar Data Center provides mission and instrument expertise to enable high-quality analysis of solar physics mission data. It provides leadership for community-based, distributed development efforts to facilitate identifying and accessing solar physics data, including ground-based coordinated observations residing in the Virtual Solar Observatory. The project also provides a repository for software used to analyze these data. The Virtual Solar Observatory is a software system that links together distributed archives of solar data into a unified whole, along with data search and analysis tools.

DATA AND MODELING SERVICES

This project supports missions in extended operations and missions transitioning to decommissioning to prepare their data holdings for long-term archival curation. This project also provides for the creation of higher-level data products, which are of significant use to the science community and not funded during the prime mission. Higher-level data products are data that combine results of multiple missions and/or instruments. Elements of this project are competed through the annual ROSES competitive announcement.

SPACE PHYSICS DATA ARCHIVE

The Space Physics Data Archive ensures long-term data preservation and online access to non-solar heliophysics science data. It operates key infrastructure components for the Heliophysics Data Environment, including inventory and web service interfaces to systems and data. It also provides unique enabling science data services.

GUEST INVESTIGATOR PROGRAM

The Guest Investigator program maximizes the return from currently operating Heliophysics missions by supporting studies consistent with the science goals of these missions and those expressed in the 2013 decadal survey and 2014 SMD Science Plan. These competitive research investigations use data from multiple spacecraft, as appropriate. Investigations addressing global system science are strongly encouraged, as Heliophysics is, by its nature, the investigation of a large-scale, complex, connected system.

COMMUNITY COORDINATED MODELING CENTER

The Community Coordinated Modeling Center is a multi-agency partnership to enable and perform the research and development for next-generation heliophysics and space weather models. The project provides the United States and international research community access to simulations to enable “runs on demand,” using models to study space weather events in near-real time. This allows the comparison of observational data and model parameters during or shortly after solar activity, thereby improving accuracy of the models.

OTHER MISSIONS AND DATA ANALYSIS

SPACE SCIENCE MISSION OPERATIONS SERVICES

Space Science Mission Operations Services manages the on-orbit operations of GSFC Space Science missions. Services include consistent processes and infrastructure for missions operated at GSFC, Johns Hopkins University Applied Physics Laboratory, Orbital-Alliant Techsystems, Pennsylvania State University, and University of California at Berkeley. Space Science Mission Operations Services also sustains an operational infrastructure for current and future missions.

Operating Missions

VOYAGER

The Voyager Interstellar Mission is exploring the interaction of the heliosphere and the local interstellar medium. Voyager 1, launched in 1977, is making the first in-situ observations of the region outside the heliosphere from about 148 astronomical units (AU), or 148 times Earth's distance from the Sun, and is traveling at a speed of 3.6 AU per year. Voyager 2 is about 123 AU from the Sun and traveling at a speed of about 3.3 AU per year. Spacecraft power should be adequate for currently operating instruments through 2021.

Recent Achievements

Voyager 2 crossed the heliopause on November 5, 2018. Voyager 2 is the second human-made object to cross the heliosphere - the protective bubble of particles and magnetic fields created by the Sun. Its twin, Voyager 1, crossed the heliopause on August 25, 2012, and continues to sail outward through the local interstellar medium. The Voyager Science Team is currently working on a special edition of Science Magazine, which will feature science papers from the five Voyager 2 instruments. Among others results, comparisons of data from the crossings of the two Voyager spacecraft and subsequent interstellar areas have improved our understanding of the heliosheath, including calculations of particle pressure on the edge of our solar system.

SOLAR AND HELIOSPHERIC OBSERVATORY (SOHO)

SOHO, launched in 1995, is a joint mission of the European Space Agency (ESA) and NASA, and it has been a dependable solar watchdog, providing the only Earth-Sun line coronagraph images of solar storms. Citizen scientists have used SOHO to discover more than 3,000 comets, a capability no one anticipated before launch. Coronal mass ejections (CME) drive most of the space weather effects in the inner heliosphere. SOHO continues to provide essential early alert space weather observations used as inputs to models that further our understanding of the Sun's effect on the Earth.

Recent Achievements

Combined observations from SOHO, the Solar Dynamics Observatory (SDO), the Reuven Ramaty High Energy Spectroscopic Imager (RHESSI), and the Geostationary Operational Environmental Satellite-16 provided a unique opportunity to study the genesis, magnetic morphology, and impulsive dynamics of a very fast CME. Data from these instruments show that a CME observed on September 10, 2017 was very fast and contained a hot bright rim around a quickly expanding cavity, embedded inside a much larger

OTHER MISSIONS AND DATA ANALYSIS

CME shell. Deformations in the CME structure are a severe challenge and source of uncertainty in predictions of the arrival time of a CME at Earth and the space weather effects it produces. Improving current models of CME physics to incorporate the behavior and structure of this CME will help in understanding CME activity and effects on Earth.

WIND

The Wind spacecraft, launched in 1994, studies the solar wind and its impact on the near-Earth environment. It addresses wave-particle interaction processes in the space environment, evolution of solar activity in the heliosphere, and geomagnetic impact of solar activity. Wind performs in-situ studies using unique capabilities, such as three-dimensional particle distributions over a wide range of energies, and delivers higher time resolution than available from any other mission. Wind provides critical measurements of the solar wind and space weather events. Correlating those critical measurements with measurements from the Parker Solar Probe mission and upcoming SOC mission will improve our understanding of these events as they move out from the Sun. These multi-spacecraft measurements constrain models of space weather events and improve their predictive capabilities.

Recent Achievements

CME expelled from the solar corona are a major space weather driver, both in space and on the ground. The fast-traveling CME plasma, which carries a twisted magnetic field, is a common source of geomagnetic disturbances that can affect a wide range of human technologies and exploration. Understanding the magnetic structure and dynamics of CMEs is of critical importance for space weather forecasting. Thanks to the past and current heliophysics system observatories, we have advanced our understanding by, for instance, connecting the traditional "magnetic clouds" or flux-ropes with the CMEs. However, our proficiency in predicting the internal magnetic structure of the Interplanetary CMEs (ICMEs) is still limited.

Wind also observed and aided in the first long-duration (approximately 10 years) statistical analysis of the temperatures, plasma betas, and temperature ratios for the electron, proton, and alpha-particle populations in the solar wind near Earth. This analysis is the first and only statistically significant analysis of the solar wind temperature parameters near Earth, which are relevant for long-term statistical models, parameter range limits for empirical models, constraints for inaccessible astrophysical plasmas, and a reliable baseline for Parker Solar Probe and Solar Orbiter.

GEOTAIL

Geotail, launched in 1992, enables scientists to assess data on the interaction of the solar wind and magnetosphere. July 24, 2019, marked the 27th anniversary of the launch of Geotail. Its instruments continue to function, sending back crucial information about how auroras form, how energy from the Sun funnels through near- Earth space, and the ways in which magnetic field lines move and rebound, creating explosive bursts that rearrange the very shape of our magnetic environment. The Geotail mission is a collaborative project undertaken by the Japanese Institute of Space and Astronautical Science and NASA.

Recent Achievements

Geotail helped contribute to an analysis of five decades of satellite data. This analysis pieced together the most comprehensive picture yet of substorms, the magnetic disturbances that cause surges of aurora. An

OTHER MISSIONS AND DATA ANALYSIS

American Geophysical Union (AGU) EOS Research Spotlight featured the unified data set results, which mined and merged the archives of 15 satellites from NASA, NOAA, ESA, and JAXA, spanning five decades. This global picture could help scientists better understand substorms on Earth, including their risk to infrastructure. It could also help scientists understand similar observed processes in the magnetic fields of other planets and stars.

LIVING WITH A STAR

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Solar Orbiter Collaboration	27.1	12.8	**8.1**	8.2	8.1	8.2	8.2
Other Missions and Data Analysis	108.2	--	**119.7**	126.3	238.2	217.3	225.0
Total Budget	**135.3**	--	**127.9**	**134.5**	**246.4**	**225.5**	**233.3**

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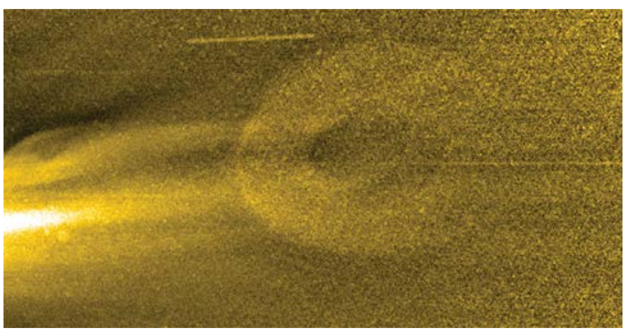

This image from Parker Solar Probe's WISPR (Wide-field Imager for Solar Probe) instrument suite shows the expelling of solar wind particles and magnetic fields from the Sun, seen as the ring-shape here. It is the first near-solar image of such magnetic clouds ever recorded, and it provides evidence for what had only been theory until now.

The Living With A Star (LWS) program targets specific aspects of the Sun-Earth system that affect life and society. LWS provides a predictive understanding of the Sun-Earth system, linkages among the interconnected systems, and, specifically, space weather conditions at Earth and the interplanetary medium. Measurements and research from LWS missions may contribute to advances in operational space weather forecasting that help prevent damage to spacecraft, communications and navigation systems, and power grids. LWS products improve our understanding of ionizing radiation, which has human health implications on the ISS and high-altitude aircraft flight, as well as operations of future space exploration with and without human presence. LWS products improve the characterization of solar radiation for global climate change, surface warming, and ozone depletion and recovery.

For more information, go to http://science.nasa.gov/about-us/smd-programs/living-with-a-star/

EXPLANATION OF MAJOR CHANGES IN FY 2021

This budget increases funding to LWS Futures to commence initial studies and activities for the Geospace Dynamics Constellation (GDC), the next Decadal Survey priority for LWS following the launch of Solar Orbiter Collaboration mission. The Van Allen Probes mission surpassed its original expected life span but both spacecraft exhausted their propellant and were decommissioned at the end of 2019.

SOLAR ORBITER COLLABORATION

Formulation	Development	Operations

FY 2021 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	BTC	Total
Formulation	41.5	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	41.5
Development/Implementation	244.8	27.1	7.8	**0.0**	0.0	0.0	0.0	0.0	0.0	279.8
Operations/Close-out	0.0	0.0	5.0	**8.1**	8.2	8.1	8.2	8.2	19.4	65.3
2020 MPAR LCC Estimate	**286.3**	**27.1**	**12.8**	**8.1**	**8.2**	**8.1**	**8.2**	**8.2**	**19.4**	**386.6**
Total Budget	**286.3**	**27.1**	**12.8**	**8.1**	**8.2**	**8.1**	**8.2**	**8.2**	**19.4**	**386.6**
Change from FY 2020				**-4.7**						
Percentage change from FY 2020				**-36.7%**						

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The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

This ESA-led mission, depicted here, will improve the understanding of how the Sun determines the environment of the inner solar system and how fundamental plasma physical processes operate near the Sun.

PROJECT PURPOSE

The NASA and European Space Agency (ESA) Solar Orbiter Collaboration (SOC) mission will provide measurements that will give NASA better insight on the evolution of sunspots, active regions, coronal holes, and other solar features and phenomena. The instruments will explore the near-Sun environment to improve our understanding of the origins of the solar wind streams and the heliospheric magnetic field; the sources, acceleration mechanisms, and transport processes of solar energetic particles; and the evolution of CMEs in the inner heliosphere. To achieve these objectives, SOC will make in-situ measurements of the solar wind plasma, fields, waves, and energetic particles. SOC will also make imaging/spectroscopic observations. SOC will provide close-up views of the Sun’s polar-regions and far side. SOC will adjust its orbit to the direction of the Sun’s rotation to allow the spacecraft to observe one specific area for much

SOLAR ORBITER COLLABORATION

Formulation	Development	Operations

longer than is currently possible.

ESA provides the spacecraft and operations; the ESA member states provide the majority of the instruments; and NASA provides the launch vehicle and two science investigations/instruments: the Solar Orbiter Heliospheric Imager (SoloHI) and the Heavy Ion Sensor (HIS). In return for its contributions, NASA will have access to the entire science mission data set.

For more information, go to https://science.nasa.gov/missions/solar-orbiter

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

PROJECT PARAMETERS

A NASA launch vehicle will place the ESA SOC spacecraft into an inner heliospheric orbit around the Sun, with its closest approach ranging from 0.23 to 0.38 Astronomical Unit (AU) and the farthest distance from 0.73 to 0.88 AU. In the first phase of mission operations, SOC will orbit around the Sun's equator at about the same rate as the Sun's rotation. In the second phase, it will perform a Venus gravity-assist maneuver between each rotation around the Sun. Each gravity assist maneuver will increase the SOC's inclination with respect to the Sun's equator so that the inclination will reach 27.5 degrees by the end of prime mission operations. This inclination will enable the instruments to image the polar regions of the Sun clearly for the first time and make key measurements that will advance our understanding of the solar dynamo and the polarity reversal of the global magnetic field. The inclination will increase to 34 degrees by the end of a possible three-year extended mission, allowing better insight into the polar-regions.

ACHIEVEMENTS IN FY 2019

The integrated spacecraft completed environmental testing at the IABG site in Germany. The team completely assembled the spacecraft and prepared it for shipment to Kennedy Space Center.

WORK IN PROGRESS IN FY 2020

NASA, ESA, and the instrument teams will continue preparations for the anticipated February 2020 launch and the subsequent start of data collection. In November 2019, the project successfully completed the Solar Orbiter final pre-ship review and completed shipment to Kennedy Space Center. The planned launch is February 2020.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

Solar Orbiter will be in the operational phase collecting science data.

SOLAR ORBITER COLLABORATION

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2021 PB Request
Key Decision Point-C (KDP-C)	Mar 2013	Mar 2013
SoloHI Instrument Critical Design Review (CDR)	Jun 2013	Oct 2013
HIS Instrument CDR	Feb 2014	Mar 2014
Pre-ship review	Jan 2015	Mar 2017
Launch	Oct 2018	Feb 2020
Begin Phase E	Oct 2018	May 2020
End of Prime Mission	Nov 2026	Mar 2028

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2014	376.9	N/A	2020	279.8	-25.8%	LRD	Oct 2018	Feb 2020	+16

Note: The confidence level (CL) estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

SOLAR ORBITER COLLABORATION

Formulation	Development	Operations

Development Cost Details

NASA confirmed SOC to proceed into implementation phase in March 2013.

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**376.9**	**279.8**	**-97.1**
Aircraft/Spacecraft	0.0	0.0	0.0
Payloads	23.7	70.0	+46.3
Systems I&T	0.0	0.0	0.0
Launch Vehicle	250.0	188.4	-61.6
Ground Systems	0.0	0.0	0.0
Science/Technology	1.3	2.9	+1.6
Other Direct Project Costs	101.9	18.5	-83.4

Project Management & Commitments

Goddard Space Flight Center (GSFC) has program management responsibility for the Living With a Star program and the SOC project. NASA procured all instruments provided by the United States through a competitive AO.

Element	Description	Provider Details	Change from Baseline
SoloHI	Measures the solar wind formations, shock disturbance, and turbulence	Provider: Naval Research Lab Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
HIS	Measures the range of heavy ion energies, charge states, masses, and elevation angles as part of the United Kingdom-provided Solar Wind Analyzer instrument suite	Provider: SwRI Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

SOLAR ORBITER COLLABORATION

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Expendable Launch Vehicle	Launch vehicle	Provider: ULA Lead Center: KSC Performing Center(s): KSC Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: The current launch using our launchpad is delayed, Then: NASA launch vehicle and development costs will increase.	Monitor Orbital Flight Test's progress and investigate additional launch date opportunities.

Acquisition Strategy

NASA selected the instruments and science investigations from a competed AO. NASA competitively selected the launch vehicle through the NASA Launch Services-II contract.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
SoloHI	Naval Research Lab	Washington, DC
HIS	SwRI	San Antonio, TX

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board (SRB)	Nov 2012	Preliminary Design Review (PDR) to assess readiness for KDP-C	Successful, project ready to proceed to development	Sept 2013

SOLAR ORBITER COLLABORATION

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Sept 2013	SoloHI Instrument to assess readiness for CDR	Successful	Mar 2014
Performance	SRB	Mar 2014	HIS Instrument to assess readiness for CDR	Successful	Mar 2017
Performance	SRB	Mar 2017	Pre-ship Review to assess readiness for shipment to ESA	Successful	Oct 2019
Performance	ESA-chaired SRB-observer	Oct 2019	Operations Readiness Review/Qualification Acceptance Review (ESA term) Mission Readiness Review to assess readiness for KDP-E	Successful	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
LWS Space Environment Testbeds	0.7	--	**0.0**	0.0	0.0	0.0	0.0
LWS Science	29.0	--	**30.3**	30.3	30.3	30.3	30.3
LWS Program Management and Future Missions	12.1	--	**41.8**	49.0	160.7	139.8	147.5
Van Allen Probes (RBSP)	14.3	--	**0.0**	0.0	0.0	0.0	0.0
Solar Dynamics Observatory (SDO)	12.0	--	**12.0**	12.0	12.3	12.3	12.3
Parker Solar Probe	20.0	--	**21.0**	20.4	20.3	20.3	20.4
Space Weather Science and Applications	20.0	--	**14.6**	14.6	14.6	14.6	14.6
Total Budget	**108.2**	--	**119.7**	**126.3**	**238.2**	**217.3**	**225.0**

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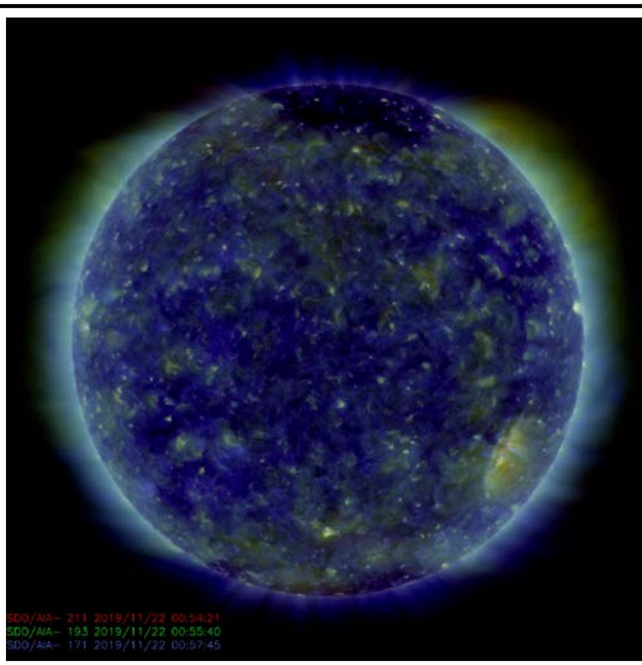

The Solar Dynamics Observatory (SDO) continues to monitor and image solar activity throughout the sun's 11-year solar cycle. This composite image of several wavelengths, taken November 22, 2019, shows an example of activity in the quiet stage of the sun as it nears the low-point in the solar cycle.

LWS Other Missions and Data Analysis budget includes operating LWS missions, a science research program, program management, and funding for missions to launch in the next decade.

For more information, go to: http://science.nasa.gov/about-us/smd-programs/living-with-a-star/

Mission Planning and Other Projects

SPACE WEATHER SCIENCE AND APPLICATIONS

The Space Weather Science and Applications project works to support the effective transition of heliophysics science results to applications that enhance the user communities' ability to address impacts caused by the dynamic space environment. This activity supports interagency space weather efforts and is consistent with the

OTHER MISSIONS AND DATA ANALYSIS

recommendations of the National Academy 2013 Decadal Survey for Solar and Space Physics and the White House Office of Science and Technology Policy (OSTP) 2019 National Space Weather Strategy and Action Plan. NASA plans to competitively fund ideas and products, leverage existing agency capabilities, collaborate with other agencies, and partner with user communities.

Recent Achievements

NASA established Space Weather Science and Applications in collaboration with sister federal agencies, academia, and industry. Recent achievements include the award of grants that target research efforts to advance science priorities identified by our operational agency partners, investments in high end computing, the Community Coordinated Modeling Center, and the development of an interagency framework with NOAA to transition research results and observation techniques to improved forecast capabilities.

LWS SCIENCE

Understanding space weather and improving the capability to address problems, such as predicting geomagnetic storms, pose two major challenges for the research community. First, research must couple traditionally separate disciplines in heliophysics, such as solar-heliospheric and geospace physics. Second, to be truly successful, research must also demonstrate how results would enhance an operational capability, such as the generation of forecasts for geomagnetic storms.

LWS Science addresses these challenges through three main approaches:

- Builds expertise: This component includes funding to train the next generation of heliophysics experts, conduct a heliophysics graduate-level summer school, develop graduate course content, and support a limited number of space weather postdoctoral positions at universities and government laboratories.

- Addresses scientific needs: The goal of the project is to develop the scientific understanding needed for the United States to address those aspects of heliophysics that may affect life and society. The targeted research element solicits large-scale problems that cross discipline and technique boundaries.

- Addresses strategic capabilities: A primary goal of this project is the development of first-principles-based models for the coupled Sun-Earth and Sun-solar system, similar to the first-principles models for the lower terrestrial atmosphere. Such models can act as tools for science investigations, as prototypes and test beds for prediction and specification capabilities, as frameworks for linking disparate data sets at vantage points throughout the Sun-solar system, and as strategic planning aids for enabling exploration of space and testing new mission concepts.

Recent Achievements

Recent studies progressed and explored notably in four of the LWS-focused Science Topics research areas: 1) understanding the onset of major solar eruptions, 2) a systems approach to energetic particle acceleration and transport on the sun and in the heliosphere, 3) ion circulation and effects on the magnetosphere and magnetosphere-ionosphere coupling, and 4) understanding physical processes in the magnetosphere-ionosphere/thermosphere/mesosphere system during extreme events.

OTHER MISSIONS AND DATA ANALYSIS

The long-term goal of understanding the onset of major solar eruptions is the ability to quantitatively describe - and ultimately predict - the occurrence of major solar eruptions and how they will influence Earth's environment. This topic considers nearly all aspects of the LWS program, such as how Solar Energetic Particle (SEP) events generated by flares and Coronal Mass Ejections (CMEs) increase radiation hazards throughout the solar system and adversely impact our space- and ground-based assets. The current aim of this active research is to build on previous LWS research and combine insights from theory, modeling, and observations to improve probabilistic forecasts of major solar eruptions required by the user community.

Additional recent studies are working toward a systems approach to energetic particle acceleration and transport on the Sun and in the heliosphere. The radiation environment in the upper atmosphere here on Earth can change rapidly with different amounts of arriving galactic cosmic rays and solar energetic particles (SEP). Changes in the solar wind due to high-speed streams, coronal mass ejections (CME), and periods of southward interplanetary magnetic field (IMF) are all also able to affect this environment. The timescale for each of these elements is different, creating complex interactions between the eleven-year solar cycle and, for example, the galactic cosmic rays background that varies by day, or the SEP environment that can vary by seconds to minutes. Together, the effect of these phenomena on the Earth’s magnetosphere–ionosphere–thermosphere system create the weather of the radiation environment. Recent observations and modeling developments have permitted substantial progress in understanding the radiation environment, but the variability and complexity of these interactions require better measurement; this research pursues and supports this systems approach as part of a long-term community research goal.

Ion circulation and effects on the magnetosphere and magnetosphere-ionosphere coupling focuses on gaining accurate knowledge and understanding of the magnetospheric composition, which is critical for understanding the space environment. Heavy ions, including positively charged oxygen, transfer from the ionosphere to the magnetosphere during storms, and their composition ultimately plays an important role in understanding geomagnetic variability and the radiation environment. Current research focuses on how and when ions, and in particular oxygen, are supplied from the ionosphere to the magnetosphere and where they become available for energization. Newly available data from the Van Allen Probes and MMS satellites as well as older datasets such as Cluster and the Defense Meteorological Satellite Program provide important input to this ongoing research.

Finally, Understanding physical processes in the magnetosphere--ionosphere / thermosphere / mesosphere system during extreme events examines superstorms: unusually strong geomagnetic storms where the geomagnetic activity index drops to low levels. Understanding the effects of superstorms and the strongest space weather events is a key component of the National Space Weather Action Plan, in part to develop mitigation strategies for scenarios for navigation, communication, and spacecraft. Coupling processes for extreme events may be very different from typical conditions and standard models. This research focuses on investigations of key physical processes needed to extend modeling capabilities to the conditions that occur during extreme events.

LWS PROGRAM MANAGEMENT AND FUTURE MISSIONS

Program Management and Future Missions provide the resources required to manage the planning, formulation, and implementation of all LWS missions. The office resolves technical and programmatic issues and risks, monitors and reports on progress, and is responsible for achieving overall LWS cost and

OTHER MISSIONS AND DATA ANALYSIS

schedule goals. In addition, Future Missions support strategic planning for addressing the LWS recommendations of the Heliophysics Decadal Survey and the pre-formulation activities for missions that are still merely concepts.

Recent Achievements

The next LWS mission identified by the Heliophysics Decadal Survey is the Geospace Dynamics Constellation (GDC). The primary objective of GDC is to "characterize and understand how the ionosphere-thermosphere behaves as a system, responding to, and regulating, solar wind/magnetospheric energy input." This mission will provide crucial understanding of the processes that govern the interactions between the solar wind that continually streams from the Sun and the Earth's upper atmosphere. These interactions affect the conditions and variability of the upper atmosphere that, in turn, impact the properties of a broad range of phenomena that range from natural geomagnetic events to the ionospheric effects on communication and navigation.

NASA is continuing to support this upcoming opportunity. During FY 2018, NASA convened the GDC Science and Technology Definition Team (STDT) to update and refine the mission science objectives from the Heliophysics Decadal Survey. The STDT submitted its final report to the Heliophysics Advisory Committee in October 2019. The Heliophysics Advisory Committee endorsed the science in the report and delivered it to NASA with a recommendation to continue mission pre-formulation. NASA has formed a pre-project office to determine technically feasible, cost-effective implementations of the STDT-recommended science investigation.

For more information, go to:

https://science.nasa.gov/about-us/science-strategy/decadal-surveys

https://science.nasa.gov/heliophysics/resources/stdts/geospace-dynamics-constellation

Operating Missions

LWS SPACE ENVIRONMENT TESTBEDS

The Space Environment Testbeds (SET) project seeks to improve the accommodation and/or mitigation of the effects of solar variability on spacecraft by studying how to protect satellites in space. It addresses the identification and understanding of the mechanisms of space environment interactions, modeling of these interactions, and development and validation of ground test protocols to qualify technologies for space. The mission characterizes the harsh space environment near Earth and how it affects spacecraft and their instruments. This information can be used to improve spacecraft design, engineering, and operations in order to protect spacecraft from harmful radiation driven by the Sun. As the complexity of the technologies increases, models derived from the physics-based understanding of the effects are required, and the SET mission responds to these needs.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

SET launched on June 25, 2019 as a rideshare payload on the U.S. Air Force Research Laboratory's Demonstration and Space Experiments spacecraft and is currently operating in medium-Earth orbit.

PARKER SOLAR PROBE

Parker Solar Probe, launched in 2018, is on target to unlock the mysteries of the Sun's atmosphere. Parker Solar Probe will fly through the solar corona 24 times, gradually lowering its orbit closer to the Sun using Venus' gravity during seven flybys over its seven-year mission. After the seventh Venus flyby, the spacecraft will fly though the Sun's atmosphere as close as 3.8 million miles to our star's surface - well within the orbit of Mercury and more than seven times closer than any spacecraft has come before (Earth's average distance to the Sun is 93 million miles).

Flying into the outermost part of the Sun's atmosphere, the corona, for the first time, Parker Solar Probe will employ a combination of in situ measurements and imaging to revolutionize our understanding of the corona and expand our knowledge of the origin and evolution of the solar wind. It will also make critical contributions to our ability to forecast changes in Earth's space environment that affect life and technology on Earth.

Recent Achievements

On April 4, 2019, and September 1, 2019, Parker Solar Probe successfully completed its second and third of 24 approaches to the Sun, at 16 percent of the distance of the Earth from the Sun. Each approach pass sets a successive new record for all-time speed and close-solar-approach distance. The public release of science data from the first two orbits occurred on November 12, 2019. Twenty-one additional solar approaches are planned, with the last three bringing the probe to as close as approximately four percent of the Earth's distance from the Sun in 2024.

VAN ALLEN PROBES

The Van Allen Probes mission, launched in 2012, is helping scientists to understand the Sun's influence on Earth and near-Earth space by studying Earth's radiation belts on various scales of space and time. The mission observes the processes that energize and transport radiation belt electrons and ions in Earth's inner magnetosphere, the area in and around Earth's radiation belts. These observations are providing new knowledge on the dynamics and extremes of the radiation belts that are important to all technological systems that fly in and through geospace. The mission will enable an understanding, ideally to the point of predictability, of how populations of relativistic electrons and penetrating ions in space form or change in response to variable inputs of energy from the Sun.

Recent Achievements

After seven years of operations, and upon finally running out of propellant, the second of the twin Van Allen Probes spacecraft was retired on October 18, 2019. On this date, operators at the Johns Hopkins University Applied Physics Lab in Laurel, Maryland, shutdown Spacecraft A of the Van Allen Probes mission. The command follows one three months earlier that terminated operations for spacecraft B, the second spacecraft of the mission. Now both spacecraft will spiral silently into the Earth's atmosphere over the next 15 years, eventually burning up safely in orbit. Originally designed to survive at least two years, the spacecraft repeatedly flew through the hazardous Van Allen radiation belts — rings of charged particles trapped by Earth's magnetic field. Their long lifetime means that scientists will be able to determine how the belts gain and lose particles over the course of most of the 11-year solar cycle. The spacecraft made major discoveries that revolutionized how we understand our near-Earth environment. The results of these discoveries will help us improve spacecraft design. Scientists used Van Allen Probe observations as the subject of over 640 publications to date in the refereed literature. Authors not directly funded by Van Allen Probes led more than 50 percent of publications.

SOLAR DYNAMICS OBSERVATORY (SDO)

Launched on February 11, 2010, the SDO seeks to understand the Sun's influence on Earth and near-Earth space by simultaneously studying the solar atmosphere on small scales of space and time and in many wavelengths. The observatory enables scientists to determine how the Sun's magnetic field is generated and structured and how stored magnetic energy is converted and released in the form of solar wind, energetic particles, and variations in the solar irradiance. SDO collects data to help explain the creation of solar activity, which drives space weather. Measurements of the interior of the Sun, the Sun's magnetic field, the hot plasma of the solar corona, and the irradiance that creates Earth's ionosphere are the primary data products.

Recent Achievements

The SDO project made large strides using machine learning to enhance our scientific goals of understanding the Sun and solar activity. In collaboration with the Frontier Development Lab, the SDO team devised a deep neural network to translate narrowband ultraviolet (UV) and extreme UV (EUV) images from the Atmospheric Imaging Assembly (AIA) into the EUV spectral irradiance measurements taken by the EUV variability experiment. These EUV spectral irradiances heat and expand the outer atmosphere, while also creating the ionosphere of the Earth. When their levels are high, the drag force on satellites orbiting the Earth is increased and the ionosphere is denser, which more strongly affects radio communication and navigation. The neural network was able to use the AIA images to generate the irradiance levels even at wavelengths that AIA does not directly measure. Therefore, when necessary, we can model and predict measurements of the Sun made at other planets or the EUV irradiances at another planet. This would allow spacecraft to more accurately plan their orbits around those planets. Investigators published this research in Science Advances on October 2, 2019.

SOLAR TERRESTRIAL PROBES

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Other Missions and Data Analysis	180.5	--	**126.3**	262.2	202.6	195.6	115.5
Total Budget	**180.5**	**--**	**126.3**	**262.2**	**202.6**	**195.6**	**115.5**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

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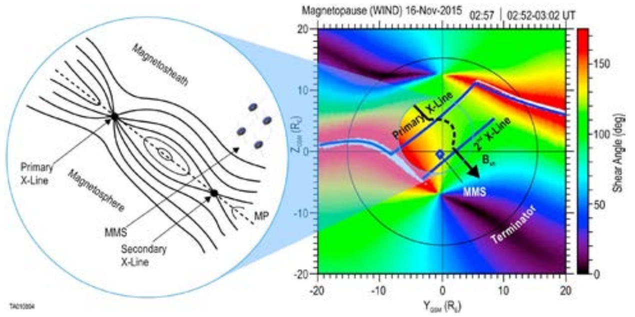


Magnetic reconnection at the Earth's magnetopause drives the interaction between the solar wind and Earth. Previously, scientists believed that this reconnection occurred along one single long reconnection "X" line across the magnetopause, like a "crack" across the front of Earth's protective shield that allowed solar wind plasma to enter. However, the MMS mission has revealed that there are multiple such large-scale reconnection lines at the magnetopause. These X lines are fairly stationary, with both a primary X line and at least one secondary X line. The right image above is a false-color image of the magnetopause and illustrates these multiple reconnection lines as observed on November 16, 2015. The left panel shows a schematic of the reconnecting magnetic field relative to the MMS 4-spacecraft formation (seen approximately to scale).

The Solar Terrestrial Probes (STP) program focuses on understanding the fundamental physical processes of the space environment, from the Sun to the Earth, other planets, and beyond to the interstellar medium. STP provides insight into the basic processes of plasmas (fluids of charged particles) inherent in all astrophysical systems. STP missions focus on processes such as the variability of the Sun, responses of the planets to those variations, and the interaction of the Sun and the solar system. NASA defines specific goals for STP missions and selects investigations for each mission competitively. These missions allow the science community an opportunity to address important research focus areas and make significant progress in understanding fundamental physics.

For more information, go to https://science.nasa.gov/heliophysics/programs/solar-terrestrial-probes

EXPLANATION OF MAJOR CHANGES IN FY 2021

The budget for IMAP is decreased without impact. Additional FY 2019 funds were provided in the FY 2019 Initial Operating Plan for IMAP. To take advantage of the novel rideshare opportunity that

SOLAR TERRESTRIAL PROBES

IMAP is offering, NASA plans to purchase the IMAP launch vehicle in the summer of 2020. This purchase will use FY 2019 funds, thus reducing the requirements for FY 2021 funds. Purchasing the launch vehicle earlier in the lifecycle of the mission allows all spacecraft flying on the rideshare to better coordinate and understand their requirements, reducing potential cost and logistics risks.

ACHIEVEMENTS IN FY 2019

NASA selected two science Missions of Opportunity (MO) (SIHLA and GLIDE) and two technology demonstration MOs (SETH and Solar Cruiser) to complete Phase A concept studies.

WORK IN PROGRESS IN FY 2020

Operations of the MMS, STEREO, Hinode, and TIMED missions continue. The science and technology demonstration MOs will deliver their concept studies to NASA for evaluation and NASA will make both science and technology demonstration MO selections. Both selected MOs will rideshare with the Interstellar Mapping and Acceleration Probe (IMAP) mission to about one million miles (1.5 million kilometers) away from Earth towards the Sun at the first Lagrange point (L1).

KEY ACHIEVEMENTS PLANNED FOR FY 2021

IMAP plans to pass its Key Decision Point-C (KDP-C) review and enter its final design and fabrication phase. The science and technology demonstration MOs will continue their preliminary design and technology completion efforts.

Program Schedule

Date	Significant Event
FY 2019	Selection of science and technology demonstration mission of opportunities to prepare concept studies
FY 2020	Down-selection of science and technology demonstration mission of opportunities
FY 2021	Announcement of opportunity for next mission (STP-6)

Program Management

GSFC manages the STP program.

Acquisition Strategy

In the acquisition of STP scientific instruments, spacecraft, and science investigations (including Research and Analysis), NASA will use full and open competitions to the greatest extent possible. NASA may acquire certain instruments, missions, or mission systems without competition (e.g., through international partnerships or in-house builds) if there is a clear scientific, technological, or programmatic benefit to NASA to do so. NASA will acquire launch vehicles through existing contracts, managed by the Human Exploration and Operations Mission Directorate (HEOMD), except when an international partner provides them under an approved agreement.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Program Independent Review	SRB	Feb 2019	Assess performance of program	Successful	Nov 2023
Program Independent Review	SRB	Nov 2023	Assess performance of program	TBD	

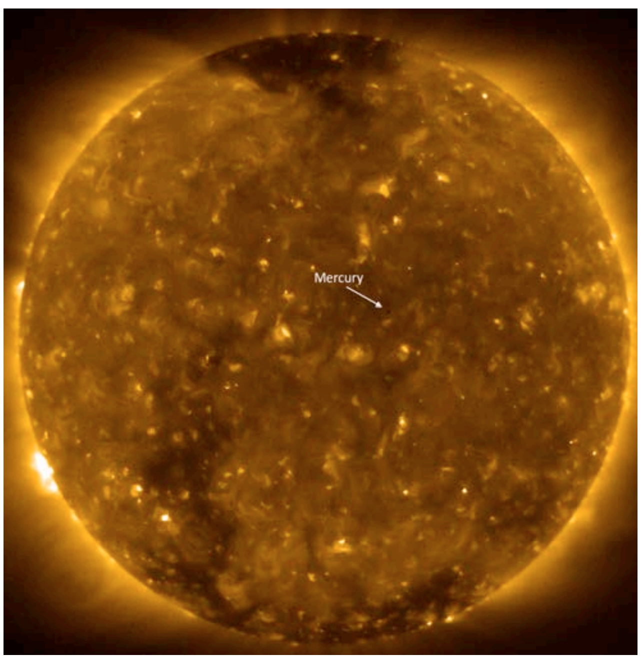
OTHER MISSIONS AND DATA ANALYSIS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
IMAP	126.8	--	**72.6**	185.7	107.0	100.0	66.8
STP Program Management and Future Missions	9.8	--	**17.6**	42.3	62.8	62.8	16.0
Magnetospheric Multiscale (MMS)	26.0	--	**18.7**	16.8	15.8	15.8	15.8
Solar Terrestrial Relations Observatory (STEREO)	8.3	--	**7.8**	7.8	7.8	7.8	7.8
Hinode (Solar B)	7.0	--	**7.0**	7.0	6.5	6.5	6.5
TIMED	2.7	--	**2.6**	2.6	2.6	2.6	2.7
Total Budget	**180.5**	**--**	**126.3**	**262.2**	**202.6**	**195.6**	**115.5**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.



The x-ray telescope on Hinode captured the transit of Mercury as it passed between Earth and the Sun, shown here, on November 11, 2019. Researchers can use transits like this one to measure the distance between Earth and the Sun.

The Solar Terrestrial Probes (STP) Other Missions and Data Analysis budget includes operating STP missions, program management, and funding for future missions launching in the next decade.

For more information, go to: http://stp.gsfc.nasa.gov

Mission Planning and Other Projects

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

The Interstellar Mapping and Acceleration Probe (IMAP) mission will help researchers better understand the boundary of the heliosphere, a magnetic bubble surrounding and protecting our solar system. This region is where the constant flow of particles from our Sun, called the solar wind, collides with material from the rest of the galaxy. This collision limits the amount of harmful cosmic radiation entering the heliosphere. IMAP will collect and analyze particles that make it through to the heliosphere.

Another objective of the mission is to learn more about the generation of cosmic rays in the heliosphere. Cosmic rays created locally and from the galaxy and beyond affect human explorers in space and can harm technological systems, and likely play a role in the presence of life itself in the universe.

The spacecraft will operate about 1 million miles (1.5 million kilometers) away from Earth towards the Sun at the first Lagrange point (L1). This location will allow the probe to maximize use of its instruments to monitor the interactions between solar wind and the interstellar medium in the outer solar system.

For more information, go to: https://www.nasa.gov/press-release/nasa-selects-mission-to-study-solar-wind-boundary-of-outer-solar-system

Recent Achievements

The IMAP project has been working in Phase A on its concept study for the duration of FY 2019, achieving goals to allow it to enter Phase B. In addition to establishing baseline mission requirements, the project developed the mission design, architecture for each element, and concept of operations. The team developed and documented the design architecture for the spacecraft, instruments, and ground system.

PROGRAM MANAGEMENT AND FUTURE MISSIONS

Program Management and Future Missions provide the resources required to manage the planning, formulation, and implementation of all STP missions. The program office ensures successful achievement of STP program cost and schedule goals, while managing cross-project dependencies, risks, issues, and requirements as projects progress through formal key decision points. In addition, Future Missions supports the STP program strategic planning for addressing the recommendations of the Heliophysics Decadal Survey and the pre-formulation activities for STP missions not yet approved as projects.

Operating Missions

MAGNETOSPHERIC MULTISCALE (MMS)

The MMS mission, launched in 2015, investigates how the magnetic fields of the Sun and Earth connect and disconnect, explosively transferring energy from one to the other. This magnetic reconnection process occurs throughout the universe. MMS uses Earth's magnetosphere as a natural laboratory to study the microphysics of magnetic reconnection, a fundamental plasma-physical process that converts magnetic energy into heat and charged particle kinetic energy. In addition to seeking to solve the mystery of the small-scale physics of the reconnection process, MMS investigates how the energy conversion that occurs in magnetic reconnection accelerates particles to high energies and what role plasma turbulence plays in reconnection events. Magnetic reconnection, particle acceleration, and turbulence occur in all astrophysical plasma systems. Researchers can only study them in-situ in the solar system, and most efficiently in Earth's magnetosphere, where these processes control the dynamics of the geospace environment and play an important role in the phenomena known as space weather. MMS helps us understand reconnection elsewhere as well, such as the atmosphere of the Sun and other stars, near black holes and neutron stars, and at the boundary between our solar system's heliosphere and interstellar space, where it is more difficult to study.

The MMS mission consists of four identically instrumented spacecraft that measure particles, fields, and plasmas. The MMS instrument payload measures electric and magnetic fields and the plasmas found in the regions where magnetic reconnection occurs. Fast, multi-point measurements are enabling dramatically revealing direct observations of these physical processes. A highly elliptical orbit explores how Sun-Earth magnetic fields reconnect in Earth’s neighborhood. The four spacecraft fly in a tetrahedron formation that allows them to observe the three-dimensional structure of magnetic reconnection events. The separation between the observatories is adjustable over a range of 6 to 250 miles during science operations in the area of interest.

For more information, go to http://nasa.gov/mms

Recent Achievements

Since its launch in 2015, MMS has been revealing, for the first time, the small-scale structure and dynamics of key reconnection regions by passing directly through them. On the Sun-facing side of Earth, reconnection can link the Sun's magnetic field lines to Earth's, allowing material and energy from the Sun to funnel into Earth's magnetic environment. On the night side of Earth, researchers believe reconnection helps trigger auroras. By observing magnetic reconnection in action, MMS a key component of space weather, which affects modern technological systems such as communications networks, GPS navigation, and electrical power grids.

MMS also examines the microphysics of energetic particle acceleration and turbulence. These processes occur universally in plasmas, the electrically-conducting material made of positively and negatively charged particles, that account for an estimated 99 percent of the observable universe. Operating in a highly elliptical orbit around Earth, the MMS satellites set the Guinness World Record for highest altitude fix of a GPS signal at 43,500 miles above the surface. When the satellites are closest to Earth, they move at up to 22,000 miles per hour, making them the fastest known operational use of a GPS receiver.

In spring 2019, MMS altered its orbit to provide observations of a new part of near-Earth space. For three weeks, MMS studied the solar wind, the stream of supersonic charged particles flung around the solar system by the Sun, to better understand turbulence in plasmas, the heated, electrified gases that make up 99 percent of ordinary matter in the universe. Turbulence is the chaotic motion of a fluid. It shows up in daily life everywhere from eddies in a river to smoke from a chimney, but it is incredibly hard to study because it’s so unpredictable and it remains one of the least well understood disciplines in all of physics. The mini-campaign provided scientists with an up close and in-situ view to push the frontiers of the field.

SOLAR TERRESTRIAL RELATIONS OBSERVATORY (STEREO)

STEREO, launched in 2006, enables studies of the origin of the Sun’s coronal mass ejections (CME) and their consequences for Earth, other planets, and interplanetary space. The mission launched with two spacecraft, one Ahead of Earth (STEREO-A) and the other Behind Earth (STEREO-B) in its orbit. STEREO’s instrumentation targets the fundamental process of energetic particle acceleration in the low solar corona and in interplanetary space. The mission can image the structure and evolution of solar storms as they leave the Sun and move through space toward Earth. The mission also provides the foundation for understanding space weather events and developing predictive models. The models, in turn, help to identify and mitigate the risks associated with space weather events. In addition, STEREO improves our space weather situational awareness not only for Earth and in low Earth orbit, but also throughout the solar system.

On October 1, 2014, NASA lost communication with STEREO-B, just as the spacecraft was about to orbit around the other side of the Sun. In late 2015, the spacecraft orbit finally carried it out from behind the Sun and NASA was able to re-establish contact with STEREO-B for a short period in 2016. NASA attempted to establish control of the spacecraft with limited success. Beginning in December 2017, the project team made monthly attempts to re-establish contact with the spacecraft, until October 2018, when attempts ceased. STEREO-A continues to operate nominally and is still providing significant science data.

For more information, go to: https://stereo.gsfc.nasa.gov/

Recent Achievements

With over ten years in space, the STEREO mission continues to provide new observations about the Sun and its effects on space weather near Earth. Working in concert with other NASA missions, STEREO is a key sensor in tracking how events propagate through the solar system.

Combined with data from the ESA/NASA Solar and Heliospheric Observatory (SOHO) as well as computer models, scientists using STEREO data collected in 2016 were able to determine how "stealth CMEs" form. CMEs often come with a warning: the bright flash of a flare, a burst of heat, or a flurry of solar energetic particles. Another kind of storm has been puzzling for its lack of typical warning signs. The research showed how these stealthy solar storms develop: a slow, quiet process can unexpectedly create a twisted mass of magnetic fields on the sun, which then pinches off and speeds out into space, all without any advance warning. To uncover the origins of stealth CMEs, scientists developed a model of the sun's magnetic fields, simulating their strength and movement in the sun's atmosphere. Central to the model was the sun's differential rotation, meaning different points on the sun rotate at different speeds. Unlike Earth, which rotates as a solid body, the sun rotates faster at the equator than it does at its poles.

The model showed differential rotation causes the sun's magnetic fields to stretch and spread at different rates. The scientists demonstrated this constant process generates enough energy to form stealth CMEs over the course of roughly two weeks. The sun's rotation increasingly stresses magnetic field lines over time, eventually warping them into a strained coil of energy. When enough tension builds, the coil expands and pinches off into a massive bubble of twisted magnetic fields, and without warning, the stealth CME quietly leaves the sun.

HINODE

Hinode, launched in 2006, is a joint JAXA and NASA mission. The mission consists of a coordinated set of optical, extreme ultraviolet, and X-ray instruments that are studying the basic heating mechanisms and dynamics of the active solar corona. Hinode explores the magnetic fields of the Sun to improve understanding of what powers the solar atmosphere and drives solar eruptions. By investigating the fundamental processes that connect the Sun's magnetic field and the solar corona, Hinode is discovering how the Sun generates magnetic disturbances and the high-energy particle storms that propagate from the Sun to Earth.

OTHER MISSIONS AND DATA ANALYSIS

Hinode's solar optical telescope is the first spaceborne instrument to measure the strength and direction of the Sun's magnetic field on the Sun's surface, the photosphere. Combined with two other Hinode instruments, the EUV imaging spectrometer and the X-ray/EUV telescope, the project designed the mission to understand the causes of eruptions in the solar atmosphere and relate those eruptions to the intense heating of the corona and the mechanisms that drive the constant outflow of solar radiation, the solar wind.

Recent Achievements

Researchers used observations from Hinode with observations from NASA's Solar Dynamics Observatory (SDO) to create a model of what triggers different types and sizes of solar eruptions, from long, tapered jets to massive explosions of solar material and energy. Because they erupt at such vastly different scales, scientists believed that different processes drove jets and the massive clouds called coronal mass ejections.

Hinode observations support a proposal that a universal mechanism can explain the whole spectrum of solar eruptions. High-resolution observations of filaments from Hinode and SDO motivated the above proposed study. Filaments are dark, serpentine structures suspended above the Sun's surface and consist of dense, cold solar material. Researchers had known that the onset of CME eruptions was associated with filaments, but improved observations have recently shown that jets have similar filament-like structures before eruption. The scientists call their proposed mechanism for how these filaments lead to eruptions the breakout model, for the way the stressed filament pushes relentlessly at, and ultimately breaks through, its magnetic restraints into space. The key for understanding a solar eruption is recognizing how the filament system loses equilibrium. The loss of equilibrium triggers eruption. In the breakout model, the culprit is magnetic reconnection, a process in which magnetic field lines come together and explosively realign into a new configuration.

In stable conditions, loops of magnetic field lines hold the filament down and suppress eruption. The filament naturally wants to expand outward, which stresses its magnetic surroundings over time and eventually initiates magnetic reconnection. The process explosively releases the energy stored in the filament, which breaks out from the Sun's surface and ejects into space.

The type of eruption depends on the initial strength and configuration of the magnetic field lines containing the filament. In a CME, field lines form closed loops, surrounding the filament, so a bubble-shaped cloud ultimately bursts from the Sun. In jets, nearby field lines stream freely from the surface into interplanetary space, so solar material from the filament flows out along those reconnected lines away from the Sun.

Understanding what sets off eruptions on the Sun is one of the keys to creating better models to predict such solar activity and its subsequent effects on radio communications, space technology, and astronauts before it happens.

THERMOSPHERE, IONOSPHERE, MESOSPHERE ENERGETICS AND DYNAMICS (TIMED)

The TIMED mission, launched in 2001, characterizes and studies the physics, dynamics, energetics, thermal structure, and composition of the least explored and understood region of Earth's atmosphere: the mesosphere, the lower thermosphere, and the ionosphere. This region, located between altitudes of approximately 35 to 100 miles above the surface of Earth, helps protect Earth from harmful solar radiation. It is a gateway between Earth's environment and space, where the Sun's energy first affects Earth's environment. Solar events, as well as temperature changes in the stratosphere, can perturb this region, but scientists do not understand the overall structure of and responses to these effects. Advances in remote sensing technology employed by TIMED enable us to explore this region on a global basis from space.

TIMED's 18 years of data provides scientists an unrivaled perspective on changes in the upper atmosphere. The long lifespan allows scientists to track the upper atmosphere's response to both quick-changing conditions, like individual solar storms, throughout the sun's 11-year activity cycle, as well as longer-term trends, such as those related to climate change. All of TIMED's instruments are still producing data, enabling continuing studies of the upper atmosphere.

Recent Achievements

Scientists used TIMED measurements to evaluate the presence of a trace chemical called nitric oxide in the upper atmosphere. Produced by the changing chemistry triggered by different types of space weather, such as solar flares and geomagnetic storms, nitric oxide can actually counteract some of the effects of space weather. When solar flares or geomagnetic storms transfer energy into Earth's atmosphere, some of that energy manifests as heat, and that heat causes the upper atmosphere to swell, as individual molecules fight for more room. This swelling can envelop spacecraft in space at higher altitudes than we would otherwise expect, leading to satellite drag, which disrupts their orbits and makes them more difficult to track.

A priori understanding of the upper atmosphere's response would have the most powerful eruptions from the sun ultimately creating the largest amount of swelling and, therefore, more powerful satellite drag. However, observations show nitric oxide counteracts that swelling. During some geomagnetic storms, the energy input triggers a chemical reaction that produces larger amounts of this nitric oxide. Nitric oxide acts as a cooling agent at very high altitudes, radiating energy to space, so a significant increase in this compound sometimes causes overcooling. Overcooling causes the atmosphere to shed energy quickly from the geomagnetic storm much quicker than anticipated. That quick energy loss counteracts the previous expansion, causing the upper atmosphere to collapse back down, sometimes to an even smaller state than it started in, leaving satellites to orbit through lower-density regions than anticipated. One of TIMED's instruments tracks the quantity of nitric oxide in the upper atmosphere. Researchers compared this TIMED data with data on geomagnetic storms to determine what types of coronal mass ejections, giant clouds of ejected solar material, lead to an overproduction of nitric oxide and rapid collapse of the upper atmosphere. Counterintuitively, the most energetic CMEs are likely to trigger the geomagnetic storms that provide a net cooling and shrinking effect on the upper atmosphere, rather than heating and expanding it as had been previously understood.

Researchers used TIMED observations to further astrobiology studies. Looking at views of Earth from TIMED can help researchers simulate how signatures of certain elements in the atmosphere, elements that could serve as smoking guns for life on the planet below, might appear when seen on exoplanets from afar. What we know about infrared radiation emitted by Earth's atmosphere, as seen by TIMED, helps us understand what kind of signals we might detect elsewhere. If we find exoplanet signals in nearly the same proportion as Earth's, it could be an indicator that that planet is a good candidate for hosting life.

OTHER MISSIONS AND DATA ANALYSIS

TIMED was instrumental in laying the groundwork for the realization that not only impacts from the Sun, but also terrestrial weather percolating upward, drive space weather near Earth. Those insights led to questions that new missions - GOLD, launched in 2018, and ICON, launched in 2019 - will answer to explore further the way terrestrial weather and space weather interact. Together the three missions are currently creating a multi-point view of this dynamic region where our atmosphere gives way to outer space.

HELIOPHYSICS EXPLORER PROGRAM

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Other Missions and Data Analysis	147.9	--	**148.4**	192.4	167.6	189.0	230.8
Total Budget	**147.9**	**--**	**148.4**	**192.4**	**167.6**	**189.0**	**230.8**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

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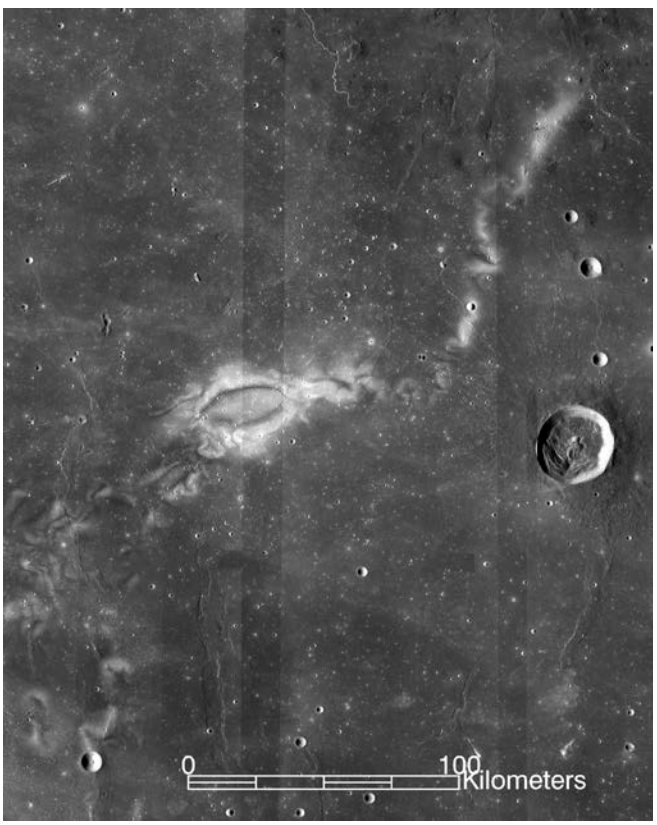

This image from the Lunar Reconnaissance Orbiter shows the Reiner Gamma lunar swirl on the moon. Data collected by THEMIS-ARTEMIS suggest that swirls such as this are a result of the solar wind interacting with isolated pockets of magnetic field found on the Moon. These pockets create small shields that deflect solar particles and concentrate them around the edges of the magnetic field, where the particles darken the regolith.

The Heliophysics Explorer Program provides frequent flight opportunities for world-class scientific investigations on focused and timely science topics. Explorers use a suite of smaller, fully competed missions that address these topics to complement the science of strategic missions of the LWS and STP programs. Competitive selections ensure accomplishment of the most current and best science.

The Explorers Program provides two classes, Medium Explorers (MIDEX) and Small Explorers (SMEX), of flight opportunities to accomplish the goals of the science program. These mission classes enable NASA to increase the number of flight opportunities in response to recommendations from the scientific community.

Explorers Missions of Opportunity (MO) are smaller investigations, typically an instrument, characterized as being part of a host space mission, sub-orbital flight, small complete mission, and new science investigation using existing spacecraft or ISS-attached payloads.

HELIOPHYSICS EXPLORER PROGRAM

Other Missions and Data Analysis supports numerous operating Heliophysics Explorer missions, as well as program management functions and funding for future mission selections.

For more information, go to https://explorers.gsfc.nasa.gov/

EXPLANATION OF MAJOR CHANGES IN FY 2021

None

ACHIEVEMENTS IN FY 2019

The program downselected for implementation one Mission of Opportunity (MO) in February 2019 and two SMEX missions in June 2019. The teams based their concept study reports on proposals originally submitted to the 2016 Heliophysics Explorers Program SMEX AO. The two SMEX missions are Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (TRACERS) and Polarimeter to Unify the Corona and Heliosphere (PUNCH).

For more information, go to: https://www.nasa.gov/press-release/nasa-selects-proposals-to-study-sun-space-environment

The one MO selection is Atmospheric Waves Experiment (AWE).

For more information, go to: https://www.nasa.gov/press-release/nasa-selects-mission-to-study-space-weather-from-space-station

NASA selected three MOs for competitive concept studies (Phase A) from proposals submitted to the 2018 Heliophysics Explorer Program MO AO. The three MOs are Extreme Ultraviolet High-Throughput Spectroscopic Telescope Epsilon Mission (EUVST); Aeronomy at Earth: Tools for Heliophysics Exploration and Research (AETHER), and Electrojet Zeeman Imaging Explorer (EZIE).

For more information, go to: https://www.nasa.gov/press-release/nasa-selects-proposals-to-advance-understanding-of-space-weather

The program released the 2019 Heliophysics Explorers Program MIDEX AO in July 2019 and received proposals in September 2019.

WORK IN PROGRESS IN FY 2020

NASA launched the ICON mission on October 10, 2019, and conducted the post-launch assessment review on December 16, 2019.

NASA will make initial concept study (Phase A) selections for the 2019 Heliophysics Explorer Program MIDEX. NASA will receive and review for down-selection the 2018 Heliophysics Explorer Program MO competitive concept studies (Phase B). PUNCH, TRACERS, and AWE will pass their Key Decision Point-C (KDP-C) reviews and enter into final design and fabrication activities phase. KDP-C is the agency-level approval for the project to begin implementation and baselines the project's official schedule and budget. The 2018 Heliophysics Explorer Program MO teams selected for Phase A concept studies will deliver their reports to NASA for evaluation.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

NASA will release the 2021 Heliophysics Explorer Program SMEX and MO Draft AO. The 2019 Heliophysics Explorer Program MIDEX missions selected for Phase A concept studies will deliver their reports to NASA for evaluation, and NASA will make new 2019 Heliophysics Explorer Program MIDEX mission selections. NASA will make new 2018 Heliophysics Explorer Program MO selections for Phase B.

Program Schedule

Date	Significant Event
FY 2019	Down select at two SMEX and one MO mission for implementation
FY 2019	Select Explorers MO opportunity for Phase A study
FY 2019	AO announcement for MIDEX opportunity to propose
FY 2020	MIDEX Phase -A selections
FY 2020	Final selection of one Explorers Science MO mission for implementation
FY 2021	Final selection of one MIDEX mission for implementation
FY 2021	AO announcement for SMEX and MO opportunity to propose
FY 2022	SMEX Phase -A selections
FY 2023	Down select at least one SMEX and one MO mission for implementation
FY 2024	AO announcement for MIDEX opportunity to propose
FY 2025	MIDEX Phase -A selections

Program Management & Planned Cadence

The Heliophysics and Astrophysics Explorer elements are both coordinated sets of uncoupled missions, wherein each mission is independent and has unique science, and share a common program office at GSFC and a common management structure. The Explorer program manager resides at GSFC, reporting functionally to the Center Director and programmatically through the Heliophysics and Astrophysics Division Directors to the Associate Administrator for SMD.

This budget brings the Heliophysics Explorer Program into alignment with the Decadal Survey's recommendation of a two-to-three-year mission cadence.

HELIOPHYSICS EXPLORER PROGRAM

Acquisition Strategy

NASA competitively selects new Explorer missions, releasing solicitations when available funding allows, with the expectation of a three-year cadence. NASA acquires launch vehicles through existing contracts held by the Human Exploration and Operations Mission Directorate (HEOMD), except when an international partner provides them under an approved agreement or when the Explorer mission is not a primary payload on the launch vehicle.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Program Independent Review	SRB	Dec 2019	Assess performance of program	Successful	Jan 2024

OTHER MISSIONS AND DATA ANALYSIS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Ionospheric Connection Explorer (ICON)	4.7	--	**3.3**	1.9	0.0	0.0	0.0
Global-scale Observations of the Limb and Disk (GOLD)	4.0	--	**4.0**	3.8	3.8	3.9	3.9
Heliophysics Explorer Future Missions	23.2	--	**23.8**	80.4	73.6	141.7	194.1
Heliophysics Explorer Program Management	19.2	--	**9.8**	9.7	10.3	8.0	7.3
Interface Region Imaging Spectogr (IRIS)	6.1	--	**6.5**	6.5	6.5	6.5	6.6
Interstellar Boundary Explorer (IBEX)	3.4	--	**3.4**	3.4	3.4	3.4	3.5
TWINS	0.4	--	**0.1**	0.0	0.0	0.0	0.0
Aeronomy of Ice in Mesophere (AIM)	3.0	--	**3.0**	3.0	3.0	3.0	3.1
THEMIS	4.5	--	**5.0**	5.0	5.0	4.8	4.8
Advanced Composition Explorer (ACE)	3.0	--	**3.0**	3.0	3.1	3.1	3.1
RHESSI	1.0	--	**0.2**	0.0	0.0	0.0	0.0
Polarimeter to Unify the Corona and Heliosphere (PUNCH)	32.6	--	**55.5**	53.1	47.6	6.8	1.5
Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (TRACERS)	32.0	--	**17.4**	15.7	7.7	4.8	1.5
Atmospheric Wave Experiment (AWE)	10.8	--	**13.4**	7.2	3.7	2.9	1.5
Total Budget	**147.9**	**--**	**148.4**	**192.4**	**167.6**	**189.0**	**230.8**

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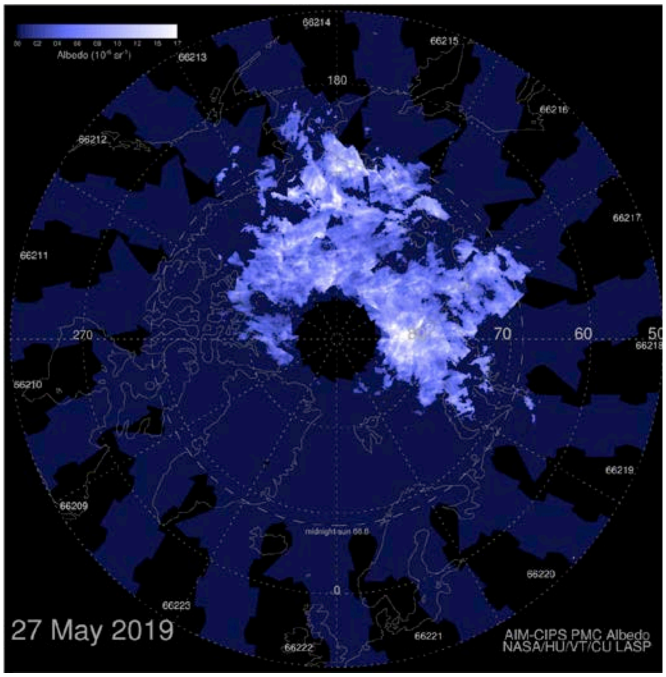
OTHER MISSIONS AND DATA ANALYSIS



Data from NASA's AIM spacecraft shows the sky over the Arctic glowing electric blue due to noctilucent, or night-shining, clouds, seeded by meteor smoke particles. AIM has improved our understanding of the global atmospheric structure and is now focusing on the role of gravity waves in atmospheric circulation.

The Heliophysics Explorer Other Missions and Data Analysis budget includes operating Explorer missions, program management, and funding for future missions not yet approved as projects.

For more information, go to https://explorers.gsfc.nasa.gov/

Mission Planning and Other Projects

POLARIMETER TO UNIFY THE CORONA AND THE HELIOSPHERE (PUNCH)

The Polarimeter to Unify the Corona and Heliosphere (PUNCH) mission will focus directly on the Sun's corona and how the corona generates the solar wind. Composed of four suitcase-size satellites, PUNCH will image and track the solar wind as it leaves the Sun. The spacecraft will also track coronal mass ejections—large eruptions of solar material that can drive large space weather events near Earth—to better understand their evolution and develop new techniques for predicting such eruptions. These observations will enhance national and international research by other NASA missions, such as Parker Solar Probe and the upcoming ESA/NASA Solar Orbiter, due to launch in 2020. PUNCH will be able to image, in real time, the structures in the solar atmosphere that these missions encounter by blocking out the bright light of the Sun and examining the much fainter atmosphere. Together, these missions will investigate how the star we live with drives radiation in space.

NASA selected PUNCH under the 2016 Small Explorers (SMEX) AO. PUNCH is in preliminary design and technology completion phase (Phase B) with an expected launch date of February 2023.

TANDEM RECONNECTION AND CUSP ELECTRODYNAMICS RECONNAISSANCE SATELLITES (TRACERS)

The Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (TRACERS) mission will observe particles and fields at the Earth's northern magnetic cusp region, the region encircling Earth's pole, where our planet's magnetic field lines curve down toward Earth. Here, the field lines guide particles from the boundary between Earth's magnetic field and interplanetary space down into the atmosphere.

OTHER MISSIONS AND DATA ANALYSIS

NASA is planning to launch TRACERS as a rideshare mission, launched as a secondary payload with PUNCH.

In the northern magnetic cusp area, with its easy access to our boundary with interplanetary space, TRACERS will study how magnetic fields around Earth interact with those from the Sun. In a process known as magnetic reconnection, the field lines explosively reconfigure, sending particles out at speeds that can approach the speed of light. Earth's magnetic field will guide some of these particles into the region where TRACERS can observe them.

Magnetic reconnection drives energetic events all over the universe, including coronal mass ejections and solar flares on the Sun. It also allows particles from the solar wind to push into near-Earth space, affecting its space weather. TRACERS will be the first space mission to explore this process in the cusp with two spacecraft, providing observations of how processes change over both space and time. The cusp vantage point also permits simultaneous observations of reconnection throughout near-Earth space. Thus, it can provide important context for NASA's Magnetospheric Multiscale mission, which gathers detailed, high-speed observations as it flies through single reconnection events at a time. TRACERS' unique measurements will help with NASA's mission to safeguard our technology and astronauts in space.

NASA selected TRACERS to go into an extended study phase, since further study is required before NASA is willing to start Phase B formulation of the mission. TRACERS is a NASA-launched rideshare mission, and if approved in the future, it will launch as a secondary payload with PUNCH.

ATMOSPHERIC WAVE EXPERIMENT (AWE)

The Atmospheric Wave Experiment (AWE) will obtain observations of how atmospheric gravity waves in the lower atmosphere, caused by variations in the densities of different packets of air, affect the upper atmosphere. These observations will provide a broader understanding of space weather interactions, specifically the relation between terrestrial weather below and the solar wind. This interaction occurs in a dynamic region of the upper atmosphere, and it is important due to the interference it can create in radio and GPS communications. NASA will attach AWE to the exterior of the International Space Station, where it will focus on colorful bands of light in Earth's atmosphere, called airglow, to determine what combination of forces drive space weather in the upper atmosphere.

AWE is in preliminary design and technology completion phase (Phase B), with an expected launch date of August 2022.

EXPLORER FUTURE MISSIONS

Explorer Future Missions provides the resources required to manage the planning, formulation, and implementation of all Explorer missions. The program office ensures successful achievement of Explorer program cost and schedule goals, while managing cross-project dependencies, risks, issues, and requirements as projects progress through formal key decision points. Additionally, Future Missions supports pre-formulation activities for missions not yet approved as projects.

OTHER MISSIONS AND DATA ANALYSIS

EXPLORER PROGRAM MANAGEMENT

Explorer Program Management encompasses the program office resources required to manage Explorer projects. The program office is responsible for providing support and guidance to projects in resolving technical and programmatic issues and risks, for monitoring and reporting technical and programmatic progress of the projects, and for achieving Explorer cost, schedule, and technical goals and requirements.

Operating Missions

IONOSPHERIC CONNECTION EXPLORER (ICON)

Ionospheric Connection Explorer (ICON), launched on October 10, 2019, is a single spacecraft mission dedicated to understanding neutral-ion coupling in the Earth's upper atmosphere, also known as the thermosphere. It will resolve both long-standing and newly emerging questions about the mechanisms that control the daily development of plasma in Earth's space environment.

ICON will study the ionosphere by simultaneously measuring altitude profiles of the thermosphere and ionosphere's neutral winds, composition, density, temperature, and ion density. It will also make in-situ plasma measurements. Understanding what drives variability in the ionosphere requires a careful look at a complicated system driven by both terrestrial and space weather. ICON will study the frontier of space: the dynamic zone high in our atmosphere where Earth's weather meets space weather. This is a hard-to-reach area that, despite being close to home, remains mysterious. ICON provides in-situ measurements of this complicated region of near-Earth space, which can be difficult to fly through given the variable drag on spacecraft. Better understanding of the ionosphere also has practical repercussions, given our ever-increasing reliance on technology. Radio communications and GPS signals travel through the ionosphere, and variations in this region can result in distortions, or even complete disruption, of these signals. As spacecraft travel through this region regularly, improved knowledge will increase our situational awareness to protect satellites and astronauts.

ICON will help determine the physics of our space environment and pave the way for mitigating its effects on our technology, communications systems, and society.

Recent Achievements

ICON launched successfully to orbit on October 10, 2019, from Cape Canaveral Air Force Station on a Northrop Grumman Pegasus XL small expendable launch vehicle. After an approximately month-long commissioning period, ICON began sending back its first science data in December 2019.

GLOBAL-SCALE OBSERVATIONS OF THE LIMB AND DISK (GOLD)

GOLD, launched in 2018, performs unprecedented imaging of Earth's thermosphere and ionosphere. Capturing never-before-seen images of Earth's upper atmosphere, GOLD explores our space environment, which is home to astronauts, radio signals used to guide airplanes and ships, as well as satellites that provide communications and GPS systems in detail.

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For the first time, GOLD will answer fundamental scientific questions about how the thermosphere/ionosphere system responds to geomagnetic storms, solar radiation, and upward propagating waves and tides. Gathering observations from geostationary orbit above the Western Hemisphere, GOLD measures the temperature and composition of neutral gases in Earth's thermosphere. This part of the atmosphere co-mingles with the ionosphere's charged particles. Both the Sun from above and terrestrial weather from below can change the types, numbers, and characteristics of the particles found here, and GOLD helps track those changes.

Activity in this region is responsible for a variety of key space weather events. GOLD scientists are particularly interested in the cause of dense, unpredictable bubbles of charged gas that appear over the equator and tropics, sometimes causing communication problems. As we discover the very nature of the Sun-Earth interaction in this region, the mission could ultimately lead to ways to improve forecasts of such space weather and mitigate its effects.

Recent Achievements

GOLD reached orbit in October 2018. In March 2019, the mission made data available to the public for analysis.

Phenomena in the low- and mid-latitude ionosphere, the Equatorial Ionization Anomaly (EIA), and the variations that occur within it, have been the subject of decades of research because they have significant effects on communications and navigation systems. Yet scientists do not understand them sufficiently for reliable forecasting.

Because of GOLD's unique perspective from geostationary orbit and its rapid imaging cadence (a complete scan of each hemisphere every 15 minutes), GOLD is providing new information that has not been available in previous EIA observations. From its geostationary vantage some 22,000 miles above the Earth, GOLD observes the same longitudes repeatedly every night and provides large-scale images of the EIA. During the first three months of observations, October-December 2018, GOLD observed gaps occurring three to ten times more frequently than was expected from observations during the previous solar minimum. GOLD also observed more irregularly detected abrupt changes in the location of the EIA. The team will rely on additional measurements before attempting to determine the cause of variability in the EIA and its changing location.

INTERFACE REGION IMAGING SPECTROGRAPH (IRIS)

IRIS is a small explorer mission selected in June 2009 and launched on June 27, 2013. IRIS joined a network of solar spacecraft and ground-based observatories to provide unprecedented insight into a little understood region of the Sun called the interface region. IRIS makes use of high-resolution observations and state-of-the-art computer models to unravel how matter, light, and energy move through the dense region of solar material at the bottom of the sun's atmosphere. Understanding the interface between the sun's surface and its atmosphere, the corona, is crucial to understanding what drives heat and energy into the corona, as well as what powers solar flares and coronal mass ejections. Improvements in technology allow scientists to study this region. In the past, it was not possible to trace how light and material move through the dense area.

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IRIS provides key insights into all these processes, and thereby advances our understanding of the solar drivers of space weather from the corona to the far heliosphere by combining high-resolution imaging and spectroscopy for the entire chromosphere and adjacent regions.

Recent Achievements

One key focus of IRIS research is to use its unprecedented resolution to help unravel how plasma moves through the lower regions of the Sun's atmosphere and what drives the constant change in this dynamic region. Recent research showed how a tiny jet called a spicule forms. At any given moment, as many as 10 million of these wild jets of solar material burst from the sun's surface. They erupt as fast as 60 miles per second, and can reach lengths of 6,000 miles before collapsing. Despite the abundance of these spicules, scientists did not understand how they form. IRIS has been able to provide observations of these spicules—a boon for researchers who can then try to create simulations based on theories and compare to actual observations. For the first time, a computer simulation, so detailed it took a full year to run, matched observations of spicules from IRIS.

INTERSTELLAR BOUNDARY EXPLORER (IBEX)

IBEX, launched in 2008, is the first mission designed to image the edge of the solar system. As the solar wind from the Sun flows out beyond Neptune, it collides with the material between the stars, forming several boundaries. These interactions create energetic neutral atoms, particles with no charge that move very quickly. This region emits no light that conventional telescopes can see, so IBEX measures the particles that happen to be traveling inward from the boundary instead. IBEX contains two detectors designed to collect and measure energetic neutral atoms, providing data about the mass, direction of origin, and energy of these particles. From these data, researchers create maps of the boundary, creating a new map every six months. The mission's focused science objective is to discover the nature of the interactions between the solar wind and the interstellar medium at the edge of the solar system. This region is important because it shields a large percentage of harmful galactic cosmic rays from Earth and the inner solar system.

Recent Achievements

For several years, IBEX has been measuring particles that travel from the Sun to the edges of the heliosphere and back in toward Earth. In late 2014, NASA spacecraft detected a substantial change in the solar wind. For the first time in nearly a decade, the solar wind pressure—a combined measure of its speed and density—had increased by approximately 50 percent and remained that way for several years thereafter. Two years later, in 2016, IBEX, with its view of the boundaries where the solar wind hits interstellar space, detected the first sign of the aftermath. Solar wind particles from the initial 2014 pressure increase had reached the edge of the heliosphere, neutralized themselves into energetic neutral atoms, or ENAs, and shot all the way back to Earth.

Scientists used IBEX data along with sophisticated numerical models to understand what these rebounding atoms could tell us about the evolving shape and structure of our heliosphere—the giant bubble carved out by the solar wind. Research showed that the solar wind pressure increase had propagated from the Sun to the outer heliosphere, morphing and expanding our heliosphere's boundaries. The initial brightening in ENAs was observed approximately 20° south of the upwind direction of the heliosphere (the direction through which the solar system is moving through interstellar space), indicating it as the closest point from Earth to the heliosheath. From early 2017 to early 2018, the ENA emissions

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rapidly expanded northward and covered nearly the entire upwind side of the heliosphere. This preferential expansion shows that the next closest regions span the upwind side from the north-port to the south-starboard directions—consistent with the shaping of the heliosphere by the combined flow and magnetic pressures of the local interstellar medium. These observations also appear inconsistent with recent suggestions of a roughly spherical heliosphere.

TWO WIDE-ANGLE IMAGING NEUTRAL ATOM SPECTROMETERS (TWINS)

TWINS provided stereo imaging of Earth's magnetosphere for 11 years, observing the region surrounding the planet controlled by its magnetic field and containing the Van Allen radiation belts and other energetic charged particles. TWINS provided a three-dimensional global visualization of this region, which led to a greatly enhanced understanding of the connections between different regions of the magnetosphere and their relation to solar variability. TWINS is a NASA-sponsored mission of opportunity that will shortly end operations. Scientists are archiving all data and processing it for future research opportunities.

AERONOMY OF ICE IN THE MESOSPHERE (AIM)

AIM is a mission to determine why polar mesospheric clouds form and why they vary. Polar mesospheric clouds, Earth's highest-altitude clouds, form each summer in the coldest part of the atmosphere about 50 miles above the polar regions. These clouds are of particular interest, as the number of clouds in the middle atmosphere, or mesosphere, over Earth's poles has been increasing over recent years, possibly related to climate change. The spacecraft launched on April 25, 2007, completed its prime mission in FY 2009, and is currently in extended phase.

Recent Achievements

After more than 10 years of data collection, during which AIM observed how noctilucent clouds formed as ice crystals over tiny microparticles produced when meteors burn up in Earth's atmosphere and showed that noctilucent clouds have been steadily increasing over the past decade, AIM entered a new scientific phase in 2017. Because of the way the spacecraft's orbit has shifted over time, AIM is now in an ideal position to study gravity waves, oscillations in the air usually caused by weather and winds near Earth's surface. Gravity waves affect the entire circulation of the middle and upper atmosphere and affect the global atmospheric structure and composition—and even affect the polar vortex.

TIME HISTORY OF EVENTS AND MACROSCALE INTERACTIONS DURING SUBSTORMS (THEMIS)

THEMIS is a MIDEX mission that launched on February 17, 2007 and is currently in extended operations. Starting as a five-spacecraft mission, the three inner probes of THEMIS now focus on collecting data related to the onset and evolution of magnetospheric substorms, while the two outer probes (now referred to as ARTEMIS) have been repositioned into lunar orbits. Magnetospheric substorms are the explosive release of stored energy within the near-Earth space environment that can lead to space weather effects. The two ARTEMIS probes orbit the Moon's surface at approximately 100 miles in altitude and provide new information about the Moon's internal structure and its atmosphere. ARTEMIS provides two-point observations essential to characterizing the Moon's plasma environment and hazardous lunar radiation. THEMIS and ARTEMIS, among others in the Heliophysics portfolio, are examples of missions offering important dynamics knowledge useful for future human spaceflight.

Recent Achievements

In 2019, THEMIS helped reveal the cause of the mysterious auroral phenomenon known as STEVE, short for Strong Thermal Emission Velocity Enhancement. Citizen scientists previously spotted this phenomenon, appearing in purplish streaks at latitudes some 10° closer to the equator than the more typical green aurora, but did not officially categorize it until 2016. The first step towards understanding the nature of STEVE came from a statistical study of THEMIS' ground-based all-sky imager observations of the nighttime sky. STEVE occurs within the hour following the end of the strongest geomagnetic substorms. STEVE remains visible for about 1 hour, with a very narrow latitudinal width of only around 12 miles, about one-fourth the width of typical auroral streamers.

Using data from THEMIS, the origins of the phenomenon were then determined. Magnetic explosions called substorms—some 13,000 miles above Earth—shoot material downward, racing along Earth's magnetic field lines. When the material reaches an altitude of about 150 miles, it begins to emit a mauve light. Researchers do not yet understand why it is that color.

ADVANCED COMPOSITION EXPLORER (ACE)

ACE, launched in 1997, observes particles of solar, interplanetary, interstellar, and galactic origins as they pass by its location near the L1 Lagrange point, located about 1 million miles from Earth toward the Sun. Changing conditions over the solar cycle are presenting new opportunities, including providing new insights relevant to space weather events.

Recent Achievements

Scientists continue to use ACE data to track and analyze the particles streaming toward Earth from the Sun—including the largest solar energetic particle events, or SEPs, which can be hazardous to exposed astronauts and space-based instrumentation. Research in 2019 helped collect some of the biggest examples of such events during the most recent solar cycle—noting the largest of the cycle in the fall of 2017. In late summer of 2017, an active region on the Sun first appeared, which went on to generate 27 M-class and 4 X-class flares, including the largest of solar cycle 24 —an X9.3 on September 6, 2017. The region also erupted with four coronal mass ejections (CMEs) with velocities greater than 600 miles per second, as well as multiple solar energetic particle events observed by near-Earth spacecraft. Of these events, the one on September 10, 2017, was the largest seen since June 2015 and one of only two ground-level enhancement (GLE) events of the current cycle.

New theoretical work in 2018, based on ACE data, also showed that the monotonic pattern of heavy element enhancements may be due to a “filtering” process occurring as supra-thermal ions penetrate a small amount of material in the solar atmosphere during the early stages of particle acceleration. The attachment of orbital electrons by nuclei passing through the coronal plasma affects the distance they can travel depending on particle mass and energy. Researchers found a simple model capable of producing enhancement patters similar to those observed in 3He-rich events. These results suggest new avenues for investigating the decades-old mystery of extreme fractionation in 3He-rich events. They should have immediate bearing on understanding SEP observations expected from Parker Solar Probe and Solar Orbiter.

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RAMATY HIGH ENERGY SOLAR SPECTROSCOPIC IMAGER (RHESSI)

After more than 17 years of successful operations since its launch in 2002, NASA decommissioned RHESSI on August 16, 2018. The RHESSI satellite focused on the highest energy X-rays and gamma rays produced by the Sun, helping to observe solar flares of all shapes and sizes. NASA Goddard Space Flight Center and the Space Sciences Lab at the University of California, Berkeley, carried out the RHESSI Mission Archive Plan in FY 2019 and will continue it in FY 2020. GSFC and SSL will share a minimum level of effort to ensure the health and safety of the mission while retrieving over 95 percent of the data and ensure continuity of research access to the mission's observations.

AERONAUTICS

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Airspace Operations and Safety Program	105.7	--	**90.4**	92.6	94.4	96.2	96.2
Advanced Air Vehicles Program	272.1	--	**212.7**	222.2	230.3	261.2	266.2
Integrated Aviation Systems Program	209.6	--	**269.0**	256.4	244.4	209.5	204.5
Transformative Aero Concepts Program	137.4	--	**129.9**	132.3	134.6	136.7	136.7
Aerosciences Evaluation and Test Capabilities	0.0	--	**117.0**	117.1	117.1	117.1	117.1
Total Budget	**724.8**	**783.9**	**819.0**	**820.7**	**820.7**	**820.7**	**820.7**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

AERONAUTICS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
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Aerosciences Evaluation and Test Capabilities	0.0	--	**117.0**	117.1	117.1	117.1	117.1
Total Budget	**724.8**	**783.9**	**819.0**	**820.7**	**820.7**	**820.7**	**820.7**
Change from FY 2020			**35.1**				
Percentage change from FY 2020			**4.5%**				

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

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NASA Aeronautics is leading a new era of flight, depicted above, that will include new aircraft configurations with electric propulsion and urban air mobility vehicles.

An efficient and effective transportation system is fundamental to the future of the U.S. economy. Aviation is a highly visible and forward-looking component of transportation. Aviation moves the world, and the U.S. is a global leader in aviation technology.

The aviation industry accounts for more than $1.6 trillion annually of total U.S. economic activity[1] and is one of only a few U.S. industry sectors that generates a positive trade balance - $88 billion in 2018 alone.[2] It supports more than 10.6 million direct and indirect jobs, including more than one million high-quality manufacturing jobs.

[1] *"The Economic Impact of Civil Aviation on the U.S. Economy," FAA, November 2016*

[2] *"Leading Indicators for the U.S. Aerospace Industry," ITA, March 15, 2019*

AERONAUTICS

NASA explores technologies that reduce aircraft noise and fuel use, allow passengers to travel safely and on time, and transform aviation into an economic engine at all altitudes.

NASA's aeronautics research directly affects the success of the vital U.S. air transportation system. NASA-developed technologies are on board every U.S. commercial aircraft and inside every U.S. control tower today. Investments in NASA's cutting-edge aeronautics research support U.S. global leadership in an industry that, driven by market interest, is quickly evolving to create exciting new capabilities, such as:

- An urban air mobility system that provides safe, economical, and environmentally-friendly means to move people and packages in population centers;
- A revolutionary travel option made real – quiet commercial supersonic flight for the masses enabled by overcoming the current ban on supersonic flight over land;
- Subsonic aircraft with alternative propulsion that are more efficient and help maintain U.S. market leadership; and
- A transformed airspace system that supports an increasingly diverse range of vehicles operating seamlessly throughout the airspace and gives citizens the confidence that every flight is safe and secure.

To ensure that research focuses on enabling this aviation transformation, NASA's Aeronautics Research Mission Directorate (ARMD) guides its efforts with its strategic implementation plan. The plan lays out NASA's approach to addressing growing demand for global air mobility, the increasing demands of energy efficiency and environmental sustainability, and the opportunity for convergence between traditional aeronautical disciplines and technology advances in information, communications, energy, and other rapidly evolving technologies. The strategic implementation plan identifies six research thrusts:

Thrust 1: Safe, Efficient Growth in Global Operations

A modernized air transportation system that allows much greater capacity and operational efficiency while maintaining or improving safety and other performance measures is essential for the United States. ARMD will contribute specific research and technology to support the Federal Aviation Administration's (FAA) continued development of NextGen and beyond to enable safe, scalable, routine, high-tempo airspace access for all users. ARMD is working with the FAA to develop a long-term vision for a transformed National Airspace System (NAS) to accommodate more diverse and increasingly complex operations in a safe and affordable manner. Due to the international nature of aviation, ARMD will continue to ensure that developments made in the U.S. go through the International Civil Aviation Organization (ICAO).

Thrust 2: Innovation in Commercial Supersonic Aircraft

Development of efficient, cost-effective, and environmentally compatible commercial supersonic transports could be a "game-changer" for transcontinental and intercontinental transportation, provide an opportunity to maintain U.S. leadership in aviation systems and generate economic and societal benefits. ARMD will perform focused research and advance groundbreaking technologies to overcome the major environmental and efficiency barriers to market innovation in supersonic transport and achieve practical, affordable commercial supersonic air transport. Since overcoming these barriers will likely involve modifications to regulations and certification standards for supersonic flight, ARMD will conduct its research in cooperation with the FAA, ICAO, and other aviation regulatory agencies.

Thrust 3: Ultra-Efficient Subsonic Transports

Large leaps in aircraft efficiency, coupled with reductions in noise and harmful emissions, are critical to the aviation community's roadmap for achieving greatly improved environmental sustainability. ARMD will develop critical technologies to enable realization of revolutionary improvements in economics and environmental performance for subsonic transport with opportunities to transition to alternative propulsion and energy.

Thrust 4: Safe, Quiet, and Affordable Vertical Lift Air Vehicles

Future generations may have the option to utilize flight largely as an option to carry out their day-to-day activities when vertical lift enables ubiquitous air travel. ARMD will develop critical technologies and knowledge to support regulations and standards that enable realization of extensive use of vertical lift vehicles for transportation and services, including new missions and markets.

Thrust 5: In-Time System-Wide Safety Assurance

Projected growth in air travel will require a sustained focus on reducing safety risks to maintain acceptable levels of safety. ARMD will work with the FAA, the Commercial Aviation Safety Team (CAST), and others to perform research and to contribute technology addressing current and future safety risks. New operational concepts will change and diversify aviation and create the need for advanced safety capabilities, which operate on a broad scale. The future air transportation system will require a safety net that utilizes system-wide information to provide alerting and mitigation strategies in time to address emerging risks. Moving forward, aviation safety needs to take advantage of modern information availability and intelligent systems to predict, detect, and mitigate emerging safety risks throughout aviation systems and operations.

Thrust 6: Assured Autonomy for Aviation Transformation

Ever-increasing levels of automation and autonomy are transforming aviation, and this trend will continue to accelerate. ARMD will lead in the research and development of intelligent machine systems capable of operating in complex environments, including the safe integration of Unmanned Aircraft Systems (UAS) in the NAS. Complementary methods will provide safety assurance, verification, and validation of these systems. To pave the way for increasingly autonomous airspace and vehicles, ARMD will explore human-machine teaming strategies, and advanced metrics, models, and testbeds will enable the effective evaluation of autonomous systems in both laboratory and operational settings, which will enable the safe implementation of autonomy in aviation applications.

For more information, go to: http://www.aeronautics.nasa.gov/strategic-plan.htm

NASA Aeronautics programs and projects work together to contribute to each of the strategic thrusts. These contributions build upon each other to deliver key knowledge and technologies used by industry and other Government organizations to improve national economy and expand the impact of the U.S. aviation industry around the world. The FY 2021 Budget Request includes major activities that are closely coordinated across the mission directorate. The following examples demonstrate how this approach is working in several priority areas.

The Low-Boom Flight Demonstration (LBFD) mission is a major activity within Aeronautics that will enable U.S. industry to open new commercial supersonic markets. Through the LBFD mission, NASA will fly a quiet supersonic X-plane that will generate a community response database that U.S. and international regulators can use to develop new noise standards for supersonic overland flight. The LBFD mission is closely coordinated across three projects: LBFD project, Commercial Supersonic Technology (CST) project, and Flight Demonstrations and Capabilities (FDC) project. The LBFD project is responsible for building and flight validation of the X-59 QueSST aircraft. The X-59 aircraft is NASA's newest experimental supersonic aircraft designed to reduce the sonic boom to an acceptable level. While the LBFD project is building the aircraft, the CST and FDC projects are planning for the community response testing phase of the mission. In FY 2021:

- The LBFD project will build the X-59 QueSST aircraft, complete most ground testing, and prepare the aircraft for flight.
- The CST project will develop, test, and mature the ability to predict the aircraft's sonic boom and the ability to gather human response data from the people in the communities near the aircraft flight path.
- The FDC project will prepare the operational and test infrastructure required to execute the community overflights for testing and deployment.

The LBFD mission ends in FY 2026 with the delivery of the final set of community response data to the ICAO. When a new standard is set, the U.S. aviation industry will be in position to lead a new commercial supersonic market, and passengers will benefit from significantly shorter travel times.

A second major priority is developing new subsonic aircraft technologies that the U.S. aviation industry will use to produce the next generation of aircraft with better fuel efficiency and reduced environmental impact. The technologies include advanced wing design, transformative structures, propulsion-airframe integration, small core turbine engines, and electrified aircraft propulsion (EAP). Among these technologies, EAP has shown great potential and has strong industry interest. EAP is a focus area for NASA. The NASA Electric Aircraft Testbed (NEAT) facility is enabling full-scale ground test of high-power electric propulsion systems. Technical accomplishments performed in this facility will serve as building blocks that demonstrate progress with integration and testing. In FY 2020, NASA began a multi-year effort to solve the technical challenges of a megawatt (MW)-class power electrified propulsion system (1-MW is the equivalent of powering 165 homes). Further, NASA will initiate new ground and flight research activities to validate these new electric systems in flight. Much of this sustained work occurs using advanced fundamental computational tools along with advances in technologies, such as structures and materials.

Another NASA focus is enabling new UAS markets and leveraging this work to enable a new urban air mobility (UAM) market. To make progress in this new market area, work in Thrusts 4, 5, and 6 is essential. From air traffic management to quiet vertical lift, NASA is working to eliminate key barriers to establish these new UAM markets. NASA will develop a series of Grand Challenge (GC) events that will help companies work together to demonstrate progress in advancing the technologies needed to execute these new concepts of operations. NASA and industry will learn from these demonstrations to inform future investments.

NASA investments support the early stages of the future airspace system that will enable all users – from UAS to UAM to traditional airlines – to seamlessly access the airspace and safely and efficiently execute their missions. In FY 2021, NASA will complete a series of airspace technology demonstrations supporting the development of NextGen. In addition, new activities in the Air Traffic Management Exploration Project and System Wide Safety project will begin to address the challenges of a more complex airspace supporting a broad range of new users.

EXPLANATION OF MAJOR CHANGES IN FY 2021

As specified in the FY 2020 appropriation, the Aerosciences Evaluation and Test Capabilities (AETC) portfolio is a new program within NASA Aeronautics. This consolidation will improve the efficiency and effectiveness of managing ground testing capabilities within the Agency.

ACHIEVEMENTS IN FY 2019

Thrust 1: Safe, Efficient Growth in Global Operations

In FY 2018, NASA began a comprehensive operational evaluation and demonstration of air traffic management technologies known as ATD-2. ATD-2 technologies enable improved sharing of operational information that significantly increases the efficiency of aircraft movements at busy airports. In FY 2019, NASA successfully conducted major demonstrations of ATD-2 technologies in close coordination with the FAA, airlines, and airports. Since starting the ATD-2 trial, NASA estimates that airlines have saved more than 3.7 million pounds of fuel and 481 hours of surface delays. NASA will complete the ATD-2 demonstrations in FY 2021 and then transition the technologies to the FAA.

For additional Thrust 1 information, see the Airspace Operations and Safety Program (AOSP) section.

Thrust 2: Innovation in Commercial Supersonic Aircraft

To change the regulation related to supersonic flight, NASA will develop the X-59 aircraft that creates a quieter sonic boom, characterize its acoustic signature, and measure the impact of the noise level on the population. In 2019, NASA made significant progress in all three areas. NASA completed the final design of the X-59 aircraft and began building the aircraft. NASA advanced the methods for measuring the shock waves generated from a supersonic aircraft in flight. These methods will be very important for assessing the performance of the X-59 when it takes flight. Finally, NASA held a first-of-its-kind community response test in Galveston, TX. The test results will help develop the methods and procedures for capturing acoustic signatures from the X-59 when it flies over U.S. cities. During the Galveston test, a special maneuver by a NASA F/A-18 generated an approximate low-boom signal that an array of ground sensors captured. This successful experiment will inform plans for collecting X-59 flight test community response data that is essential for developing new standards regarding supersonic flight.

For additional Thrust 2 information, see the Advanced Air Vehicle Program, Integrated Aviation Safety Program, and Low Boom Flight Demonstration sections.

Thrust 3: Ultra-Efficient Subsonic Transports

NASA focuses on delivering new technologies, tools, and knowledge to U.S. industry that will help significantly improve the efficiency and performance of the design and build of new subsonic aircraft. In FY 2019, NASA matured new subsonic aircraft technologies, improved the efficiency of certifying composite materials, and set the stage for future flight experiments demonstrating electric aircraft propulsion. As an example of an advanced subsonic technology, NASA helped develop and mature a new truss-braced wing aircraft configuration. Working closely with industry, NASA tested the new configuration and showed that the concept increases efficiency compared to today's vehicles.

With considerable support from our cost-sharing partners, NASA successfully completed the Advanced Composites Project, which had three major milestones to improve the efficiency of certifying new composites structures. The first major element was improving the ability to simulate the performance of composite structures to enable more effective testing during the certification phase and improved design capabilities. A second element was improving the means used to detect flaws in composite structures. Finally, the project created a new capability to model the manufacturing process to achieve further optimization.

NASA has recognized that electric aircraft propulsion can provide significant reductions in fuel consumption and emissions. NASA has tested critical propulsion technologies that are more electric. Using the NEAT facility at Glenn Research Center, NASA tested components and gained insights that lay the path for further experiments in flight. Additionally, NASA progressed toward flight testing the all-electric X-57 aircraft in FY 2020. This general aviation-sized aircraft will provide key knowledge and insight to inform regulations and standards associated with smaller electric air vehicles. To advance the state-of-the-art for larger vehicles, NASA initiated conceptual design work with industry to pave the way for flight testing of larger (MW-class) electrical systems.

For additional Thrust 3 information, see the AAVP, IASP, and Transformative Aeronautics Concepts Program (TACP) sections.

Thrust 4: Safe, Quiet, and Affordable Vertical Lift Air Vehicles

Industry and the FAA are looking to NASA to lead the development of several key areas to enable widespread use of more electric vertical lift vehicles. Noise has traditionally been one of the limiting factors for helicopters and is likely to be a key issue for urban air mobility vehicles. NASA demonstrated the ability to model noise and include noise performance improvements in the design phase. In addition, NASA conducted flight demonstrations of smart vehicle operations that lowered noise. Another critical area for new vehicles is failure mode. NASA worked closely with industry to study and better understand failure modes associated with more electric air vehicles. This work sets the stage for overcoming the operational barriers of new vertical lift vehicles that will be operating soon.

For additional Thrust 4 information, see the AAVP section.

Thrust 5: In-Time System-Wide Safety Assurance

NASA focused on successfully completing a series of research efforts defined by the CAST. These efforts focus on addressing identified safety needs, such as training guidance for pilots to improve recovery in upset or stall conditions. NASA delivered a framework for analyzing and identifying hazards in a more proactive manner. This work sets the stage to enable proactive, in-time hazard analysis by the FAA and guides future NASA research to enable the detection, assessment, and mitigation of safety risks in near real-time.

For additional Thrust 5 information, see the AOSP section.

Thrust 6: Assured Autonomy for Aviation Transformation

NASA made significant progress in enabling more routine use of unmanned aircraft at both high- and low-altitudes. Two key enablers for unmanned vehicles operating in the Airspace are the abilities to communicate with and avoid colliding with other aircraft. NASA conducted successful demonstrations in both of these critical areas, which will provide the information needed to set standards for safe operations of unmanned systems in the NAS.

At very low-altitudes, there is not an existing system to safely control and coordinate small vehicle operations. NASA is solving this problem with the development of the Unmanned Traffic Management (UTM) System. Development of this system includes a series of demonstrations of increasing complexity each year. NASA concluded these experimental efforts through a demonstration of UAS operations in real urban environments in both Reno, NV, and Corpus Christi, TX. This research involved close coordination with the FAA, commercial operators, and local governments, and it showed a viable path forward for greater utilization of unmanned vehicles in both rural and urban settings.

For additional Thrust 6 information, see the AOSP and IASP sections.

Cross-Cutting Capabilities

Not all of NASA's work is applicable to just one Strategic Thrust. Some fundamental work or innovations can be broadly applicable. NASA has implemented several strategies to tap into both the talent within the NASA workforce and the university community to create new ideas and innovations that can help solve key aviation challenges. The Convergent Aeronautics Solutions (CAS) project began in FY 2015 to stimulate new ideas from the NASA workforce that can directly contribute to the challenges in aviation. In FY 2019, several activities under CAS completed critical feasibility assessments. NASA has also broadened engagement with the academic community and encouraged comprehensive teaming to solve important challenges for aeronautics. Three additional awards occurred under this University Leadership Initiative (ULI). Another important component of cross-cutting research is developing fundamental tools and techniques for use in multiple applications. NASA created a new design capability that improves the ability to predict how different components, such as the propulsion system and the airframe, will work together. NASA is also beginning to explore how advanced computational tools make the certification process more efficient and more effective.

For additional cross-cutting capabilities information, see the TACP and AETC sections.

Hypersonic Capabilities

Hypersonic flight involves speeds of Mach 5 and above and holds the potential for new military and civilian capabilities. Traditionally, NASA has pioneered advances in the flight regime. NASA works closely with the Department of Defense (DoD) to mature necessary capabilities, while focusing on the fundamental research that will lead to new, long-term capabilities to lay the foundation for potential future civil and commercial use. NASA expertise assists the DoD by solving key problems and reducing risk for a variety of activities, which in turn provides key validation data that NASA can use to support its own research. NASA further advanced hypersonic vehicle design capabilities by improving the methods to define and understand uncertainties associated with data from ground tests. The application of these design tools and approaches enables improved performance estimates for new concepts earlier in the design process.

For additional hypersonic capabilities information, see the AAVP section.

WORK IN PROGRESS IN FY 2020

Thrust 1: Safe, Efficient Growth in Global Operations

NASA will complete the final demonstration of the ATD-2 effort, which includes a comprehensive demonstration of a suite of tools designed to improve the managing surface traffic to enable an overall improvement of arrival and departure efficiencies. This demonstration will involve multiple airlines and several air traffic management facilities in the Dallas / Ft. Worth, TX, area. Following completion of this experiment, NASA will transition the tools and knowledge related to ATD-2 to the FAA and airlines.

Thrust 2: Innovation in Commercial Supersonic Aircraft

NASA will complete most of the X-59 aircraft build and refine the techniques for collecting data from the aircraft. NASA will finalize the approach for the field study methodologies that will be used during X-59 flight tests. NASA will share results of the FY 2019 Galveston community response test with the ICAO to help ensure support for the community response testing plan. NASA will also coordinate with ICAO and the international community to improve NASA's flight testing and data collection approach.

Thrust 3: Ultra-Efficient Subsonic Transports

In partnership with industry over several years, NASA will test a wing concept for a commercial transport aircraft application. The testing of the wing includes detailed rendering of structures such as flaps, slats, and other control surfaces that will inform how we design wings in the future. Additionally, NASA will complete testing on components that enable development of new turbine engine cores that are smaller in diameter and more efficient.

Development of more electric propulsion concepts will also be a key focus area. NASA component testing in the NEAT facility will include simulating higher altitude effects. This capability is the first of its kind in the world, and it is critical for understanding how to design hardware that can safely perform at altitude. NASA will also conduct the first flight of its all-electric X-57 aircraft. Lessons learned from these flights will feed into industry standards for the development of all-electric systems. With this testing and coordination with the FAA and industry, NASA is setting the stage for larger aircraft to use electric propulsion systems.

Thrust 4: Safe, Quiet, and Affordable Vertical Lift Air Vehicles

Building on the initial analysis of potential failure modes for more electric vertical lift systems, NASA will move to test concepts in a laboratory environment. An important step is configuring the right capabilities to support such testing. The intent is to characterize a wide range of systems to inform future regulations and standards. Continued work in this area will help ensure that noise from new urban air mobility vehicles shows the proper characterization, and it will inform standards that limit impact to the public. NASA will extend its modeling techniques to predict noise from fleets of vehicles.

Thrust 5: In-Time System-Wide Safety Assurance

NASA will build on the frameworks for improved in-time system-wide safety analysis and apply these concepts to commercial operations and the new urban air mobility mission. As aviation systems increase in complexity, assurance of these systems will become increasingly difficult and costly. NASA will work closely with the FAA and industry to develop and evaluate tools and techniques for assurance of increasingly autonomous systems. The information that NASA generates is critical for setting the stage to develop standards for more autonomous systems.

Thrust 6: Assured Autonomy for Aviation Transformation

NASA plans to finish analysis of the urban UTM experiments conducted in FY 2019 and complete the UTM Project. NASA will transition key technical products and knowledge and continue to support the FAA. Building on the success of managing small, unmanned vehicles, NASA will apply these concepts to manned UAM missions. The initial phase of this work involves simulations with industry partners to analyze how humans interact with machines in such an application.

NASA will complete work related to integration of larger unmanned systems into the NAS. This process includes finishing testing associated with new radios that will facilitate greater operational benefits. In close cooperation with industry, NASA will complete a series of capstone demonstrations showing the viability of key technologies to enable new commercial UAS missions. NASA will produce reports on key lessons learned and vehicle certification insights that will enable new UAS entrants to have greater confidence in navigating the requirements for safe operations in the NAS.

Cross-Cutting Capabilities

NASA will award a third set of ULI research proposals. NASA will implement changes to the CAS project based on the lessons learned over the first five years. In support of fundamental capabilities, NASA will complete an assessment of the best opportunities for futures structures and materials research.

Hypersonic Capabilities

Building on the design work in FY 2019, NASA will incorporate the uncertainty quantification techniques into more comprehensive design tools that help predict key performance parameters. In addition to improving design tools, NASA is working on developing specific technologies that will enable expanded use of air-breathing hypersonic vehicles. One such concept involves enabling the transition from a turbine engine to a scram or ram jet. NASA will conduct experiments to help understand how to design such systems, which enable re-usable hypersonic flight.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

Thrust 1: Safe, Efficient Growth in Global Operations

NASA will complete transition of tools and data associated with ATD-2 to industry and the FAA, marking the end of the ATD Project. The delivery of multiple tools that contribute to NextGen and improve the overall effectiveness of air traffic management will be complete. NASA will also lay the groundwork for the follow-on to NextGen. Leveraging the initial success of the unmanned traffic management concept, NASA will explore the potential for an expanded application of service-based architectures to improve efficiency and better accommodate a wider range of air vehicles expected in the future.

Thrust 2: Innovation in Commercial Supersonic Aircraft

NASA will begin final preparations for initial flight of the X-59 and the accompanying flight and ground systems that will be used to measure flight data and the response from the population. NASA will conduct integrated systems testing to ensure that the vehicle is functioning properly and is ready for flight testing. The airborne measurement capability carried by the supporting NASA F-15 aircraft will be completed and tested. NASA will also complete the final development of the ground measurement system and associated test methods used to collect data from X-59 flights.

Thrust 3: Ultra-Efficient Subsonic Transports

NASA will conduct additional flight testing of the all-electric X-57 aircraft and will modify the vehicle to integrate additional electric motors to drive smaller propellers distributed along the wing. This modification will allow NASA to evaluate electrical systems that are more complex to better support standards development. NASA will advance the planning for the larger scale flight testbed with approval of a plan to proceed with detailed design of a flight system. This work will be closely coordinated with industry. NASA will ground test flight-weight electrical systems in support of development of the flight test concepts. NASA will also validate noise reduction technologies for advanced wing and engine acoustic concepts in support of the aviation industry's goal of decreasing aircraft noise generated near airports.

Thrust 4: Safe, Quiet, and Affordable Vertical Lift Air Vehicles

In FY 2021, NASA will deliver an initial set of data to help inform standards for electric vertical takeoff and landing (eVTOL) vehicles based on testing and evaluation from prior years. These standards will help ensure that systems developed by industry have a basis of sound fundamentals and incorporate lessons learned to improve safety. NASA will develop methods to predict noise generated by future eVTOL vehicles designs with multiple rotors or propellers, which complicates the calculations needed to predict noise. Such a capability will allow industry to better account for reducing noise earlier in the design process.

Thrust 5: In-Time System-Wide Safety Assurance

NASA will develop techniques that process environment and vehicle state information to monitor and make predictions about system safety to evaluate potential courses of action. NASA will demonstrate these predictive techniques for UAM vehicles. This research feeds into the development of requirements to enable in-time system-wide safety assurance.

Thrust 6: Assured Autonomy for Aviation Transformation

In the future, airspace operations will rely on greater application of autonomy to safely manage the increased number and variety of vehicles. NASA will begin to identify potential concepts that could greatly expand operations. The initial applications will focus on urban air mobility and will be coordinated with NASA's UAM GC as a potential proving ground. In addition, NASA will research techniques for monitoring these systems to ensure certification at a safe level.

Cross-Cutting Capabilities

NASA will initiate and execute another round of the competitive ULI proposals that will engage universities to address technical barriers intrinsic to achieving ARMD’s strategic outcomes. Using the results of the materials and structures studies, NASA will initiate new fundamental research to develop models and tools to enable the application of new materials concepts. NASA will conduct fundamental cross-cutting autonomy research focusing on areas such as trust and certification of new systems that will have broad application across aeronautics.

Hypersonic Capabilities

NASA will mature its new design capabilities and apply them to predict the performance of turbine based combined cycle propulsion (TBCC) systems, which may be a viable option for re-usable hypersonic vehicles. To validate these design approaches and further mature TBCC technologies, NASA will conduct comprehensive validation experiments.

Programs

NASA Aeronautics has five major programs that focus on particular research areas and are coordinated to achieve key commitments at the Strategic Thrust level. For example, new vehicles such as supersonic aircraft or UAM vehicles cannot function effectively without advances in how we manage the airspace. At the same time, there is value in continuing to explore new concepts and fundamental knowledge that could be the key to solving some of the toughest challenges for aviation in the future. Additional detail can be found in each of the following Program sections, but it is important to remember that they do not operate independently.

AIRSPACE OPERATIONS AND SAFETY PROGRAM

AOSP develops and explores fundamental concepts, algorithms, and technologies to increase throughput and efficiency of the NAS safely. The program works in close partnership with the FAA and the aviation community to enable and extend the benefits of NextGen, the Nation's program for modernizing and transforming the NAS to meet evolving user needs. Integrated demonstrations of these advanced technologies will lead to clean air transportation systems and gate-to-gate efficient flight trajectories. The program researches increasingly autonomous aviation systems, including innovation in the management of UAS traffic and other novel aviation vehicles and business models. The program is also pioneering the real-time integration and analysis of data to support system-wide safety assurance, enabling proactive and prognostic aviation safety assurance. The program takes lead responsibility for three of ARMD's Strategic Thrusts:

- Thrust 1: Safe, Efficient Growth in Global Operations;
- Thrust 5: In-Time, System-Wide Safety Assurance; and
- Thrust 6: Assured Autonomy for Aviation Transformation (co-lead).

ADVANCED AIR VEHICLES PROGRAM

AAVP develops the tools, technologies, and concepts that enable new generations of civil aircraft that are safer, are more energy-efficient and have a smaller environmental footprint. The program focuses on enabling major leaps in the safety, efficiency, and environmental performance of subsonic fixed and rotary wing aircraft to meet challenging and growing long-term civil aviation needs; pioneering low-boom supersonic flight to achieve new levels of global mobility; and advancing fundamental hypersonic research while sustaining hypersonic competency for national needs. In partnership with academia, industry and other Government agencies, such as the FAA, AAVP pioneers fundamental research and matures the most promising technologies and concepts for transition to system application by the aviation industry. The program works in partnership with the DoD to ensure both NASA and DoD vehicle-focused research is fully coordinated and leveraged. The program takes lead responsibility for three of ARMD's Strategic Thrusts:

- Thrust 2: Innovation in Commercial Supersonic Aircraft;
- Thrust 3: Ultra-Efficient Subsonic Transports; and
- Thrust 4: Safe, Quiet, and Affordable Vertical Lift Air Vehicles.

INTEGRATED AVIATION SYSTEMS PROGRAM

IASP focuses on experimental flight research and the spirit of integrated, technological risk-taking that can demonstrate transformative innovation. Therefore, the program complements both AOSP and AAVP by conducting research on the most promising concepts and technologies at an integrated system level. The program explores, assesses, and demonstrates the benefits of these potential technologies in a relevant environment. The program works in partnership with the other aeronautics programs, other Government agencies, academia, the aviation industry, and international partners as appropriate. The program supports the flight research and demonstration needs across all six ARMD Strategic Thrusts, but it shares lead responsibility with AOSP for the following Strategic Thrust:

- Thrust 6: Assured Autonomy for Aviation Transformation (co-lead).

TRANSFORMATIVE AERONAUTICS CONCEPTS

TACP cultivates multi-disciplinary, revolutionary concepts to enable aviation transformation and harnesses convergence in aeronautics and non-aeronautics technologies to create new opportunities in aviation. The program's goal is to demonstrate initial feasibility of internally and externally originated concepts to support the discovery and initial development of new, transformative solutions for all six ARMD Strategic Thrusts. The program provides flexibility for innovators to explore technology feasibility and provide the knowledge base for transformational aviation concepts by using sharply focused activities. The program solicits and encourages revolutionary concepts, creates the environment for researchers to become immersed in trying out new ideas, performs ground and small-scale flight tests, allows failures and learns from them, and drives rapid turnover into new concepts. The program also supports research and development of major advancements in cross-cutting computational tools, methods, and single discipline technologies to advance the research capabilities of all aeronautics programs.

AEROSCIENCES EVALUATION AND TEST CAPABILITIES

The aerosciences ground test research capabilities (facilities, systems, workforce, and tools) necessary to achieve the future air vehicles described above require efficient and effective investment, use, and management of NASA's suite of world-class wind tunnels. Efforts in this area preserve and enhance those specific ground test capabilities that are necessary to achieve the missions. Among these assets are subsonic, transonic, supersonic, and hypersonic wind tunnels and propulsion test facilities at the Ames Research Center in Mountain View, CA, the Glenn Research Center in Cleveland, OH, and the Langley Research Center in Hampton, VA. These test facilities and capabilities also serve the needs of non-NASA users. NASA also offers research customers high-quality data that accurately reflect the simulated test environment and the interactions of test articles in those test environments in conjunction with the ground experimentation capabilities. Furthermore, NASA expertise helps ensure safe and successful use of the assets and high-quality of the research outcomes. The project is cross-cutting and supports ARMD Strategic Thrusts as well as other Agency efforts and those of key industry partners.

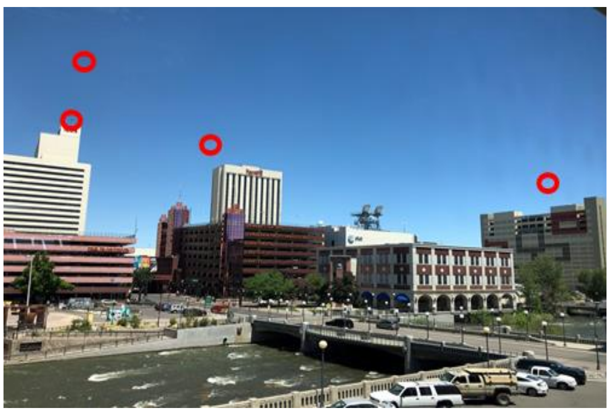
AIRSPACE OPERATIONS AND SAFETY PROGRAM

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	105.7	--	90.4	92.6	94.4	96.2	96.2

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.



Multiple simultaneous drone operations are shown over downtown Reno, NV, enabled by Unmanned Aircraft Systems Traffic Management (UTM) Technical Capability Level 4 (TCL4).

The current U.S. air transportation system is widely recognized to be among the safest in the world. While the Federal Aviation Administration (FAA)-led NextGen effort will meet growing air traffic demand by enabling efficient passage through the increasingly crowded skies, it will come with increased operating complexity. Current aviation participants and the Air Traffic Management (ATM) system face many challenges related to global competitiveness, efficiency, productivity, increasing mobility needs, and the emergence of new airspace users.

For the U.S. to meet the public expectations for safety in this complex, dynamic domain, advanced automation technologies will be required. This automation will need to work in an integrated fashion across multiple domains and stakeholders, in harmony with human operators. NASA is working with the FAA to develop a long-term vision for the future NAS and looks to ensure that the system will accommodate these diverse and increasingly complex operations in a safe and affordable manner for service providers, vehicle/platform operators, passengers, and cargo. In the coming years, the sustained, integrated efforts of the FAA and its many stakeholders will systematically transform the systems and processes of today's National Airspace System (NAS) to accommodate these new operations. NASA will play a critical role in this transformation through its research and development of autonomous technologies for aircraft/platforms as well as tools and technologies for managing the airspace to support increasingly diverse operations.

The Airspace Operations and Safety Program (AOSP) performs research and technology development to enable transformation of air traffic management and operational safety concepts. These technologies ultimately benefit the public by increasing capacity and reducing the total cost of air transportation. AOSP (with the FAA and its other industry and academic partners) conceives, develops, and demonstrates technologies to improve the intrinsic safety of current and future aircraft systems that will operate in the NAS. Furthermore, the program develops advanced technologies for a service-oriented and federated NAS architecture to enable seamless integration of emergent vehicles, such as unmanned aircraft systems

AIRSPACE OPERATIONS AND SAFETY PROGRAM

(UAS) and urban air mobility (UAM) vehicles, with present-day aircraft. AOSP also works with other ARMD programs to define safe NAS operational requirements for next generation vehicles, mature new transformative seedling concepts, and demonstrate integrated systems. AOSP directly supports three of the ARMD Strategic Thrusts:

- Thrust 1: Safe, Efficient Growth in Global Operations
- Thrust 5: In-Time System-Wide Safety Assurance
- Thrust 6: Assured Autonomy for Aviation Transformation

AOSP aims to:

- Enable completion of NextGen from gate-to-gate to support projected growth and reduce the total cost of air transportation operations. NASA will work to develop technologies to reduce operator workload, fuel consumption, and environmental impacts while identifying and mitigating safety risks in a manner that is scalable over time to meet anticipated operational growth.
- Enable transformation of the NAS to a more scalable, service-oriented architecture to allow safe operation of emerging aviation markets. Participants in the transformed NAS include low altitude autonomous vehicles ranging from small autonomous UAS through passenger-carrying autonomous urban air taxis, high-altitude, long-endurance UAS, and autonomous freight-carrying vehicles operating in the NAS. NASA will support the safe and efficient integration of traditional and emerging market operations from many more access points in current low-density airspace.
- Enable "in-time" system-wide safety assurance by developing tools and technologies for prognostic detection of safety hazards, integrated risk assessment, monitoring and mitigation, and assurance of new systems and operations.

EXPLANATION OF MAJOR CHANGES IN FY 2021

The Advanced Air Mobility (AAM) project moves from the AOSP into the Integrated Aviation Systems Program (IASP) portfolio for FY 2021. The AAM Project will be managing large complex demonstrations beginning with the Urban Air Mobility Grand Challenge, which involves industry, the FAA and other Aeronautics projects. The IASP has the expertise to conduct this type of cross program integrated demonstration. In addition, the AOSP will receive additional funding to augment the series of Grand Challenges (GC) to support the development and evaluation of artificial intelligence capabilities relevant to UAS traffic management and unmanned aerial vehicles' command-and-control and collision avoidance systems. This funding structure is consistent with the FY 2021 Budget's support for "Industries of the Future."

At the end of each achievement identified in this document, there is a mapping to link it to the related Strategic Research Thrust and Program Element.

ACHIEVEMENTS IN FY 2019

- NASA conducted the ATD-2 Phase 2 demonstration to evaluate the fused Integrated Arrival/Departure/Surface (IADS) system at Charlotte International Airport. This capability enables precision in how the airlines schedule their gate pushback times such that the aircraft have a non-stop taxi to the departure runway and, then, a continuous climb to the available high-altitude overhead stream slot. NASA coordinated with the FAA Charlotte terminal area control center, the American Airlines ramp tower, the Charlotte International Airport air traffic control tower, and the en-route air traffic control centers for Washington, D.C., and Atlanta, GA. Operational use of ATD-2 schedules and more accurate departure times resulted in direct savings in fuel, time, and money. Since the start of ATD-2 deployment, NASA estimates more than 3.7 million pounds of fuel saved, 481 fewer hours of surface delays, and reduced carbon dioxide emissions by 11.6 million pounds, and reduced 2,869 hours of runtime on engines. (Thrust 1/ATD)

- NASA completed a technology transfer to the FAA for Dynamic Routes for Arrivals in Weather (DRAW). DRAW is a tool that helps fuse weather information with traffic flow data to allow controllers to more efficiently route aircraft – especially in adverse weather conditions. The transfer included preliminary extended metering and couple-scheduling requirements, as well as DRAW functionalities integrated into the FAA's Time-Based Flow Metering system, including demonstration in high-fidelity human-in-the-loop simulation. (Thrust 1/ATD)
- NASA developed and demonstrated the fourth and final technical capability level (TCL) for Unmanned Aircraft Systems Traffic Management (UTM), focusing on large-scale UAS operations in higher-density urban areas. The demonstrations occurred in Reno, NV, and Corpus Christi, TX. TCL4 represents a culmination of UTM research technology development to enable safe low-altitude UAS operations. UTM enabled adoption of global standards for small UAS operations, providing the FAA with a federated architecture for further development of its flight information management interface. UTM enabled commercial UAS service suppliers to develop operational systems for their clients and the FAA to execute its small UAS pilot programs. (Thrust 6/UTM)
- NASA provided an initial demonstration of near real-time hazard identification by using a NASA-developed framework at the FAA to monitor and identify incident precursor patterns. NASA transferred the flight anomaly detection code to the FAA for integration into its daily Aviation Safety Information Analysis and Sharing program operations. (Thrust 5/SWS)
- NASA completed final deliverables for reducing the risk of loss-of-control accidents to the Commercial Aviation Safety Team (CAST). CAST is a U.S. Government and aviation industry partnership that is working to adopt an integrated, data-driven strategy to reduce the fatality risk in commercial air travel in the U.S. The final deliverables included formal reporting methods to reduce risk of loss-of-control accidents and an evaluation of display strategies to provide control guidance for recovery from approach-to-stall. NASA demonstrated new capabilities that enabled pilots to better understand and respond safely to complex situations and improved human operator effectiveness. Closeout activities for the effort concluded in the fourth quarter of FY 2019. (Thrust 5/SWS)
- In support of developing urban air mobility operations, NASA conducted simulations to evaluate automated trajectory negotiation, collaborative decision-making, and connected trajectory-based technologies. (Thrust 6/ATM-X)

WORK IN PROGRESS IN FY 2020

- NASA will conduct the ATD-2 Phase 3 demonstration at the Fort Worth Air Route Traffic Control Center and the Terminal Radar Approach Control and Air Traffic Control Tower facilities at the Dallas/Fort Worth and Dallas Love Field airports. The demonstration will also involve American Airlines facilities at Dallas/Fort Worth and Southwest Airlines facilities at Dallas Love Field. Phase 3 will be a high-fidelity demonstration of all integrated IADS system capabilities, and it aims to validate the benefits of strategic surface metering during periods of significant demand/capacity imbalance. The ATD Project will begin close out in late FY 2020 after completing all NASA milestones and providing FY 2020 deliverables to the FAA research transition team. (Thrust 1/ATD)

- NASA will complete data analysis from its TCL4 demonstrations and transfer final research technical products to FAA Research Transition Team working groups for Concepts, Data Exchange, and Architecture; Sense and Avoid; and Communications and Navigation. The UTM project will continue to support the FAA for the UTM Pilot Program, and a joint final report on the results will be produced. (Thrust 6/UTM)
- NASA will develop models and metrics that characterize the safe operations of on-demand mobility/urban air mobility (UAM) air vehicles and that allow the safe integration and operation of these emergent users into the NAS. In addition, the project will analyze the safety of overall system designs that enable autonomy by reliance on backup/failover strategies. Current NASA work builds on recent experiments with industry partners and includes development of additional tools and techniques that can reduce the costs and improve effectiveness of the assurance of autonomy, potentially enabling new operations and new markets. (Thrust 5/SWS)
- NASA will conduct a human-in-the-loop evaluation in collaboration with external partners in FY 2020 to assess UAM operations and airspace integration suitable for the ARMD GC. In one such partnership, NASA will collaborate with Uber in the UAM arena to develop safe and efficient air transportation in highly populated U.S. cities. This collaboration is a first for the Agency regarding agreements for UAM operations modeling and simulation. NASA plans to simulate small passenger-carrying aircraft fights during peak scheduled air traffic. This process will enable establishment of the concept of operations for these emergent vehicles, new airspace procedural requirements, and new automation technology. (Thrust 6/ATM-X)

KEY ACHIEVEMENTS PLANNED FOR FY 2021

- The ATD project will close out in FY 2021 after providing final deliverables (including research documentation) to the FAA Research Transition Team. With this project close out, NASA's contribution to the FAA's NextGen effort is complete. NASA technologies will enable the FAA's deployment of NextGen technologies in FY 2021 and beyond and will enable airlines to leverage the FAA's NextGen information architecture to realize operational benefits. (Thrust 1/ATD)
- NASA will develop and deliver airspace management capabilities to enable UAM operations and airspace integration suitable for the ARMD GC. The demonstration will be enabled by an airspace and traffic management capability for Urban Air Mobility vehicles. (Thrusts 1 and 6/ATM-X)
- NASA will conduct concept evaluation simulations to determine airspace requirements for integration of unmanned autonomous operations into the National Airspace. These simulations will leverage prior work with Boeing's ecoDemonstrator aircraft to determine requirements for digital trajectory negotiations, data exchange, and concepts of operations that will ultimately establish requirements for research to enable autonomous freighter operations in FY 2021 and beyond. (Thrusts 1 and 6/ATM-X)
- NASA will conduct a FY 2021 flight test on Boeing's ecoDemonstrator aircraft to determine requirements for digital trajectory negotiations, data exchange, and concepts of operations that will establish research requirements for future research on autonomous freighter operations in FY 2021 and beyond. (Thrust 6/ATM-X)
- NASA will evaluate the use of a tool to actively monitor components while in operation to constrain the behavior of machine learning-enabled (e.g., autonomous) components in a system.

AIRSPACE OPERATIONS AND SAFETY PROGRAM

This evaluation will enable the FAA's development requirements for certification of autonomous systems. (Thrust 6/SWS)

- NASA will develop techniques that process vehicle state information to monitor and make predictions about system safety to evaluate potential courses of action. This research is critical to the development of an advanced in-time system-wide safety assurance system that would enable automated monitoring, assessment, and mitigation of risks. (Thrust 5/SWS)

Program Elements

AIR TRAFFIC MANAGEMENT – EXPLORATION (ATM-X)

The Air Traffic Management - eXploration (ATM-X) project will transform the air traffic management system to accommodate the growing demand of new entrants with new mission requirements while also allowing established, large commercial aircraft operators to fly more user-preferred routes with improved predictability. The project will explore challenging use cases in an open airspace management system architecture to establish key performance parameters and prioritize technical challenges. An example exercise is the definition of requirements for high-density vertical lift vehicle operations for UAM. ATM-X will provide early demonstration of emerging market operations by simulating higher levels of industry-provided services to validate the potential for more rapid modernization by incorporating innovations at "industry" speeds.

ATM-X will demonstrate that an open architecture approach, integration of air traffic technologies, system-wide data use, advances in human-machine teaming, and increasingly autonomous decision-making will provide comprehensive situational awareness, improved coordinated decision-making, and disruption management. This demonstration will enable flexible, user-preferred, predictable, and robust operations. The project will validate and transfer key concepts and technologies to the FAA and industry stakeholders.

SYSTEM-WIDE SAFETY (SWS)

The System-Wide Safety (SWS) project will develop tools, methods, and technologies to enable capabilities envisioned by ARMD’s Strategic Thrust 5 (In-Time System-Wide Safety Assurance). The SWS project will perform research to explore and understand the impact on safety of the complexity introduced by technology advances aimed at improving the efficiency of flight, broader access to airspace, and the expansion of services provided by air vehicles. The project will also develop and demonstrate innovative solutions that enable the aviation transformation envisioned by ARMD through proactive mitigation of risks in accordance with target levels of safety. The following are drivers of increased system safety awareness:

- increased access to relevant data;
- integrated analysis capabilities;
- improved real-time detection and alerting of hazards at the domain level;
- decision support; and
- in some cases, automated mitigation strategies.

AIRSPACE OPERATIONS AND SAFETY PROGRAM

The SWS project also addresses the need, identified in Strategic Thrusts 1 and 6, for safety-related advances in methods used for the verification and validation of advanced, increasingly autonomous systems.

Program Schedule

Date	Significant Event
Jun 2019	UTM – Initiate TCL4 testing to incorporate TCL3 research and to manage large-scale contingencies.
Aug 2019	ATD – Conduct Phase 2 Fused IADS Demonstration. UTM – Perform TCL4 flight validation and demonstration of the UTM system in complex urban environments. Transfer of technology to the FAA: delivery of a prototype cloud-based server for low-altitude UAS traffic management and related documentation.
Aug 2019	ATM-X – Develop UAM Services dynamic scheduling and congestion management operations.
Sep 2019	ATM-X – Release the NASA Test Bed Build 2 with modeling of emergent vehicles and missions. SWS – Develop a safety assurance dashboard that can give a comprehensive view of retired and residual risks.
Jun 2020	SWS – Develop models and metrics that characterize the safe operations of on demand mobility/urban air mobility (UAM) air vehicles and that allow the safe integration and operation of these emergent users into the NAS. ATD – Conduct Phase 3 full-system demonstration of the IADS metroplex departure scheduling concept.
Jun 2020	UTM – Complete final concept of operations and project closeout.
Aug 2020	ATM-X – Partner with Boeing to demonstrate autonomous: (1) digital data transfer; and (2) trajectory management technologies through tailored arrival management of separation assurance and optimized-profile descents during arrival.
Sep 2020	ATM-X – Develop and deliver airspace management capabilities to enable UAM operations and airspace integration suitable for the ARMD GC.
Sep 2020	ATM-X – Perform human-in-the-loop simulation of mixed legacy and new entrants interacting in controlled airspace.
Mar 2021	ATD – Complete final research documentation and project closeout.
Sep 2021	SWS – Demonstrate in-time safety monitoring for an on-demand/urban air mobility integrated flight test in relevant airspace.
Dec 2021	ATM-X – Initiate Phase 2 development with integrated elements of multiple Phase 1 technologies towards defined, focused research and field demonstrations supporting Technical Challenges.

AIRSPACE OPERATIONS AND SAFETY PROGRAM

Program Management & Commitments

Program Element	Provider
Air Traffic Management - Exploration (ATM-X)	Provider(s): Ames Research Center (ARC), Langley Research Center (LaRC), Glenn Research Center (GRC) Lead Center: ARC Performing Center(s): ARC, LaRC, GRC Cost Share Partner(s): FAA, Boeing, General Electric (GE), Uber, American Airlines, Port Authority of New York and New Jersey, German Aerospace Center (DLR)
System-Wide Safety (SWS)	Provider(s): ARC, LaRC, GRC Lead Center: LaRC Performing Center(s): ARC, LaRC, GRC Cost Share Partner(s): FAA, Department of Homeland Security, Department of Defense (DoD) Naval Medical Research Unit, DoD Air Force Research Laboratory, National Research Council, Networking and Information Technology Research and Development Program, Defense Advanced Research Projects Agency, MITRE, Collins Aerospace, Honeywell, Boeing Flight Services, GE Global Research, American Airlines, Southwest Airlines, Swiss International Airlines, easyJet, Denver International Airport, Commercial Aviation Safety Team, Unmanned Aircraft Safety Team, Association for Unmanned Vehicle Systems International, RTCA, French Aerospace Lab (ONERA), DLR

Acquisition Strategy

The AOSP spans research and technology from foundational research to integrated system capabilities. This broad spectrum necessitates the use of a wide array of acquisition tools relevant to the appropriate work awarded externally through full and open competition. Teaming among large companies, small businesses, and universities is highly encouraged for all procurement actions.

MAJOR CONTRACTS/AWARDS

NASA’s Aeronautics programs award multiple smaller contracts, which are generally less than $5 million. The contracts are widely distributed across academia and industry.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance (Annual)	Expert Review	Oct 2019	The 12-month review is a formal independent peer review. Experts from other Government agencies report on their assessment of technical and programmatic risk and/or program weaknesses.	Determined that the projects made satisfactory progress in meeting technical challenges as well as all annual performance indicators.	Oct 2020

ADVANCED AIR VEHICLES PROGRAM

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**272.1**	**--**	**212.7**	**222.2**	**230.3**	**261.2**	**266.2**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Multirotor Test Bed installed in the U.S. Army 7-foot x 10-foot wind tunnel at NASA Ames Research Center, shown above in October 2019, for Initial Functional Checkouts.

The Advanced Air Vehicles Program (AAVP) develops knowledge, technologies, tools, and innovative concepts to enable safe new aircraft that will fly faster, cleaner, and quieter and use fuel far more efficiently than in the past. All major modern U.S. aircraft incorporate NASA research and technology. The type of research performed by AAVP will prime the technology pipeline, enabling continued U.S. leadership, competitiveness, and high-quality jobs in the future. Reducing fuel usage, noise, and emissions and improving intrinsic safety by these advanced integrated technologies and capabilities improves vehicle performance. Fuel efficiency and environmental factors will play an increasingly significant role as the aviation market grows in capacity. The broad range of technologies developed by AAVP will help ensure continued U.S. industrial leadership that will benefit both the economy and the environment. Across the program, NASA will continue to engage partners from industry, academia, and other Government agencies to maintain a sufficiently broad perspective on technology solutions to these challenges, to pursue mutually beneficial collaborations, and to leverage opportunities for effective technology transition. AAVP directly supports three of the ARMD Strategic Thrusts:

- Thrust 2: Innovation in Commercial Supersonic Aircraft
- Thrust 3: Ultra-Efficient Subsonic Transports
- Thrust 4: Safe, Quiet, and Affordable Vertical Lift Air Vehicles

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

ADVANCED AIR VEHICLES PROGRAM

At the end of each achievement identified in this document, there is a mapping to link it to the related Strategic Research Thrust and Program Element.

ACHIEVEMENTS IN FY 2019

- NASA performed a series of exploratory tests of methodologies to measure community response to sonic boom noise in Galveston, TX. The purpose of these tests was to gain experience with remote aircraft operations, community noise exposure estimations, social surveys, and overall community engagement. Conducting community response field studies using these methods (including indoor and outdoor noise metrics, exposure estimates, and survey tools and protocols) will help define and validate this flight data. The data and experience gained will inform future community response studies and support the X-59 QueSST aircraft, which is currently under development within IASP. (Thrust 2/CST)
- NASA and Boeing completed high-speed tests and initiated low-speed and high-lift tests of an advanced transonic truss-braced wing (TTBW) design for higher cruise speeds incorporating an integrated high-lift system. The TTBW technology enables a larger wingspan for reduced drag and fuel burn while meeting a reduced structural weight requirement. Results of the high-speed tests confirmed a nine percent fuel burn benefit for the technology. To investigate the structural weight reduction, NASA, in collaboration with Aurora Flight Sciences and the University of Michigan, completed post-test analysis of the advanced wing structure to assess airframe weight limitations and the potential fuel burn reduction of the technology. (Thrust 3/Advanced Air Transport Technology-AATT)
- NASA matured Megawatt (MW)-class Hybrid Gas-Electric Propulsion (HGEP) aircraft concepts and technologies for commercial transport aircraft. A focus for FY 2019 was the design, assembly and initial testing of a MW-scaled electric aircraft powertrain in the NASA Electric Aircraft Testbed (NEAT) facility. The design and assembly of a representative electrified aircraft powertrain with commercial off-the-shelf (COTS) non-flight weight components, which occurred in the NEAT facility, demonstrated communications and controls. This advanced HGEP powertrain provides an aircraft system-level fuel burn reduction according to system studies, potentially enabling HGEP introduction into new U.S. aviation markets for smaller transport aircraft. (Thrust 3/AATT)
- NASA completed an assessment of test results on an advanced, low-emission, fuel-flexible combustor concept for a small core engine in collaboration with the United Technologies Research Center. This concept focused on reducing harmful NOx emissions 80 percent below the 2008 international NOx emissions limits set forth by the Committee on Aviation Environmental Protection, with minimal impacts on weight, noise, and component life. NASA identified stable and efficient combustion operations for small-core engine technologies as critical to advanced, low-emissions, fuel-flexible small core engine combustors. (Thrust 3/AATT)
- In FY 2019, NASA closed out the Advanced Composites Project (ACP). NASA demonstrated computational tools and methods, including Non-Destructive Evaluation (NDE) simulations, validating tools and methodologies through integrated component-level testing and enabling collectively more than a 20 percent reduction in the timeline to develop and certify composite structures, as shown by system analysis. These tools and computational methods enable the ability to rapidly inspect a composite structure, transfer the findings into a structural analysis, and make a decision on the need to repair damage or manufacturing defects found during inspection. Multiple technologies were developed and validated through research conducted by Government and multi-industry cooperative research teams executing within the NASA Advanced Composites

Consortium or supported by NASA Research Announcement (NRA) awards. The reduction in the timeline to develop and certify composite structures will help U.S. industry retain a global competitive advantage in aircraft manufacturing to support emerging markets for transport and urban air mobility vehicles. (Thrust 3/ACP)

- NASA completed the initial demonstration of multi-disciplinary tools to optimize low-noise rotor Vertical Take Off and Landing (VTOL) designs. In a series of flight experiments with Federal Aviation Administration (FAA) partners, NASA also demonstrated low-noise flight operations that provided a 58 percent reduction in the Sound Exposure Level footprint area for commercial rotary wing vehicles. Based on these successful flight tests, NASA developed flight guidelines and distributed them to the helicopter community, which implemented the guidelines to provide a positive impact on community noise. The low-noise design tools will assist in future VTOL designs that will reduce community noise impact while simultaneously maintaining or improving aerodynamic performance. (Thrust 4/RVLT)
- NASA initiated the development of a database of computed Urban Air Mobility (UAM) vehicle sounds that can assess the cumulative noise impact of UAM fleet operations on the community. With very limited acoustic data for these new UAM vehicle configurations, the potential noise impact on the community is unknown. This new focus area is leveraging previous noise prediction research and tool development to establish initial predictions of UAM vehicle noise. The FAA, industry, and municipalities will use the new tools to assess and minimize the impact of UAM operations on the community. Other ARMD projects, such as ATM-X, will provide the expected flight conditions and trajectories for the vehicle operations. (Thrust 4/RVLT)
- NASA funded a study assessing the Failure Modes, Effects and Criticality Analysis (FMECA) for four electric and hybrid-electric UAM propulsion system architectures. The four systems were generic systems developed by NASA to represent the many classes of propulsion systems in the UAM market. The results showed the components that are most critical to propulsion system reliability and provided guidance for the most critical areas for further NASA research. The report is publicly available as a NASA Contractor Report, and the FAA and industry can use this study as a template for how to conduct a FMECA analysis. (Thrust 4/RVLT)
- NASA began applying Uncertainty Quantification (UQ) analysis approaches to hypersonic ground tests in FY 2019, building on approaches identified in FY 2017 and successfully applied to a modeling and simulation challenge in FY 2018. Application of these UQ approaches to ground testing allows for increased testing efficiency, better quantification of test uncertainty, improved understanding of risk, improved understanding of where to invest to reduce uncertainty, and improved understanding of what changes to the vehicle design will result in increased performance of operational hypersonic vehicles. (Hypersonic)

WORK IN PROGRESS IN FY 2020

- NASA will provide a suite of prediction tools to support timely and accurate validation of the acoustic performance of the Low-Boom Flight Demonstrator aircraft. NASA will also perform a capability review ensuring work is prioritized, delivering Pre-Flight Capability prior to the Low-Boom Flight Demonstrator acoustic validation. NASA will host a sonic boom prediction workshop and conduct a sonic boom wind tunnel test using a model of the X-59 demonstrator. The wind tunnel test will support tool development, provide additional tool validation data, and inform the X-59 acoustic validation data collection. (Thrust 2/CST)
- NASA will complete the Field Study Methodology for Sonic Boom Community Response by developing models for predicting exterior pressure loads, structural vibrations, and indoor

acoustic fields caused by sonic booms. NASA will complete development of models of human response to sonic boom noise in indoor and outdoor environments. Quantifying atmospheric effects on low noise sonic booms provided for the development of a draft test plan of survey tools and test protocols for future community studies. (Thrust 2/CST)

- NASA will conduct a virtual international workshop to share survey techniques used during the FY 2019 community test in Galveston, TX. The sharing of recruitment methods, survey techniques, and lessons learned help gain feedback and influence survey designs for future X-59 tests. NASA will also identify the initial set of base locations and test communities for the future X-59 tests. (Thrust 2/CST)
- NASA will conduct wind tunnel tests on a 10 percent scale aircraft research model that includes high-lift features and "common" attributes, enabling the ability to test at multiple organizations across the U.S. The "High Lift Common Research Model" will help establish the feasibility of quiet high-lift technology concepts with use of active flow control techniques to reduce aircraft noise. The technical approach consists of using various methods to fill the gaps between aircraft wing leading- and trailing-edge flaps and slats, which produce a large fraction of aircraft noise on approach. With this knowledge, research will contribute to advancing wing designs that may be a major aspect of future product designs. (Thrust 3/AATT)
- In partnership with industry, NASA helped develop advanced compressor casing treatments, three-dimensional compressor blade designs, and high-temperature disks and seals. These technologies are critical for advancing small-core turbofan engines with higher engine bypass and pressure ratios to improve fuel efficiency. NASA will complete testing and analysis for these reduced size/flow, high-pressure compressors and high-temperature disk/seals in FY 2020. (Thrust 3/AATT)
- NASA will develop and demonstrate a testing capability at the NASA Electric Aircraft Testbed (NEAT) facility to test MW-scale aircraft electrical components and powertrains under flight altitude conditions. This test will be the first of a MW-class electrified powertrain under conditions representing flight altitude. The test will establish the practicality of employing these types of components in future aircraft systems while ensuring safe and efficient operations under flight conditions. (Thrust 3/AATT)
- NASA will re-configure an existing test lab to develop an integrated system geared towards assessing performance and reliability of electric propulsion UAM components, including thermal effects. These integrated system tests will use a 150-kilowatt (kW) electromechanical powertrain test rig. The test system will utilize motor emulators with a capacity of up to 100-kW each to simulate motor loads. The emulators allow a great deal of flexibility by enabling fast reconfigurations of the test cell for different system architectures. The data generated from integrated system tests help to validate predictive models and explore potential failure modes and mitigation strategies and provide data for means of compliance standards. (Thrust 4/RVLT)
- The Multirotor Test Bed (MTB) is a new capability that NASA developed that will be used for wind tunnel and hover testing of multirotor (up to six rotors) aircraft configurations with a focus on individual rotor loads. Data from MTB testing help to validate simulations of multirotor systems and eventually lead to better predictions of multirotor performance. (Thrust 4/RVLT)
- NASA will employ an analysis tool to assess UAM fleet noise using operations data provided by NASA ATM-X. The results of this study will help establish goals for UAM noise footprint and will establish a consistent assessment process for use within NASA and for external users. (Thrust 4/RVLT)
- NASA will develop and document new approaches to perform UQ model validation by applying UQ analysis to computational modeling and hypersonic aerodynamic, aerothermodynamic, and

propulsion ground test data for hypersonic applications. Improved UQ helps identify the most fruitful areas for targeted investment and can lead to higher performing and/or more robust hypersonic vehicle designs. (Hypersonic)

- NASA will conduct experiments of automated mode transition of a combined cycle engine propulsion system utilizing a real-time Turbojet Engine simulator and a Dual Mode Ram Jet simulator to establish the control theory and methodology for such transition. Automated control is a requirement for successful operation of a combined cycle system as it ensures operability while maximizing system performance. (Hypersonic)

KEY ACHIEVEMENTS PLANNED FOR FY 2021

- NASA will identify and procure the acoustic validation measurement systems and prepare plans for the Low-Boom Flight Demonstrator Validation in support of the Low-Boom Flight test. (Thrust 2/CST)
- NASA will complete its assessment of pre-test prediction capabilities by using prediction validation tools in preparation of the Low-Boom Flight Demonstrator Validation Process. These tools will provide model-based noise prediction values that will be validated during future flights. (Thrust 2/CST)
- NASA will conduct testing of a flight-weight, flight-like electric inverter at Megawatt-class power level under simulated altitude conditions of 30,000 feet at the NEAT facility. This test will establish key components for electrified aircraft that can perform safely under flight conditions. In addition, NASA will complete a Critical Design Review (CDR) of a turbofan engine test to determine the impact of large-scale power extraction from both high-and low-pressure engine spools. This future test will ensure that Megawatt-class power extraction from turbofan engines will not adversely affect overall Electrified Aircraft Propulsion (EAP) system performance. (Thrust 3/AATT)
- NASA will validate noise reduction technologies focusing on advanced aircraft wing slats/flaps and turbine engine acoustic liners, demonstrating approximately 25 percent lower noise than existing technology. These technologies will benefit the aviation industry by ensuring quiet operation of aircraft near airports. (Thrust 3/AATT)
- NASA RVLT will lead the Society of Automotive Engineers AE-7 Electric Aircraft Committee to develop a High Voltage Direct Current/Power Quality Standard for electric vertical take-off and landing vehicles, enabling the improvement in reliability of electric UAM propulsion. (Thrust 4/RVLT)
- NASA RVLT will demonstrate the ability to calculate multirotor vehicle acoustics for UAM by modeling the individual rotors and their interactions with the airframe, as the interactions between these types of components are a major contributor to aircraft noise. (Thrust 4/RVLT)
- NASA will apply calibrated models to compute hypersonic flight test performance predictions with quantified uncertainty. An approach to perform design optimization, with quantified uncertainties, will be developed and applied for a Turbine-Based Combined Cycle (TBCC) propulsion component. This UQ methodology will be available for use on future design and analysis efforts. (Hypersonic)
- NASA will implement its calibrated UQ methodology, coupled with Computational Fluid Dynamics (CFD) design and analysis, to design a TBCC propulsion component. The component will be fabricated (FY 2021) and ground tested in the 4-foot x 4-foot Unitary Plan Wind Tunnel (FY 2022). The Agency’s use of CFD predictions as a surrogate for High Speed Testing provides an initial assessment of test data accuracy. (Hypersonic)

ADVANCED AIR VEHICLES PROGRAM

Program Elements

ADVANCED AIR TRANSPORT TECHNOLOGY (AATT)

The Advanced Air Transport Technology (AATT) project enables revolutionary advancements in future aircraft performance. Research explores solutions to advance knowledge, technologies, and concepts, enabling major steps in energy efficiency and environmental compatibility and resulting in reduced fuel burned, harmful emissions, and noise around airports. The research also benefits U.S. industrial competitiveness in the subsonic transport aircraft market, as well as, potentially opening new markets for U.S. entrants in the regional jet and smaller size classes. The knowledge gained from this research in the form of experiments, data, system studies, and analyses, is critical for conceiving and designing more efficient, quieter aircraft. Advanced air transport research directly supports ARMD Strategic Thrust 3 and focuses on developing advanced technologies and tools for future generations of commercial transport – including the emerging area of electrified aircraft propulsion and the supporting engine core research needed to develop new engines that will ultimately power the new vehicles. Although this project focuses on the long-term technology timeframe, it also contributes to both near- and mid-term development by demonstrating interim technology advancements.

REVOLUTIONARY VERTICAL LIFT TECHNOLOGY (RVLT)

The Revolutionary Vertical Lift Technology (RVLT) project develops, demonstrates and validates tools, technologies, and flight operations methods that reduce VTOL aircraft noise and improve safety, thereby enabling expanded use of VTOL aircraft in an integrated airspace environment. The unique ability of vertical lift vehicles to hover has significant applications in the civil market for human and cargo transportation and delivery systems as evidenced by the emerging UAM industry. Additionally, advanced vertical lift technologies and capabilities are directly relevant to vehicles for inspection and surveillance missions, oil and gas exploration, disaster relief, and many more critical operations. RVLT research advances technologies that will increase safety and reduce noise and annoyance to overcome significant barriers for the emergence of a new UAM market. To accomplish this research, NASA uses advanced computer-based, multi-fidelity prediction methods, unique NASA facilities, and state-of-the-art experimental techniques. RVLT considers current and future vertical lift vehicles of many classes and sizes, ranging from small-unmanned configurations to configurations that are viable as inter- and intra-city transportation. The RVLT Project primarily supports ARMD Strategic Thrust 4.

COMMERCIAL SUPERSONIC TECHNOLOGY (CST)

Supersonic vehicle research includes tools, technologies, and knowledge that will help eliminate today's technical barriers to practical, commercial supersonic flight. These barriers include sonic boom noise, supersonic aircraft fuel efficiency, airport community noise, high-altitude emissions, vehicle aeroservoelastic design, supersonic operations, and the ability to design vehicles in an integrated, multidisciplinary manner. The Commercial Supersonic Technology (CST) project directly supports ARMD Strategic Thrust 2: Innovation in Commercial Supersonic Flight. Along with other projects in ARMD, the CST project leverages the purpose-built X-59 Low-Boom Flight Demonstrator to gather data on the human responses to low-level sonic booms. This human community response data informs national and international regulatory organizations' efforts to define certification standards that commercial aircraft manufacturers can follow to create new supersonic aircraft markets. In preparation for the use of the X-59, research establishes the necessary approaches and techniques for objectively measuring the level of supersonic overflight noise acceptable to communities living near future commercial supersonic flight paths. These approaches, techniques, and resulting data will be the foundation of annoyance limits in the international standards.

HYPERSONIC TECHNOLOGY (HT)

NASA maintains unique specialized facilities and experts who focus on key fundamental research areas that explore key challenges in hypersonic flight. This project coordinates closely with partners in the Department of Defense (DoD) so NASA can leverage their investment in ground and flight activities to develop and validate advanced physics-based computational models. At the same time, the DoD benefits from NASA expertise, analyses, testing capabilities, and computational models. NASA is able to support U.S. industry's emerging interest in civil hypersonic vehicles while supporting DoD needs. The project focuses on hypersonic propulsion systems, re-usable vehicle technologies, high-temperature materials, and systems analysis.

Program Schedule

Date	Significant Event
Jun 2019	AATT – Completion and demonstration of an advanced small core, low-emissions, fuel-flexible combustor concept focusing on reducing harmful NOx emissions 80 percent below the 2008 international NOx emissions limits with minimal impacts on weight, noise, and component life.
Sep 2019	AATT – Completion of a Hybrid Gas-Electric Propulsion (HGEP) Concept establishing a 5-10 MW hybrid gas-electric propulsion system for a commercial transport aircraft.
Sep 2019	RVLT – Achieve noise reduction of at least five decibels (dB) on approach to landing during helicopter flight test operations designed for low-noise.
Dec 2019	AC – Completion of accurate strength and life prediction methodologies to develop and validate strength and life prediction tools with known accuracy for complex composite structures and standardized procedures.
Dec 2019	AC – Completion of rapid inspection and characterization methodologies to develop and demonstrate Non-Destructive Evaluation (NDE) systems to enable technologies that fully inspect and rapidly disposition findings in complex systems.
Dec 2019	AC – Completion of efficient manufacturing process development to demonstrate advanced computational methods to relate manufacturing parameters to defect formation, and to connect commercial design and analysis software to enable structural optimization while resolving predicted manufacturing issues.
Jan 2020	CST – Completion of the sonic boom community response metrics and field study methodologies including indoor and outdoor noise metrics, survey tools and test protocols to support community studies with a demonstrator aircraft.
Mar 2020	AATT – Completion of Higher Aspect Ratio Wing (HARW) concept enabling a 1.5-2X increase in the aspect ratio of a lightweight wing with safe structures and flight control.

ADVANCED AIR VEHICLES PROGRAM

Date	Significant Event
Sep 2020	AATT – Complete a conceptual design and validate the performance of compressor and core concepts for a compact high Operating Pressure Ratio (OPR) gas generator concept, enabling reduced size/flow high-pressure compressors and high-temperature disk/seals that are critical for 50+ OPR gas generators with minimal impact on noise and component life.
Sep 2020	RVLT – Develop the theory, implement, and assess functionality of Broadband Acoustic Rotor Codes for application to Vertical Take Off and Landing (VTOL) Urban Air Mobility (UAM) vehicles.
Jun 2021	AATT – Completion of an advanced fan and high-lift noise concept to reduce fan (lateral and flyover) and high-lift system (approach) noise on a component basis by four decibels (approximately 25 percent reduction in perceived noise) with minimal impact on weight and performance.
Sep 2021	CST – Completion of a Pre-Flight Prediction Capability Review supporting timely and accurate pre-flight exposure planning for community response testing.
Sep 2021	RVLT – Trajectory optimization for UAM vehicles with noise metrics as constraints and evaluate the impact of flight operation changes on the noise footprint.

Program Management & Commitments

Program Element	Provider
Advanced Air Transport Technology (AATT)	Provider(s): ARC, AFRC, GRC, LaRC Lead Center: GRC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): U.S. Air Force, Boeing, Pratt & Whitney, Northrop Grumman, General Electric Aviation, Aurora, United Technologies Corporation, Rolls Royce/Liberty Works, Honeywell, FAA, Lockheed Martin, U.S. Navy, Department of Energy
Revolutionary Vertical Lift Technology (RVLT)	Provider(s): ARC, AFRC, GRC, LaRC Lead Center: LaRC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): FAA, U.S. Army, U.S. Air Force, Bell, Boeing, United Technologies Research Center, DLR, ONERA, U.S. Navy, QuesTek, Pennsylvania State University – Applied Research Laboratory, Workhorse/Surefly, A&P Technologies
Commercial Supersonic Technology (CST)	Provider(s): ARC, GRC, LaRC, AFRC Lead Center: LaRC Performing Center(s): ARC, GRC, LaRC, AFRC Cost Share Partner(s): Gulfstream Aerospace, FAA, JAXA, Rockwell Collins, ONERA, The University of Washington, Boeing Research and Technology, U.S. Navy

ADVANCED AIR VEHICLES PROGRAM

Program Element	Provider
Hypersonic Technology (HT)	Provider(s): AFRC, GRC, LaRC Lead Center: LaRC Performing Center(s): AFRC, GRC, and LaRC Cost Share Partners: DoD, John Hopkins University/Applied Physics Laboratory

Acquisition Strategy

Research and technology spans from foundational research to integrated system capabilities. This broad spectrum necessitates the use of a variety of acquisition tools relevant to the appropriate work awarded externally through full and open competition. Teaming among large companies, small businesses, and universities is highly encouraged for all procurement actions.

MAJOR CONTRACTS/AWARDS

NASA's Aeronautics programs award multiple smaller contracts, which are typically less than $5 million. The contracts are also widely distributed across academia and industry.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Expert Review	Oct 2019	The 12-month review is a formal independent peer review. Experts from other Government agencies report on their assessment of technical and programmatic risk and/or program weaknesses.	The Panel provided favorable reviews to the projects. The Panel also gave constructive comments and recommendations.	Oct 2020

INTEGRATED AVIATION SYSTEMS PROGRAM

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Low Boom Flight Demonstrator	105.9	103.5	**79.1**	75.5	13.8	3.8	0.0
Integrated Aviation Systems Program	103.7	--	**190.0**	180.9	230.6	205.7	204.5
Total Budget	**209.6**	**--**	**269.0**	**256.4**	**244.4**	**209.5**	**204.5**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

In preparation for X-57 aircraft integration, electric cruise motors (shown here) were tested using the Airvolt Aircraft Electric Propulsion Test Stand at Armstrong Flight Research Center.

Flight research is critically important to create a bridge between fundamental research and a level of technology readiness that enables technology transfer to the aviation community. Specifically, flight research advances technology readiness to the levels required for incorporation of new technologies into future air vehicles and operational systems.

The goal of the Integrated Aviation Systems Program (IASP) is to demonstrate integrated concepts and technologies at a maturity level sufficient to enable their incorporation into operational systems at a level of risk that is acceptable to the aviation community. To support this goal, IASP focuses on the rigorous execution of highly complex flight tests and related experiments. These flight tests support all phases of the Aeronautics Research Mission Directorate (ARMD) research, not just the culmination of research activities. IASP often works collaboratively with other ARMD programs (e.g., Advanced Air Vehicles Program) to facilitate flight test activities. For technologies at low Technology Readiness Levels (TRLs), IASP flight research accelerates the development and/or determines the feasibility of those technologies. For more mature technologies, flight research will reduce risks and accelerate transition of those technologies to industry.

IASP has been addressing the national challenge of routine access of Unmanned Aircraft Systems (UAS) into the National Airspace System (NAS) for civil use. Historically, UAS have supported military and security operations overseas, with training occurring primarily in the United States. However, significant interest is growing in civil uses, including commercial photography, aerial mapping, crop monitoring, advertising, communications, retail services, and broadcasting. The Federal Aviation Administration (FAA) is developing new policies, procedures, and approval processes to address demand for increasing

INTEGRATED AVIATION SYSTEMS PROGRAM

civil UAS operations in the NAS. NASA is completing its work culminating in the contribution of flight-validated data and capabilities that reduce technical barriers related to the safety and operational challenges associated with enabling routine civil UAS access to the NAS. IASP works closely with the Airspace Operations and Safety Program and the FAA to enable these advances.

The Advanced Air Mobility (AAM) project is in execution and will build on recent progress achieved in UAS and UAS Traffic Management (UTM) projects. AAM is working in close coordination with other NASA ARMD airspace operations and vehicle technology projects to help enable new emerging markets in aviation. AAM will conduct developmental testing activities in preparation for the Grand Challenge (GC) series, which will provide key knowledge and data to both the aviation community and the FAA. This will help inform regulations and standards for this new market.

The IASP is developing NASA's newest purpose-built experimental supersonic vehicle known as the X-59 QueSST aircraft. The aircraft supports the Low-Boom Flight Demonstration (LBFD) mission led by the AAVP and IASP and supported by both the LBFD and Flight Demonstrations and Capabilities (FDC) projects. The purpose of the LBFD mission is to develop a low-boom community response database and provide it to U.S. and international regulators in support of their development of a noise-based standard for supersonic overland flight. While the design and build portion of the LBFD mission under the Low-Boom Flight Demonstrator project is in IASP, the FDC project is also a key contributor to the LBFD mission. The FDC project will handle flight operations during the community response testing phase of the LBFD mission.

IASP leads the FDC project, which provides flight testing of technologies that enable new aircraft configurations and significantly reduce fuel consumption, noise, and emissions. One such aircraft is NASA’s first all-electric X-plane, the X-57 ‘Maxwell’. The primary goal of the X-57 project is to develop and then test the aircraft's electric propulsion design and airworthiness processes so that they can be provided to regulators. This will result in more efficient certification procedures for distributed electric propulsion systems.

The Electrified Powertrain Flight Demonstration (EPFD) project, also led by IASP, is in formulation and focuses on flight demonstrations that advance the state-of-the-art in MW-class more-electric aircraft to enable enduring leadership of the U.S. aviation industry for the benefit of the country and the U.S. flying public.

IASP directly supports three of the ARMD Strategic Thrusts:

- Thrust 2: Innovation in Commercial Supersonic Aircraft
- Thrust 3: Ultra-Efficient Subsonic Transports
- Thrust 6: Assured Autonomy for Aviation Transformation

EXPLANATION OF MAJOR CHANGES IN FY 2021

In FY 2021, the AAM project will move from the Airspace Operations and Systems Program into the Integrated Aviation Systems Program. The AAM Project will be managing large complex demonstrations beginning with the Urban Air Mobility Grand Challenge, which involves industry, the FAA and other Aeronautics projects. The IASP has the expertise to conduct this type of cross program integrated demonstration.

INTEGRATED AVIATION SYSTEMS PROGRAM

At the end of each achievement identified in this document, there is a mapping to link it to the related Strategic Research Thrust and Program Element.

ACHIEVEMENTS IN FY 2019

- In preparation for X-59 flight operations (beginning in FY 2023), NASA began developing the capability to conduct in-situ measurements and optical observations of the X-59 aircraft shockwave structure as well as a mobile command center for deployed LBFD mission community response operations. (Thrust 2/FDC)
- NASA Landing Gear Noise Reduction work demonstrated a greater than 30 percent reduction in the airframe component of community noise with minimal impact on aircraft weight and performance. This noise reduction methodology and associated airframe technologies will greatly benefit communities near airports and expand airport operations given the reduced noise impact of aircraft. (Thrust 3/FDC)
- NASA continued X-57 aircraft integration activities in preparation for first flight in FY 2020. These activities included engine mount testing, fabrication of a new, high-aspect ratio wing, and mounting electric motors for primary propulsion. Through these activities, NASA is learning how to integrate electrified aircraft power distribution and propulsion systems and is participating in the development of industry standards for electrified aircraft. (Thrust 3/FDC)
- NASA completed flight testing of a low-size, weight, and power airborne Detect and Avoid (DAA) surveillance capability for mid-size UAS. This flight demonstration was a key contributing event to inform standards that will define how unmanned aircraft can operate safely in the NAS. (Thrust 6/UAS-NAS)
- NASA began flight testing of a new control and non-payload communications radio in relevant operational environments. This test will demonstrate command and control capability in flight and contribute to standards development that will define how UAS can safely operate in the NAS. (Thrust 6/UAS-NAS)
- As a part of risk reduction activities during pre-formulation, NASA awarded three contracts to industry partners to assess integrating electric powertrain, power distribution, and energy storage components for primary propulsion onto an existing airframe and to assess propulsion system performance through flight demonstration. The focus was on high-power electrified aircraft propulsion systems of about 1-megawatt power. (Thrust 3/EPFD)
- NASA conducted an Urban Air Mobility (UAM) Industry Day and presented their intent to conduct a series of GCs for the UAM community. The purpose of the GC is to promote public confidence in UAM safety while capturing the public's interest in this future industry. As part of pre-formulation, the AAM project also conducted a tollgate review of the upcoming GC to ensure that plans and necessary agreements are in place to support timely execution of the GC as well as precursor activities. (Thrust 6/AAM)

WORK IN PROGRESS IN FY 2020

- NASA will continue preparations for X-59 flight operations, which includes further developing capabilities to conduct in-situ measurements and optical observations of the X-59 aircraft

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shockwave structure as well as developing a mobile command center for deployed LBFD mission community response operations. (Thrust 2/FDC)

- NASA will complete risk reduction activities in support of the upcoming Electrified Powertrain Flight Demonstration. In addition, the EPFD project will complete Mission Concept, Formulation, and Implementation Reviews in anticipation of establishing a baseline plan for project execution early in FY 2021. (Thrust 3/EPFD)
- NASA will complete preparations and conduct the first flight of the X-57 Maxwell aircraft (Mod II). FDC project personnel also continue to support the development of manufacturing standards for electrified aircraft systems to enable progress for U.S. companies to develop aircraft that are more-electric. (Thrust 3/FDC)
- NASA will complete flight testing of the new control and non-payload communications radio in relevant operational environments. The test will demonstrate command and control capability in flight and contribute to standards development that will define how UAS can operate safely in the NAS. (Thrust 6/UAS-NAS)
- NASA will complete planned work that contributes to safe UAS operations in the National Airspace System. The final deliverables will include research findings through a series of technology demonstrations and simulations, which will enable development of DAA and Command and Control (C2) Minimum Operational Performance Standards (MOPS) by RTCA (Radio Technical Commission for Aeronautics) for mid-size UAS. (Thrust 6/UAS-NAS)
- NASA will complete the Systems Integration and Operationalization (SIO) activity. NASA and its partners will work together to tackle challenges that prevent routine commercial UAS operations today, including development, integration, and certification of unmanned aircraft and avionics. The SIO activity will lead to multiple flight demonstrations that focus on UAS missions at altitudes greater than 500-feet above ground level and include integrated Detect and Avoid and Command and Control technologies. (Thrust 6/UAS-NAS)
- NASA will successfully complete reviews authorizing the AAM project to enter the implementation phase of the project. The project will evaluate the maturity of key systems for UAM through developmental testing in preparation for the first of a series of GCs. (Thrust 6/AAM)
- NASA will complete formulation of the AAM project and move into project implementation. In addition, NASA will continue preparations for upcoming GC events; a key element of these preparations will be establishing agreements with GC industry participants who will participate in GC Development Testing (early FY 2021) and GC 1 (FY 2022). (Thrust 6/AAM)

KEY ACHIEVEMENTS PLANNED FOR FY 2021

- In preparation for X-59 flight operations, NASA will deliver a validated F-15 based test capability that enables precise, near field probing of the LBFD shockwave structure. This capability ensures that the shockwave structure produced by the X-59 aircraft in flight is easily comparable with current simulations during the flight test campaign. (Thrust 2/FDC)
- NASA will complete a review to authorize proceeding to the implementation phase of the Electrified Powertrain Flight Demonstration project. The EPFD project will also continue to cooperate with industry on plans to integrate electric powertrain, power distribution, and energy storage components for primary propulsion onto an existing airframe as well as to assess propulsion system performance through flight demonstration. (Thrust 3/EPFD)
- NASA will continue preparation for Mod III/IV flights of the X-57 Maxwell aircraft. This flight test includes testing of electric motors moved to the wingtips on a new optimized wing as well as

with integrated distributed electric propulsion motors. FDC project personnel will continue to support the development of manufacturing standards for electrified aircraft systems to enable progress for U.S. companies to develop aircraft that are more-electric. (Thrust 3/FDC)
- NASA will complete closeout activities for the UAS Integration in the NAS Project that include programmatic closeout as well as final documentation of flight test and simulation activities. (Thrust 6/UAS)
- NASA will continue to focus on investigating barriers of entry into new emerging markets in aviation. This project will be closely coordinated with other related NASA research on both airspace operations and vehicle technologies to help prioritize and deliver on the key enabling technical challenges that are most appropriate for NASA to work. Based on developmental testing for the first GC, NASA will share lessons learned and identified gaps with the FAA and industry. The AAM Project will also conduct focused research in key areas such as autonomy that will be required to achieve NASA's vision for urban air mobility. (Thrust 6/AAM)

Program Elements

FLIGHT DEMONSTRATIONS AND CAPABILITIES (FDC)

NASA's FDC project validates various technologies' benefits and demonstrates the feasibility and maturity of new technologies through flight testing in a realistic environment. The flight experiments are campaigns focused on aggressive, success-oriented schedules utilizing the most appropriate set of assets available to accomplish the experimental objectives and collaborative partnerships from across the aeronautical industry including international partners (as appropriate). While many of the technologies are at relatively high TRLs, the FDC project supports all phases of technology maturation.

ELECTRIFIED POWERTRAIN FLIGHT DEMONSTRATION (EPFD)

NASA's EPFD project focuses on flight demonstrations that advance the state-of-the-art for subsonic transports to enable enduring leadership of the U.S. aviation industry for the benefit of the country and U.S. flying public. Previously called the Ultra-Efficient Subsonic Transport (UEST) project, the initial focus of the EPFD project is on the demonstration of electrified propulsion system technologies to determine their ability to further advance industry's focus on more-electrified aircraft. The initial flight experiment(s) will be high-power (megawatt-class) electrified powertrain demonstration(s) that evaluate the performance of hybrid electric propulsion systems. The focus is on technologies and configurations that require integration and flight demonstration to validate technical feasibility and performance as well as economic benefit.

ADVANCED AIR MOBILITY (AAM)

The Advanced Air Mobility (AAM) project focuses on helping to enable a new market in urban air mobility. This project is closely coordinated with other related NASA research on both airspace operations and vehicle technologies to help prioritize and deliver on the key enabling technical challenges that are most appropriate for NASA to work. The AAM project will conduct focused research in key areas such as autonomy that will be required to achieve NASA's vision for urban air mobility. One of the initial

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primary functions of the project is to execute a series of GCs that will help the entire community better assess the advances of key technologies and systems and help identify where future research needs to focus. NASA works closely with other government and commercial entities to achieve this objective. Another important function of the AAM project is to mature NASA's strategic vision for urban air mobility. This vision will not only help NASA prioritize its research but also facilitate planning and development in the private sector to help ensure U.S. leadership in this emerging market.

Program Schedule

Date	Significant Event
Sep 2019	UAS-NAS – Submit Consolidated Input for Detect and Avoid (DAA) MOPS Rev A to RTCA Special Committee for UAS
May 2020	FDC – X-57 Mod II First Flight
Aug 2020	SIO Demonstrations Complete
Sep 2020	UAS-NAS – Submit Consolidated Input for Command and Control (C2) Terrestrial Data Link MOPS to RTCA Special Committee for UAS
Sep 2020	UAS-NAS – Submit Consolidated Input for DAA MOPS Rev B to RTCA Special Committee for UAS
Sep 2020	EPFD – Complete Partner Selection for Electrified Aircraft Powertrain Flight Demonstration
Dec 2020	UAS-NAS – Project Closeout
Jan 2021	AAM – Initial Grand Challenge SAAs signed
Aug 2021	FDC – X-57 Final Mod III/IV Ground Vibration Test Complete

Program Management & Commitments

Program Element	Provider
Flight Demonstrations and Capabilities (FDC)	Provider(s): ARC, AFRC, GRC, LaRC Lead Center: AFRC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): DoD, Air Force Research Laboratory, Lockheed Martin, Flexsys, ESAero
UAS Integration in the NAS (UAS-NAS)	Provider(s): ARC, AFRC, GRC, LaRC Lead Center: AFRC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): N/A

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Program Element	Provider
Electrified Powertrain Flight Demonstration (EPFD)	Provider(s): TBD Lead Center: TBD Performing Center(s): TBD Cost Share Partner(s): TBD
Advanced Air Mobility (AAM)	Provider(s): TBD Lead Center: TBD Performing Center(s): TBD Cost Share Partner(s): TBD

Acquisition Strategy

NASA’s IASP develops and further matures promising technologies to the integrated system level. This necessitates the use of a variety of acquisition tools relevant to the appropriate work awarded externally through full and open competition. Teaming among large companies, small businesses, and universities is highly encouraged for all procurement actions.

MAJOR CONTRACTS/AWARDS

NASA’s Aeronautics programs award multiple smaller contracts, which are generally less than $5 million.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Annual Performance	Expert Review	Oct 2019	The purpose of 12-month review is for tracking and documenting the projects' progress made towards the Strategic Thrusts and outcomes during the fiscal year.	The Review Panel acknowledged the projects were on-track and expressed appreciation for the work done by all projects to remain relevant to their stakeholders. There were no findings.	Oct 2020

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

FY 2021 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	BTC	Total
Formulation	100.5	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	100.5
Development/Implementation	100.3	105.9	103.5	**79.1**	75.5	3.5	0.0	0.0	0.0	467.7
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	10.4	3.8	0.0	0.0	14.2
2020 MPAR LCC Estimate	**200.8**	**105.9**	**103.5**	**79.1**	**75.5**	**13.8**	**3.8**	**0.0**	**0.0**	**582.4**
Total Budget	**0.0**	**105.9**	**103.5**	**79.1**	**75.5**	**13.8**	**3.8**	**0.0**	**0.0**	**381.6**
Change from FY 2020				**-24.4**						
Percentage change from FY 2020				**-23.6%**						

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Shown here is a picture of the LBFD aircraft.

PROJECT PURPOSE

Over the past decade, fundamental research and experimentation has demonstrated the possibility of supersonic flight with greatly reduced sonic boom noise. The Low-Boom Flight Demonstrator (LBFD) project will demonstrate these advancements in flight by utilizing a purpose-built experimental aircraft that was recently designated the X-59 Quiet Supersonic Technology (QueSST). It will provide validation of design tools and technologies applicable to low sonic boom aircraft. The Low-Boom Flight Demonstration mission will create a database of community response information supporting the development of a noise-based standard for supersonic overland flight.

The LBFD project contributes to an overarching effort called the Low-Boom Flight Demonstration mission (LBFD mission) led by the Advanced Air Vehicles Program (AAVP) and the Integrated Aviation Systems Program (IASP). The AAVP Commercial Supersonic Transport (CST) project is responsible for conducting the flight research and the IASP LBFD and Flight Demonstrations and Capabilities (FDC) projects will provide the flight vehicle and conduct flight test operations. The three-phase LBFD mission

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

aims to produce an aircraft that generates a low-noise sonic boom signature and provides crucial data that could enable commercial supersonic passenger air travel over land. After test flights to validate the quiet supersonic technology are complete, NASA researchers will gather data on public acceptance of the technology by flying over a handful of U.S. cities. In FY 2025, NASA will provide the finalized data to the Federal Aviation Administration and the International Civil Aviation Organization. Using this data, these organizations can develop and adopt new rules to allow commercial supersonic flight over land.

Phase 1 of the LBFD mission includes the LBFD aircraft development activities, which are led by the LBFD project. These activities start with the detailed design, continue through fabrication, and conclude with functional checkouts and supersonic envelope expansion. In Phase 2, a NASA-led team will perform low-boom acoustic validation flights of the LBFD aircraft. These flights will characterize and evaluate the near-field, mid-field, far-field, and ground sonic boom signatures from the LBFD aircraft. All three LBFD mission projects (CST, LBFD, and FDC) will work collaboratively to conduct Phase 2 of the LBFD mission. For Phase 3, a NASA-led CST team will lead low-boom community response studies with multiple test flight campaigns using the LBFD aircraft over varied locations with aircraft operations conducted by the FDC project. The LBFD project supports Phase 1 and Phase 2 of the LBFD mission. Following the completion of acoustic validation at the end of the Phase 2, the X-59 QueSST aircraft will transfer from the LBFD project team to the FDC project to conduct planned Phase 3 flight operations. The LBFD project concludes at the end of Phase 2.

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

PROJECT PARAMETERS

The LBFD project will design, manufacture, and perform flight validation of a research aircraft that creates a shaped sonic boom signature with a calculated loudness level of 75 PLdB [Perceived Level (PL), decibels (dB)] or less during supersonic cruise (Mach $\geq$ 1.4) flight. This loudness level is a 28 percent PLdB improvement over the Concorde’s level of 105 PLdB. Although the aircraft will be smaller than potential future supersonic airliners, its sonic boom ground signature will remain sufficiently understood. This knowledge will enable the design and construction of larger aircraft that will be able to comply with regulated noise-based standards. The LBFD aircraft will be capable of performing multiple supersonic overflights of a single community with passes that are nominally 50 miles in length and up to 20 minutes apart on a single flight. The vehicle will support the low-boom community response studies with multiple overflight test campaigns in varied locations over the course of two years.

ACHIEVEMENTS IN FY 2019

NASA completed Key Decision Point-C (KDP-C) for the LBFD project. The successful completion of KDP-C represents Authorization to Proceed to the developmental phase of the project with approved baseline plans for the cost and schedule of the LBFD project to produce the LBFD aircraft.

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

Manufacturing of X-59 long-lead components began to reduce schedule impact associated with these key components, as well as subsequent integration with other aircraft systems.

NASA conducted a Critical Design Review (CDR) to substantiate final design activities for the LBFD aircraft. The contractor will conducted aircraft build activities that include component fabrication and assembly, integration of Government Furnished Equipment, and system checkouts in preparation for the Flight Readiness Review (FRR).

WORK IN PROGRESS IN FY 2020

Following the successful completion of the CDR, LBFD projects readiness to proceed with the next phase of hardware integration activities will occur at a KDP-D review early in FY 2020. This review will include a summary of the CDR content and review results, as well as an assessment of readiness to proceed from the LBFD Independent Review Board.

The focus of the LBFD project team throughout FY 2020 will be to enable steady fabrication and hardware integration progress at the contractor facilities. Final assembly of the X-59 Low-Boom Flight Demonstrator aircraft by Lockheed Martin will be complete by the end of FY 2020, and NASA will complete final aircraft subsystem checkouts and ground testing of the NASA-supplied systems.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

The focus of the LBFD project throughout FY 2021 will be to complete final aircraft subsystem checkouts and ground testing of the NASA-supplied systems. The team will also complete the FRR for the X-59 QueSST aircraft in anticipation of first flight in January 2022. A System Acceptance Review occurs once the envelope expansion flight testing is complete. In January 2023, Lockheed Martin delivers the aircraft to NASA, which signifies the Phase 1 completion of the LBFD mission. Validation of the aircraft's acoustic signature occurs in Phase 2.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Baseline Date	FY 2021 PB Request
Key Decision Point-B (KDP-B)	Aug 2016	Aug 2016
Formulation Authorization	Sep 2016	Sep 2016
Acquisition Strategy Meeting	Nov 2016	Nov 2016
Preliminary Design Review (PDR)	Jun 2017	Jun 2017
Delta PDR	Jul 2018	Jul 2018
KDP-C	Oct 2018	Oct 2018
Critical Design Review	Aug 2019	Sep 2019

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

Milestone	Baseline Date	FY 2021 PB Request
KDP-D	Oct 2019	Dec 2019
Flight Readiness Review	Oct 2021	Dec 2021
First Flight	Jan 2022	Jan 2022
System Acceptance Review (Phase 1) Complete	Jan 2023	Jan 2023
Acoustic Validation (Phase 2) Complete	Oct 2023	Oct 2023
LBFD Project Close-Out Complete	Apr 2024	Apr 2024

Development Cost and Schedule

The LBFD project completed a successful KDP-C on October 30, 2018, and the project received authority to proceed to development. The LBFD project lifecycle includes aircraft concept refinement studies, aircraft preliminary design, aircraft final design and build, and acoustic validation flight testing. These activities span from FY 2014 to FY 2024 (Phase 1 and Phase 2 of the LBFD mission).

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2017	467.743	70%	2020	467.744	0%	First Flight	Jan 2022	Jan 2022	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**467.743**	**467.744**	**+0.001**
Flight Sciences	19.456	19.455	-0.001
Flight Systems	17.002	19.785	+2.783
Aircraft	230.913	245.937	+15.024
Aircraft Operations	45.129	52.789	+7.660
Other Direct Project Costs	155.243	129.778	-25.465

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Flight Sciences	Vehicle sonic boom, aerodynamics, propulsion, structures, and mission performance NASA in-house flight simulation tools, and analysis of vehicle handling qualities and control laws	Provider: Ames Research Center (ARC), Armstrong Flight Research Center (AFRC), Glenn Research Center (GRC), Langley Research Center (LaRC) Lead Center: LaRC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): N/A	N/A
Flight Systems	Design, development, and test of Power Distribution System (PDS), Flight Test Instrumentation System (FTIS), and eXternal Vision System (XVS)	Provider: AFRC, LaRC Lead Center: AFRC Performing Center(s): AFRC, LaRC Cost Share Partner(s): N/A	N/A
Aircraft	Design/build and initial test of a single-piloted X-plane by the end of 2021	Provider: Lockheed Martin Lead Center: AFRC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Aircraft Operations	Demonstrate airworthiness of aircraft, flight operations, and develop key aircraft subsystems - including life support and crew escape systems Provide Government Furnished Equipment (GFE) to construct the research aircraft, support and maintain F414 engine, and perform insight/oversight of Ops-related tasks that the vehicle Contractor performs	Provider: AFRC, LaRC Lead Center: AFRC Performing Center(s): AFRC, LaRC Cost Share Partner(s)/subcontractors: GE, Northrop, Honeywell, and Lockheed Martin	N/A

Project Risks

Risk Statement	Mitigation
Sonic Boom Level is Not Acceptable for Community Overflight Research Given that achieving a fully shaped sonic boom ground signature in the 70-75 PLdb range requires a complex and integrated design solution that is sensitive to outer mold line changes, there is a possibility that the mission requirements related to ground signature loudness may not be achievable - resulting in an aircraft that may not be fully acceptable for community response studies.	NASA will ensure that all configuration assessments use the latest and most mature aircraft configuration and periodically assess any updates to the aircraft configuration, such as the outer mold line, or performance characteristics.
Reduced Aircraft Performance Could Impact Mission Effectiveness Given the aircraft and propulsion system selection and integration complexity, there is a possibility of reduced aircraft performance resulting in loss of mission effectiveness and leading to longer duration time to meet flight parameter(s), increased costs, and limitations of flight test points to standard-day conditions.	NASA will ensure that the contractor has sufficient margin for aircraft weight growth with propulsion configuration; assess contractor aircraft performance and thrust predictions (both computationally and experimentally) over the aircraft flight envelope; and perform a trade study on engine performance during demanding conditions.

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

Acquisition Strategy

The acquisition strategy for LBFD is to acquire through an industry partner the detailed design/build/test of the experimental low-boom demonstrator aircraft. NASA will provide in-house support that will include in-flight and ground systems, instrumentation and operations, simulation, wind tunnel testing, and safety and mission assurance. NASA supplies aircraft components and systems as Government Furnished Equipment whenever feasible and considered to add value to the development of the LBFD aircraft.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
LBFD Aircraft - Design, Build, and Initial Testing	Lockheed Martin	Palmdale, CA
F414-GE-100 Engine	General Electric Aviation	Lynn, MA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	LBFD Independent Review Board (IRB)	Jun 2017	PDR	Successfully Completed	Jul 2018
Performance	LBFD IRB	Jul 2018	Delta PDR, Assess readiness for KDP-C	Successfully Completed	Sep 2019
Performance	LBFD IRB	Sep 2019	CDR, Assess readiness for KDP-D	Successfully Completed	Dec 2021
Performance	LBFD IRB	Dec 2021	FRR	TBD	N/A

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FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	137.4	--	129.9	132.3	134.6	136.7	136.7

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

The picture above captures a flight test of a NASA system that automatically deploys and retracts small wing vanes known as vortex generators needed for takeoff and landing. The system uses NASA-developed materials that change shape in response to changes in temperature.

The Transformative Aero Concepts Program (TACP) cultivates multi-disciplinary, revolutionary concepts to enable aviation transformation. The Aeronautics Research Mission Directorate's (ARMD) strategic analysis has identified challenges in the global demand for mobility, energy, sustainability, and ongoing affordability issues for which new technologies can be a key part of the solution. TACP fosters innovative solutions to these challenges by capitalizing on advancements in the aeronautics and non-aeronautics sectors to create new opportunities in aviation. The ultimate goal of the program is to reduce or eliminate technical barriers and infuse concepts that originate either internally or externally into all six ARMD strategic research thrusts to create innovation for the aviation system. Infusing these concepts into all six ARMD strategic thrusts will help create advanced and improved computational tools, technologies, and experimental capabilities that go to other aeronautics programs, industry partners, and Government collaborators inside and outside of NASA. TACP tools and capabilities have contributed to past and present missions and hold the promise of future advances in aviation.

TACP uses sharply focused activities that offer flexibility for innovators to explore technology feasibility and provide the knowledge base for radical transformation. The program solicits and encourages game-changing concepts, creates the environment for researchers to become immersed in trying out new ideas, performs ground and small-scale flight tests, allows failures and learns from them, and drives rapid ideation into new concepts. TACP also addresses the need for computational and experimental tools that are critical for supporting technology development and enabling aviation transformation. Therefore, TACP's investments are in brand-new areas that can provide paradigm-shifting analysis and experimental capabilities. TACP's new autonomous systems research activities address the key technical barriers that will enable the use of autonomous systems in aviation. To get buy-in and foster the rapid adoption of program research products, TACP aggressively engages both the traditional aeronautics community and new, non-traditional entities through tailored partnerships.

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EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

At the end of each achievement identified in this document, there is a mapping to link it to the related Strategic Research Thrust and Program Element.

ACHIEVEMENTS IN FY 2019

- NASA successfully integrated four disciplines into an analysis toolset that has broad applicability but is currently applied to urban air mobility (UAM) class vehicles. Manufacturers can use the toolset to refine and optimize designs characterized by tightly integrated propulsion-airframe systems that involve competing requirements for performance, noise, and energy usage. In addition, NASA reduced the computational cost to run the toolset. Industry, Government, and university members of the UAM community can access these open-source design tools. (Cross Cutting/TTT)
- NASA began an effort to reduce the number of physical tests of future vehicles and replace them with virtual tests to cut down on development and certification costs and lead times. NASA's ultimate goal here is to develop, implement, and validate computationally efficient physics-based tools and methods that will reduce error in predicting aerodynamic stall, buffet, flutter, and propulsion system performance. These capabilities enable improved and accelerated multidisciplinary aircraft designs and reduced certification flight test requirements, which result in substantial cost savings. (Cross Cutting/TTT)
- NASA has completed system integration, wind tunnel testing, and ground validation testing in preparation for a flight test with an industry partner in FY 2020 to evaluate a Shape Memory Alloy Reconfigurable Technology-Vortex Generator (SMART-VG) system. The system uses NASA-developed materials to automatically deploy and retract the vortex generators attached to the wings. The vortex generators can retract in cruise flight when not needed, resulting in reduced fuel consumption. The flight test will validate the system performance and mature the technology for potential use in future transport aircraft. (Thrust 3/TTT)
- NASA completed feasibility assessments for several Convergent Aeronautics Solutions (CAS) activities. Completed activities included a new lightweight, conformal microwave antenna that may have application to UAM-category aircraft. To support the introduction of electric aircraft, NASA evaluated the use of additive manufacturing techniques to produce new motor designs with significantly more power density and efficiency. In another activity, NASA explored fundamental chemistry challenges associated with Li-Air batteries, which have the potential to provide safe, high-power energy storage with rapid recharging capabilities. (Cross Cutting/CAS)
- NASA selected three new University Leadership Initiative (ULI) awards that executed two months of work. ULI now includes eight university teams across the first two award rounds. During the year, each ULI awardee began activities to address technical barriers inherent in achieving ARMD's strategic outcomes and proposed solutions. Highlighted activities include work by Carnegie Mellon University to develop an ecosystem for qualification of additive manufacturing processes and materials in aviation that will reduce costs and increase the speed of aircraft manufacture, while maintaining or improving product quality and reliability. Another ULI award led by the University of Illinois, Urbana-Champaign addresses the global need for alternative propulsion and energy sources. This effort proposes a Cryogenic Hydrogen-Energy

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Electric Transport Aircraft concept. The concept leverages the high specific energy content of liquid hydrogen to provide an ultra-efficient propulsion system. (Cross Cutting/UI)

WORK IN PROGRESS IN FY 2020

- NASA plans to complete advanced high-fidelity computational analyses using Turbulent Heat Flux studies to improve models of flow and heat exchange around aircraft engine turbines. To prevent engine turbines from over-heating, cooler air mixes with hot combustion gases before the flow reaches the turbine blades. Current computational tools do not adequately model the complex, turbulent flows associated with this mixing, which are essential to designing the engine's cooling system. Designers would like to minimize the amount of cooling to improve overall engine performance (i.e., maximizing thrust while minimizing fuel consumption). The studies will provide crucial flow data around an engine nozzle, allowing modelers to verify that their tools accurately represent the flow conditions. The models, validated with detailed experimental measurements, will support design of new, high-efficiency propulsion systems. (Cross Cutting/TTT)
- NASA will complete a materials, structures and manufacturing analysis of alternatives supporting a cross-program (TACP and Advanced Air Vehicle Program (AAVP)) strategic approach to align resources and investments with the most critical research addressing the needs of both traditional and emerging aviation market players. (Cross Cutting/TTT)
- NASA will begin new CAS activities selected during FY 2019. These activities include a prognostics capability that incorporates embedded sensors, non-destructive evaluation, and machine learning algorithms to detect impending aircraft battery failure. Another activity investigates a new type of battery technology that intrinsically meets rigorous aerospace safety and performance criteria. Another activity explores scalable traffic management for emergency response operations using an Unmanned Aircraft System (UAS) Traffic Management (UTM) system. (Cross Cutting/CAS)
- NASA will undergo a major redesign of current practices to promote alignment of innovative technologies with the most significant aeronautics challenges, while also facilitating technology transition to other NASA programs and the aviation community. These changes will apply lessons learned from the previous five years of operations. Under this approach, research teams will develop and evaluate solutions to technical problems informed by stakeholders from NASA and the external community. New CAS activities selected in FY 2020 and beyond will use this approach. (Cross Cutting/CAS)
- NASA will award proposals from the third set of the competitive ULI solicitations and initiate the fourth set to U.S. universities, under the UI Project. Selections in the third set should emphasize a special topic in materials and structures, as well as autonomous systems applications and revolutionary vertical lift vehicles for UAM. In FY 2020, ULI will complete its first activity, an effort to develop communication capabilities for improving link and network capacity, reliability, and security in support of new ATM applications. In addition, this activity will evaluate several of the technologies developed with a flight test conducted by an industry partner. (Cross Cutting/UI)

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KEY ACHIEVEMENTS PLANNED FOR FY 2021

- NASA will begin the next phase of autonomous systems research. A key focus will involve developing human-autonomy teaming solutions for future aviation applications, including simplified vehicle operations for UAM and remote supervisory operations for air cargo flights. (Thrust 6/TTT)
- NASA will also initiate a refocus on revolutionary materials and structures. This research will develop new computational models to characterize materials, systems, and manufacturing processes, enabling an integrated approach toward vehicle design, manufacture, and certification. Both transport aircraft and UAM vehicles can support the unique requirements these capabilities can provide. This promotes full lifecycle health monitoring and rapid manufacturing processes that do not compromise quality. (Cross Cutting/TTT)
- NASA will continue development of integrated acoustics analysis capabilities for electric Vertical Take-Off and Landing (eVTOL) aircraft. These efforts have been well coordinated with AAVP/Revolutionary Vertical Lift Technology (RVLT) and support tool enhancements that RVLT is leveraging along with the U.S. manufacturers. These capabilities will support quieter UAM operations and benefit UAM vehicle manufacturers. (Cross Cutting/TTT)
- NASA will select and initiate FY 2021 CAS activities that support multiple ARMD strategic thrusts. (Cross Cutting/CAS)
- NASA will award and initiate new sets of competitive ULI proposals under the UI Project. Proposals will address additional technical barriers intrinsic to achieving ARMD’s strategic outcomes. (Cross Cutting/UI)

Program Elements

CONVERGENT AERONAUTICS SOLUTIONS (CAS)

The CAS project performs rapid feasibility assessments of early-stage innovations that challenge existing technical approaches, create alternate paths to solutions, and enable new strategic outcomes. The project’s focus is on merging traditional aeronautics disciplines with advancements driven by the non-aeronautics world to overcome barriers and enable new capabilities in commercial aviation. Internal research teams conduct initial feasibility studies, perform experiments, try out new ideas, identify failures, and try again. When a review determines that the developed solutions met their goals and identified potential for future aviation impact, ARMD considers the most promising capabilities for continued development by other programs or by direct transfer to the aviation community.

TRANSFORMATIONAL TOOLS AND TECHNOLOGIES (TTT)

The TTT project advances state-of-the-art computational and experimental tools and technologies that are vital to aviation applications in the six strategic thrusts. These new computer-based tools, models, and associated scientific knowledge provide first-of-a-kind capabilities to analyze, understand, and predict performance for a variety of aviation concepts. Applying these tools will enable and accelerate NASA’s research and enable the aviation community to introduce advanced concepts and designs. An example includes the development and validation of new computational tools used to predict complex turbulent airflow around vehicles and within propulsion systems; ultimately leading to an improved ability to

TRANSFORMATIVE AERO CONCEPTS PROGRAM

predict future vehicle performance in flight. The project also explores technologies that are critical to advancing ARMD strategic outcomes, such as understanding new types of strong and lightweight materials, innovative aircraft control techniques, and experimental methods. Such technologies will support and enable concept development and benefit assessment across multiple ARMD programs and disciplines. The TTT project also initiated the Autonomous Systems Sub-Project to explore new capabilities to enable improved performance and safety of innovative autonomous aircraft and their operational controls.

UNIVERSITY INNOVATION (UI)

The UI project contains a portfolio of disruptive technologies and other new concepts to meet the goals established by the ARMD strategic thrusts and support education of the next generation of engineers. The project utilizes NASA Research Announcement solicitations where university-led teams assess the most critical technical challenges to solve to achieve the Strategic Implementation Plan strategic outcomes; and propose independent, innovative research projects to solve those technical challenges. Universities develop their own success criteria, progress indicators, and technical approaches. Universities pursue multi-disciplinary approaches and incorporate partnerships with other universities, industry, and U.S. entities.

Program Schedule

Date	Significant Event
Mar 2019	UI – Released ULI Solicitations
Aug 2019	CAS – Closed out and initiated transition of Compact Additively Manufactured Innovative Electric Motor and Integrated Computational-Experimental Development of Lithium-Air Batteries for Electric Aircraft
Aug 2019	UI – Awarded ULI Solicitations
Sep 2019	TTT – Completed Multidisciplinary Design and Analysis Tools for Urban Air Mobility Vehicles and delivery of SMART Vortex Generator actuators to Boeing for the EcoDemonstrator flight test
Sep 2019	CAS – Closed out and initiated transition of Conformal Lightweight Antenna Structures for Aeronautical Communication Technologies
Feb 2020	TTT - Complete Juncture Flow Experiment activity
Mar 2020	UI – Release ULI Solicitations
Jun 2020	CAS – Begin close out/transition of Autonomy Teaming & Trajectories for Complex Trusted Operational Reliability, Automated Airworthiness Assessment for Commercial Drone Fleets and Quantum Technologies for UTM
Jul 2020	UI – Award ULI Solicitations
Sep 2020	TTT – Complete deployable vortex generator system and NASA's Turbulent Heat Flux Experiment

TRANSFORMATIVE AERO CONCEPTS PROGRAM

Date	Significant Event
Mar 2021	UI – Release ULI Solicitations
Jul 2021	UI – Award ULI Solicitations
Sep 2021	TTT – Descoping Combustion Modeling TC and completing Computational Prediction Tools for Fuel Sensitivity for Lean Blowout
Dec 2021	CAS – Begin close out/transition of Adhesive free Bonding of Complex Composite Structures; Aqueous, Quick-charging battery Integration for Electric Flight Research and High-Efficiency Electrified Aircraft Thermal Research

Program Management & Commitments

Program Element	Provider
Convergent Aeronautics Solutions (CAS)	Provider(s): ARC, GRC, LaRC, AFRC Lead Center: HQ Performing Center(s): ARC, GRC, LaRC, AFRC Cost Share Partner(s): PCKrause & Associates, National Institute of Aerospace, Boeing, AFRL, ESAero, Launch Point, Straight Up Imaging, DoT Volpe, Moog Inc., IDEO, Idea Couture, Tecolote Research Inc., AFRL, Universities
Transformational Tools and Technologies (TTT)	Provider(s): ARC, GRC, LaRC, AFRC Lead Center: GRC Performing Center(s): ARC, GRC, LaRC, AFRC Cost Share Partner(s): Boeing, Pratt & Whitney, Rolls Royce, Honda, UTRC, ESI, Blue Quartz Software, General Electric, FAA, AFRL, U.S. Air Force, U.S. Army, U.S. Navy, Defense Advanced Research Projects Agency (DARPA), Distributed Engine Controls Working Group Consortium, Honeywell, BAE Systems, UTC Aerospace Systems, Ohio Aerospace Institute, U.S. small businesses and universities
University Innovation (UI)	Provider(s): ARC, GRC, LaRC, AFRC Lead Center: HQ Performing Center(s): ARC, GRC, LaRC, AFRC Cost Share Partner(s): N/A

Acquisition Strategy

The research conducted through TACP activities will use variety of acquisition tools relevant to the research objectives, including external solicitations awarded through full and open competitions (e.g., challenges, prizes).

TRANSFORMATIVE AERO CONCEPTS PROGRAM

MAJOR CONTRACTS/AWARDS

NASA's Aeronautics programs award multiple smaller contracts, which are generally less than $5 million. These smaller contracts are also widely distributed across academia and industry.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Expert Review	Oct 2019	The 12-month review is a formal independent peer review. Experts from other Government agencies report on their assessment of technical and programmatic risk and/or project weaknesses.	Received expert feedback on project improvement from the panel members. Determined that the project(s) made satisfactory progress in meeting technical challenges and met all annual performance indicators.	Oct 2020

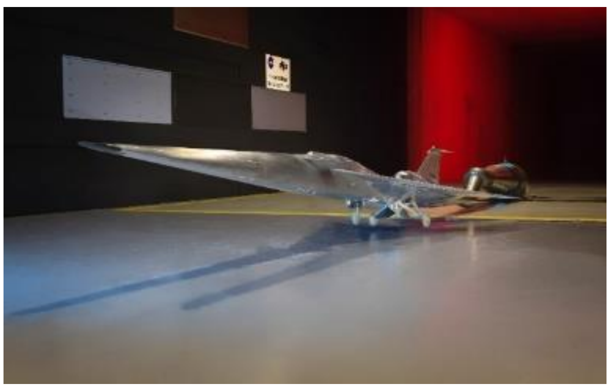
AEROSCIENCES EVALUATION AND TEST CAPABILITIES

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	0.0	--	117.0	117.1	117.1	117.1	117.1

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.



Pictured is the Quiet Supersonic Technology (QueSST) vehicle during a Ground Effects Test at the Langley Research Center (LaRC) 14-foot by 22-foot Subsonic Wind Tunnel.

The Aerosciences Evaluation and Test Capabilities (AETC) Portfolio sets the strategic direction for NASA's versatile and comprehensive portfolio of aerosciences ground test capabilities and assets. Among these assets are subsonic, transonic, supersonic, and hypersonic wind tunnels, propulsion test facilities, and specialty tunnels at Ames Research Center (ARC), Glenn Research Center (GRC), and Langley Research Center (LaRC). NASA’s integrated approach to test capability planning, use, and management considers complementary computational tools, software, and related systems to effectively acquire and process research data.

Through broad alliances outside of NASA, AETC optimizes the use of these capabilities across the Government. NASA participates in the National Partnership for Aeronautical Testing (NPAT) and collaborative working groups consisting of NASA, the Department of Defense (DoD), and other partners. Members of these working groups (1) gain awareness of capabilities across the agencies, academia, and industry; (2) share best practices; (3) provide technical support; and (4) refer test programs to facilities best suited to meet test requirements.

Within NASA, AETC directly supports the testing needs of four Agency mission directorates - Aeronautics Research Mission Directorate, Human Exploration and Operations Mission Directorate, Science Mission Directorate, and the Space Technology Mission Directorate.

EXPLANATION OF MAJOR CHANGES IN FY 2021

As specified in the FY 2020 appropriation, the Aerosciences Evaluation and Test Capabilities (AETC) portfolio is a program within NASA Aeronautics. This consolidation will improve the efficiency and effectiveness of managing ground testing capabilities within the Agency.

AEROSCIENCES EVALUATION AND TEST CAPABILITIES

ACHIEVEMENTS IN FY 2019

- AETC supported performance testing of a Low-Boom Flight Demonstrator model at the GRC 8-foot x 6-foot Supersonic Wind Tunnel. The tests provided data to inform NASA's successful Critical Design Review of the new X-59 aircraft - an experimental aircraft designed to reduce sonic boom noise to an acceptable level.
- AETC developed two new wind tunnel test technique capabilities to enable higher quality data in next generation customer testing: (1) New Optical Instrumentation for Advanced Flowfield Measurements - which are needed for next generation computational simulation development; and (2) Improved Force Balance Repeatability and Accuracy - which are needed to accommodate the needs of advanced aircraft design wind tunnel models.
- AETC completed acoustic improvements to the NASA GRC 9-foot x 15-foot Low-Speed Wind Tunnel to reduce the test section background noise. With these modifications, NASA is now able to test more advanced aircraft fan technologies.
- AETC supported NASA’s development of a modern and powerful advanced launch vehicle for the new era of human exploration beyond Earth’s orbit. AETC supported the Space Launch System (SLS) Payload Fairing Ascent Unsteady Aerodynamics Test at the ARC Unitary Plan Wind Tunnel, the SLS High Mach Number Force and Moments Test at LaRC Unitary Wind Tunnel, and the SLS Liftoff/Transition Test at the LaRC 14-foot x 22-foot Subsonic Wind Tunnel.

WORK IN PROGRESS IN FY 2020

- AETC will provide wind tunnel support for various Agency mission testing needs to include the following: Low-Boom Flight Demonstrator (X-59 aircraft), advanced aircraft engine concepts, future science mission vehicle developments (e.g., Dragonfly, SLS, Orion), entry system modeling, external customer tests, and multiple classified tests in support of national security issues.
- AETC will deploy a new propulsion-aircraft/spacecraft simulation testing and calibration capability at the NASA Ames Unitary Plan Wind Tunnel. This new capability enables acquisition of next generation aerodynamic test data from aircraft and spacecraft models that integrate with propulsion simulators (e.g., air ejection nozzle or air powered turbine-powered simulators).

KEY ACHIEVEMENTS PLANNED FOR FY 2021

- AETC will assess the condition and health of simulation testing capabilities at ARC, GRC, and LaRC. The review will identify equipment with a high-risk of failure due to age or maintenance.
- AETC wind tunnels will support NASA's various mission testing needs including those related to advanced aircraft engine concepts, future science mission vehicle developments (e.g., SLS, Orion), entry system modeling, external customer tests, and multiple classified tests in support of national security issues.
- AETC will fabricate and install a new Mach 6 nozzle in the LaRC 8-foot High-Temperature Tunnel. The upgraded wind tunnel will provide high-fidelity, true enthalpy, and true pressure Mach 6 test environments for durations of up to five minutes required to meet future NASA and DoD hypersonic vehicle ground test requirements.

AEROSCIENCES EVALUATION AND TEST CAPABILITIES

- AETC will improve integration of Computational Fluid Dynamics (CFD) and Experimental testing which will allow more efficient and optimized testing for all customers and provide strong basis in future capability sustainment. AETC will complete an assessment of the accuracy and efficiency of computational analysis compared to the LaRC Unitary Plan Supersonic Wind Tunnel testing across multiple models having a wide spectrum of aerodynamic prediction challenges. NASA will use methods learned from this assessment in future wind tunnel assessments.

Program Element

AEROSCIENCES EVALUATION AND TEST CAPABILITIES (AETC)

Aerosciences ground test capabilities (e.g., facilities, systems, workforce, and tools) that support future aircraft, space vehicles, and operations require efficient and effective investment, operations, and management. Efforts in this area preserve and enhance ground test capabilities necessary to achieve the Agency's multi-Mission requirements. Among these assets are subsonic, transonic, supersonic, and hypersonic wind tunnels and propulsion test facilities at the Ames Research Center in Mountain View, CA, the Glenn Research Center in Cleveland, OH, and the Langley Research Center in Hampton, VA. These test facilities and capabilities also serve the needs of non-NASA users. NASA's integrated approach to test capability planning, use, and management will consider the complementary computational tools, software, and related systems to effectively acquire and process research data. NASA offers research customers high-quality data that accurately reflects the simulated test environment and the interactions of test articles in those test environments. Furthermore, NASA expertise helps ensure safe and successful use of the assets and the high quality of research outcomes. The portfolio is crosscutting and supports the Aeronautics Research Mission Directorate's Strategic Thrusts, as well as other Agency efforts and those of key industry partners.

Program Schedule

Date	Significant Event
Sep 2019	AETC – Completion of facility improvements to reduce background noise levels for engine system noise measurements (GRC 9- X 15-foot Low-Speed Wind Tunnel)
Sep 2019	AETC – Completion of optically instrumented facility enhancements in the NASA Ames 11-foot wind tunnel for advanced flow field measurements needed for next generation computational simulation development and validation
Sep 2019	AETC – Completion of force balance repeatability and accuracy improvements to accommodate needs of advanced aircraft design for wind tunnel models
Sep 2020	AETC – Completion of ARC Propulsion Simulator Calibration Facility
Sep 2021	AETC – Completion of Report on the Evaluation of CFD for Testing at High Supersonic Speeds at LaRC Unitary Wind Tunnel
Sep 2021	AETC – Completion of capability for a full life cycle Mach 6 testing at long durations for NASA LaRC 8-foot High-Temperature Tunnel

AEROSCIENCES EVALUATION AND TEST CAPABILITIES

Program Management & Commitments

Program Element	Provider
Aerosciences Evaluation and Test Capabilities (AETC)	Provider: ARC, LaRC, GRC Lead Center: HQ Performing Center(s): ARC, LaRC, GRC Cost Share Partner(s): TBD

Acquisition Strategy

The nature of maintaining and adding new capabilities of aeroscience ground test assets necessitates the use of a variety of acquisition tools relevant to the appropriate work awarded externally through full and open competition.

MAJOR CONTRACTS/AWARDS

NASA's Aeronautics programs award multiple smaller contracts, which are generally less than $5 million. Contracts are also distributed across various industries that provide systems applicable to the sustainment and operations for large-scale wind tunnel assets.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance (Annual)	Expert Review	N/A	The 12-month review is a formal independent peer review. Experts from other Government agencies report on their assessment of technical and programmatic risk and/or program weaknesses.	TBD	Oct 2020

STEM ENGAGEMENT

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**110.0**	**120.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

STEM ENGAGEMENT

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**110.0**	**120.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Change from FY 2020			**-120.0**				
Percentage change from FY 2020			**0.0%**				

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Shown above are the winning teams of the First Nations Launch from Chief Dull Knife College and Northwest Indian College at Kennedy Space Center on August 14-16, 2018.

The FY 2021 Budget proposes the termination of NASA's traditional education portfolio of domestic assistance awards (i.e., grants and cooperative agreements). NASA will continue to support other Science, Technology, Engineering, and Mathematics (STEM) activities, such as internships and fellowships, within the Mission Directorates. A functional office at NASA headquarters (funded out of Safety, Security, and Mission Services) will oversee Agency-wide coordination of STEM engagement efforts. NASA will continue to support the Administration's STEM priorities, outlined in Charting a Course for Success: America's Strategy for STEM Education, with three areas of focus:

- Creating unique opportunities for students to contribute to NASA's work in exploration and discovery;
- Building a diverse future STEM workforce by engaging students in authentic learning experiences with NASA's people, content, and facilities; and
- Strengthening understanding by enabling powerful connections to NASA's mission and work.

EXPLANATION OF MAJOR CHANGES IN FY 2021

No funding is requested for Space Grant, Established Program to Stimulate Competitive Research (EPSCoR), and Minority University Research and Education Project (MUREP). NASA proposes to use unobligated balances previously appropriated to support the termination of these activities, including but not limited to, ongoing administration, oversight, monitoring, and funding of grants previously awarded by the Office of STEM Engagement.

STEM ENGAGEMENT

WORK IN PROGRESS IN FY 2020

In FY 2020, the Office of STEM Engagement continues Agency-wide coordination of the Agency and Federal priorities for engaging, inspiring, and enabling the next generation of STEM practitioners and space explorers. The Office of STEM Engagement continues to implement Agency-level initiatives to eliminate duplication of effort and inefficiency and strengthen standards and rigor in project management, fiscal accountability, and performance measurement.

Some ongoing work in FY 2020 includes an improved search engine that will help students and educators at all levels access the information and products they need on the NASA STEM Engagement website: https://www.nasa.gov/education/overview/index.html

Also, a new STEM Engagement Performance Assessment and Evaluation Framework will be continued.

EPSCoR will administer the grants and support the researchers selected through Research Infrastructure Development awards, the FY 2020 Research Award, and the FY 2020 International Space Station Flight Opportunities award solicitations.

In FY 2020, NASA MUREP will support multiple award selections to Minority Serving Institutions under the FY 2020 solicitation. In addition, MUREP and EPSCoR will initiate a collaborative program to encourage the participation of women and other underrepresented groups in STEM research.

In FY 2020, NextGen STEM will implement an integrated set of efforts to develop STEM engagement products and opportunities that provide a platform for students to contribute to NASA's endeavors in exploration and discovery. These mission-driven activities include over 20 evidence-based products and opportunities to engage students in authentic STEM experiences. NASA is also working to provide mission-driven opportunities to enhance STEM literacy and help build a vibrant and diverse next generation STEM workforce.

NASA will award new four-year Space Grant awards in FY 2020 that provide the same amount of base funding to all consortia and implement a variety of student challenges in partnership with NASA Mission Directorates. These student challenges are aimed at enabling student contributions to NASA's ongoing work through Space Grant institutions.

WORK IN PROGRESS IN FY 2021

NASA will implement an orderly shutdown of the Office of STEM Engagement programs and projects with the goals of minimizing negative impact to awardees and performing closeout in a cost-effective and efficient manner.

SAFETY, SECURITY, AND MISSION SERVICES

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Mission Services & Capabilities	1729.3	--	**1952.0**	1940.6	1940.6	1940.6	1940.6
Engineering, Safety, & Operations	1025.7	--	**1057.9**	1057.9	1057.9	1057.9	1057.9
Total Budget	**2755.0**	**2913.3**	**3009.9**	**2998.5**	**2998.5**	**2998.5**	**2998.5**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Beginning in FY 2021, SSMS has a revised budget account structure. FY 2019 reflects actual budget authority that have been re-cast into the new SSMS budget structure.

SAFETY, SECURITY, AND MISSION SERVICES

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Mission Services & Capabilities	1729.3	--	**1952.0**	1940.6	1940.6	1940.6	1940.6
Engineering, Safety, & Operations	1025.7	--	**1057.9**	1057.9	1057.9	1057.9	1057.9
Total Budget	**2755.0**	**2913.3**	**3009.9**	**2998.5**	**2998.5**	**2998.5**	**2998.5**
Change from FY 2020			**96.6**				
Percentage change from FY 2020			**3.3%**				

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Beginning in FY 2021, SSMS has a revised budget account structure. FY 2019 reflects actual budget authority that have been re-cast into the new SSMS budget structure.

NASA's Space Launch System (SLS) core stage pathfinder, shown here, is positioned in the B-2 Test Stand at NASA's Stennis Space Center (SSC) near Bay St. Louis, Mississippi. SSC work crews used it in August to train and practice handling and lifting techniques needed for the core stage flight hardware when it arrives at SSC for testing in 2020. These efforts will enable a successful Moon landing in 2024.

Safety, Security, and Mission Services (SSMS) support the capabilities, workforce, and facilities that enable NASA's ambitious portfolio of missions including sending astronauts back to the Moon and eventually on to Mars. The Agency is modernizing support capabilities and improving operations to support the Agency's priorities of scientific discovery, human presence in space, and developing the technologies of tomorrow.

These missions are accomplished by integrating critical operations at NASA Centers and facilities in 10 states and the District of Columbia (Headquarters) and by providing independent oversight to reduce risks to life and mission across all of NASA programs.

Mission support services and capabilities are critical to ensuring the Agency's competencies, technical skills, and assets are readily available to meet mission needs while also providing technically and scientifically sound support that is consistently safe and reliable across all NASA Centers. NASA is committed to ensuring these services are effective, efficient, safe, and meet the Agency's statutory, regulatory, and fiduciary responsibilities.

SAFETY, SECURITY, AND MISSION SERVICES

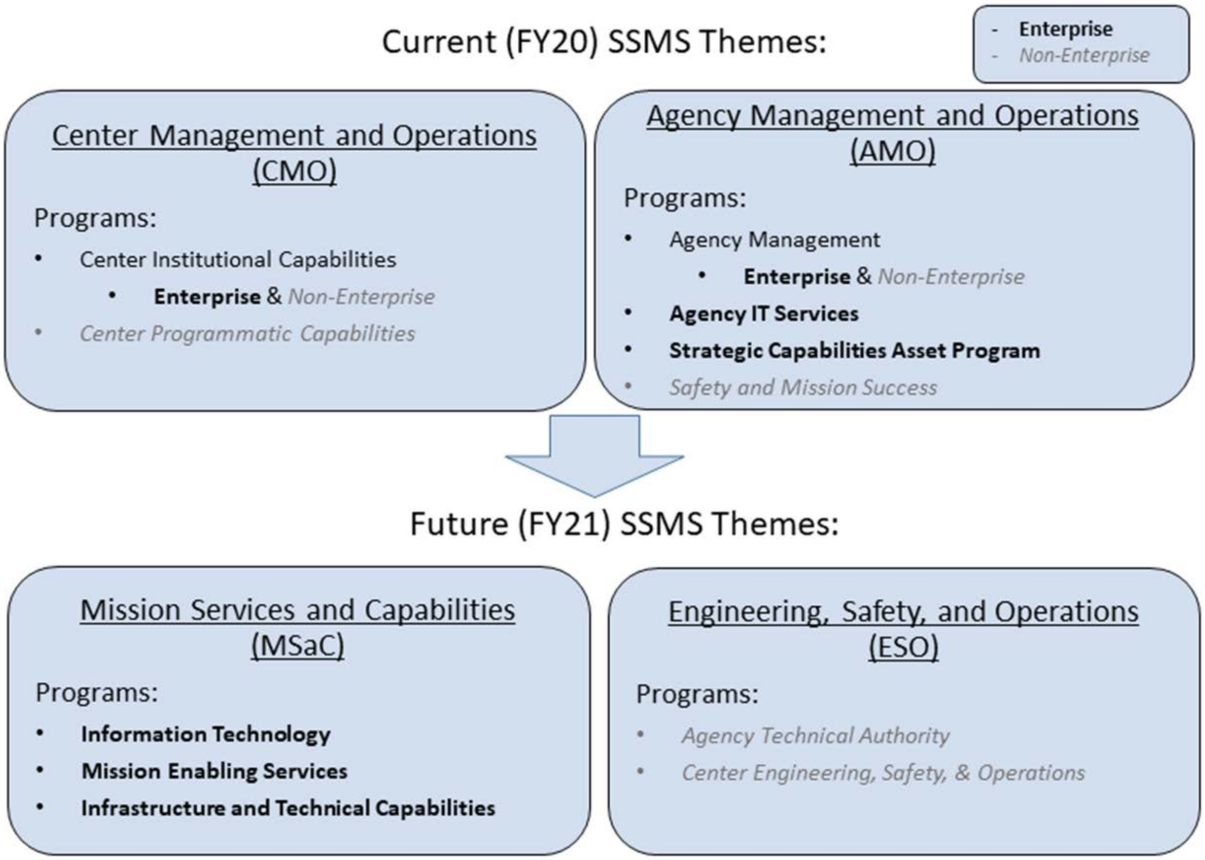
These mission enabling capabilities and related processes provide support needed to successfully and safely implement and complete requisite missions. The following are several examples of services funded under the SSMS account:

- Coordination of test facilities, laboratories, chambers, and other capabilities required to conduct research, development, and engineering for Agency mission objectives;
- Development of engineering, systems engineering, and safety and mission assurance capabilities that support technical activities;
- Governance of Information Technology (IT), sustainment of IT infrastructure, and sustainment of security capabilities to support the productivity of NASA scientists and engineers;
- Human capital, financial management, procurement, legal counsel, small business programs, occupational health and safety, and equal employment opportunity and diversity services providing strategic and operational planning and management to ensure resources are available when needed; and
- Administration of International and interagency relations, legislative and intergovernmental affairs, and strategic communications to facilitate communications with a broad range of internal and external communities.

EXPLANATION OF MAJOR CHANGES IN FY 2021

In FY 2021, NASA will complete its transformation to an enterprise business model for the delivery of Safety, Security and Mission Support (SSMS) services, to include alignment of associated budgetary resources to the enterprise function. Enterprise functions include: Financial and Resources Management, Human Capital Management, Information Technology, Legislative Affairs, Strategic Infrastructure, Communications, Procurement, Protective Services, Small Business Programs, General Counsel, Office of International and Interagency Relations, and Diversity and Equal Opportunity. The enterprise business model allows for delivery of services to customers and employees regardless of geographic locations, reduction and elimination of duplicative capabilities, opportunities for employees to work across geographic boundaries, and greater flexibility to adjust to evolving demands and meet surge requirements.

NASA has revised its existing SSMS budget account structure to fully realize the benefits of this new model, including greater efficiency and improved insight and accountability for formulating and executing the budget. A high-level depiction of the prior budget structure mapped to the revised budget structure follows (further details are discussed in subsequent sections):



Also, in FY 2021, the Mission Networks/Legacy Space Communications and Navigation (SCaN) budget will transfer from the Human Exploration and Operations Mission Directorate (HEOMD) account to the SSMS IT Program.

ACHIEVEMENTS IN FY 2019

Key mission enabling accomplishments in FY 2019 include:

Delivered more efficient and cost-effective operations and services:

- Continued a disciplined approach to improving the Agency's operating model to deliver mission enabling capabilities more effectively and efficiently. In FY 2019, completed the framework for the enterprise business model including refining transformation objectives and implementing the first phase for Human Capital, Financial Management and Legislative Affairs functions. This transformation enables mission support service delivery to NASA's programs and projects across geographic boundaries in a more effective, efficient and flexible manner.
- Since 2016, the Agency has increased investments in preventative and predictive maintenance and reduced spending on unscheduled facility maintenance from approximately 38 to 30 percent of total maintenance funding. In FY 2019, these investments resulted in a reduction to the amount of deferred maintenance and reversed a trend of increased deferred maintenance. This investment led to fewer facility failures and more reliable test schedules required to meet mission milestones.

Reduced mission risk through technical capabilities:

- The Independent Verification and Validation (IV&V) program provided software expertise to 16 major projects at eight NASA Centers. IV&V identified and documented issues that if manifested during spacecraft or system operations, could result in loss of life, physical injury, and/or mission failure.
- The NASA Engineering and Safety Center (NESC) completed 53 independent assessments and support activities touching all of NASA's Mission Directorates. These assessments furthered the Agency's goals and contributed directly to the mission through better informed decision making and an overall reduction of risk.
- NASA received a "Clean" financial audit opinion for the ninth year in a row and the Association of Government Accountants' Certificate of Excellence in Accountability Reporting for the fifth consecutive year.
- The Office of Safety and Mission Assurance provided technical leadership for the update of the U.S. Government Orbital Debris Mitigation Standards, as directed by Space Policy Directive 3.
- NASA was named the "Best Place to Work" for the ninth year in a row among large agencies in the Federal Government.

WORK IN PROGRESS IN FY 2020

Key mission enabling activities underway in FY 2020 include:

Deliver more efficient and cost-effective operations and services:

- Implement transformation of mission support service delivery to an enterprise business model for Procurement, Small Business Programs, Diversity and Equal Opportunity, Communications, and Protective Services functions.
- Stand up the Centralized IT Procurement Office to achieve consistency in IT requirements; thus enabling greater commonality in implementing IT solutions and leading to improved FITARA scorecard performance, reduced duplication in IT contracting, and improved IT buying expertise to enable "smarter" buyers.
- The Agency will leverage the Legal Enterprise Operating System (LEOS) to enable the entire NASA legal team to operate its practice as a single entity, consolidating legal work products, data, and case records that are currently maintained at a dozen different legal operating locations.
- Apply Enhanced Use Lease proceeds to permissible projects across the Agency that increase building performance, reduce energy costs and meet energy use reduction goals.

Reduce mission risk through technical capabilities:

- NESC plans to conduct over 50 independent assessments of NASA's highest risk challenges maintaining prioritization on the ISS, Commercial Crew Program, Orion/SLS, Science Missions, and Space Technology.
- The Agency is implementing a flexible and agile workforce approach through strategic workforce planning. A key element in the strategy is to quickly, fairly, and accurately acquire the best candidate for jobs. To facilitate these hires NASA will replace its aged talent acquisition and assessment system with USAStaffing/USAHire which will enable NASA to assess candidates using industry best practices.

- Implement CDM Phase III, Dynamic and Evolving Federal Enterprise Network Defense (DEFEND) capabilities as defined by DHS. DEFEND capabilities provide increased cybersecurity services and flexibility for NASA to tailor specific solutions the Agency can deploy to safeguard its networks.
- IV&V program expects to provide software expertise to 17 projects, including 15 NASA missions, Commercial Crew Program, one multi-agency mission, and across eight NASA Centers.
- Complete a requirements document and implementation plan for changes to the Agency's financial systems to achieve the full functionality in budget execution and reporting.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

Key mission enabling activities planned for FY 2021 include:

Deliver more efficient and cost-effective operations and services:

- Implement the third and final phase of transformation of mission support service delivery to the enterprise business model for General Counsel, Information Technology and Strategic Infrastructure functions.
- Continue implementation of the enterprise delivery model to streamline NASA procurements and improve the Procurement IT website platform. Projected savings for NASA Procurement in FY 2021 is $0.9 million.
- Increase investments in facility maintenance and operations to increase the reliability of mission-critical infrastructure, including utility and custodial support of more than 5,000 buildings and other structures containing 47.3 million gross square feet of building area valued at $39 billion. Centers will continue to increase reliability-centered maintenance and condition-based monitoring activities to provide more efficient and effective systems maintenance.
- In support of government-wide pay for performance initiatives, the General Scale (GS) awards pool will be increased from 1.5 to 2.5 percentage points on non-Senior Executive (SES), Senior Level, and Scientific or Professional (ST) salary spending in FY 2021. This increase addresses workforce challenges and will recognize high performing employees and employees with mission-critical talent and skills.

Reduce mission risk through technical capabilities:

- IV&V program will provide expert software analysis on NASA's safety and mission critical software to help assure safety and mission success by identifying software problems as early as possible, minimize the cost of rework, and support key milestone decisions.
- Perform planned space environmental testing for Artemis, Orion, Commercial Crew and Cargo Program launch.
- Conduct Health and Medical Technical Authority (HMTA) independent assessment and pathfinder activities in support of Artemis design and development; generate operational requirements and products necessary to support Artemis initial and evolving operations; and, provide technical content regarding human spaceflight standards to support HLS and Gateway programs.
- Initiate the FY 2020 plan for changes to the Agency's financial systems to achieve the full functionality in budget execution and reporting that provides budgetary resources and budget

execution data as specified in the Treasury Financial Manual to support the budget reporting activities defined in the Federal Accounting Standards Advisory Board Handbook and OMB Circular No. A-11, and A-136.

Themes

MISSION SERVICES AND CAPABILITIES

Mission Services and Capabilities (MSaC) provides enterprise solutions under three programs: Information Technology, Mission Enabling Services, and Infrastructure and Technical Capabilities. Strategically, these programs meet workforce, infrastructure, information technology and business operations requirements necessary to enable NASA's mission. MSaC ensures that critical Agency operations are effective, efficient, safe, and meet statutory, regulatory, and fiduciary responsibilities. These mission enabling services, capabilities and related processes provide efficient and effective administration across all NASA Centers.

ENGINEERING SAFETY AND OPERATIONS

Engineering, Safety, and Operations (ESO) provides for the ongoing management and operations of NASA Headquarters, nine Centers, and component facilities under two programs: Agency Technical Authority and Center Engineering, Safety, and Operations. The programs support scientific and engineering activities. They contribute to the reduction of program risks by ensuring that technical skills and assets are ready and available to meet program and project milestones; that mission and research endeavors are technically and scientifically sound; and that Center practices are safe and reliable including the highly skilled staff and specialized infrastructure at the centers that facilitate NASA missions.

MISSION SERVICES & CAPABILITIES

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Information Technology (IT)	501.8	--	**553.9**	553.9	553.9	553.9	553.9
Mission Enabling Services	690.8	--	**705.0**	693.7	693.7	693.7	693.7
Infrastructure & Technical Capabilities	536.8	--	**693.1**	693.0	693.0	693.0	693.0
Total Budget	**1729.3**	--	**1952.0**	**1940.6**	**1940.6**	**1940.6**	**1940.6**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Beginning in FY 2021, SSMS has a revised budget account structure. FY 2019 reflects actual budget authority that have been re-cast into the new SSMS budget structure.

Testing of the Artemis Thermal Enclosure, shown here at the Glenn Research Center (GRC) Space Environments Complex (SEC).

Mission Services and Capabilities (MSaC) provides enterprise solutions under three programs: Information Technology, Mission Enabling Services, and Infrastructure and Technical Capabilities.

The Information Technology (IT) program provides information services needed to fulfill NASA's multifaceted missions and operations. NASA's IT program helps improve Agency outcomes by driving discoveries as a strategic partner with programs/projects, accelerating mission and business results through digital productivity capabilities, sharing NASA's data and discoveries across the Agency and with the public, and increasing program/project quality, resiliency, and cost-effectiveness. The IT program drives advances in science, technology, aeronautics, space exploration, and mission support that support achievement of NASA's diverse array of missions, programs, and goals. Reliable, adaptable, and secure cloud-based IT is increasingly important as NASA embarks on its Artemis program to safely return astronauts to the lunar surface by 2024.

The Mission Enabling Services (MES) program supports all NASA missions by providing services and expertise in the following functional units: Financial Management, Human Capital Management, Procurement, Small Business Programs, Legislative Affairs, Diversity and Equal Opportunity, General Counsel, Communications, International and Interagency Relations, and Protective Services.

The Infrastructure and Technical Capabilities (I&TC) program ensures the right infrastructure is available (ready and reliable) to meet current and future mission requirements. The program provides sustainment, efficient operation and effective maintenance for facilities, utilities, structures and technical capabilities.

It also provides effective oversight and management of real property assets, environments testing activities, aircraft operations, and logistics functions.

EXPLANATION OF MAJOR CHANGES IN FY 2021

No major changes.

The MSaC budget comprises portions of the former Center Management and Operations (CMO) and Agency Management and Operations (AMO) accounts that directly support programs operating in a business enterprise model. Combining the funding will enable NASA to better transform and better ensure that budget execution is aligned with Agency strategic goals.

ACHIEVEMENTS IN FY 2019

Key mission enabling accomplishments in FY 2019 include:

Delivered more efficient and cost-effective operations and services:

- End-User Services transitioned to a new enterprise contract to deliver agile, transformative, and cost-effective services to over 55,000 end users across 18 performance sites. In FY 2019, approximately 60,000 email inboxes were migrated to cloud-based Microsoft Office 365 infrastructure. In addition, OneDrive was implemented which is an online storage service which helps protect files and enables users to access them across multiple devices.
- NASA continued to expand on the use of condition-based maintenance and initiated a tiered maintenance program. Installing remote sensing and asset monitoring enables our talented workforce to implement condition-based maintenance, which will reduce operations and maintenance costs, while extending the operational life of assets.
- NASA completed the first phase of transforming mission services and capabilities to a more effective and efficient enterprise delivery and support model which included the Office of Chief Human Capital Officer (OCHCO), the Office of Chief Financial Officer (OCFO), and the Office of Legislative and Intergovernmental Affairs (OLIA) mission support office. Shifting these mission services to an enterprise business model provided each with full budget authority across the Agency to optimize operations.

MISSION SERVICES & CAPABILITIES

Reduced mission risk through technical capabilities:

- NASA achieved the major milestone of Full Operating Capability (FOC) status for the Agency's Insider Threat Program. NASA strengthened identity vetting and access controls for foreign nationals and deployed solutions for PIV and Common Access Cards (CAC) for facilitating employee and external partner access to NASA facilities and information systems.
- Completed risk reduction activities for the Arc Jet Complex in support of Orion Exploration Mission 1 (EM-1) development and the expansion of the thermal protection system (TPS) performance envelope. These risk reduction activities are critical to Artemis by ensuring successful passage through the atmosphere upon return of the Orion capsule to Earth.
- Completed activities to achieve chamber certification of the Space Environments Complex (SEC), allowing it to be ready for the testing series required for the Artemis Orion EM-1.
- The Equal Employment Opportunity Commission and the U.S. Commission on Civil Rights recognized NASA's Anti-Harassment Campaign and Program as a model for the Federal Government for effective and prompt intervention and resolution; early intervention and resolution; and proactive corrective action.
- The OCIO standardized the IT Portfolio data collection process, enhanced transparency, and complied with OMB reporting requirements by implementing an enterprise off-the-shelf Program Project Management (PPM) tool and configuring the tool to support the Technology Business Management (TBM) categorization of IT spending. Improvements to the data collection process have provided a deep understanding of the Agency’s full IT footprint and informed investment decision-making.

WORK IN PROGRESS IN FY 2020

Key activities underway in FY 2020 in the MSaC area include:

Deliver more efficient and cost-effective operations and services:

- The second phase of transforming mission services and capabilities to a more effective and efficient enterprise delivery and support model has commenced with additional Mission Support offices beginning their implementation: Office of Procurement (OP), Office of Small Business Programs (OSBP), Office of Diversity and Equal Opportunity (ODEO), Office of Communications (OCOMM), and Office of Protective Services (OPS).
- NASA is streamlining and modernizing Human Capital Information Technology (HCIT) by standardizing position description (PD) classification, centralizing training administration, implementing a flexible and agile workforce approach through the Strategic Workforce Plan (SWP), and implementing a Strategic Talent Marketplace to replace the aging talent acquisition system.
- Multiple Centers will perform backlogged maintenance and repair projects to improve reliability of key infrastructure.
- NASA’s Office of the Chief Information Officer (OCIO) will oversee a requirements analysis for improvements to NASA’s existing financial systems and processes to address a narrow range of reporting capability gaps. In consultation with the Office of the Chief Financial Officer, OCIO will develop a plan for implementing these improvements beginning in FY 2021

MISSION SERVICES & CAPABILITIES

Reduce mission risk through technical capabilities:

- NASA will leverage the Legal Enterprise Operating System (LEOS) to enable the entire NASA legal team to operate its practice as a single entity, consolidating legal work products, data, and case records that are currently maintained at a dozen different legal operating locations.
- NASA will pilot a data governance platform to: (1) provide access to financial data across the Agency; (2) create metadata tags for NASA websites to allow easier searching and data mining; (3) use business applications such as Tableau/Power BI for data integration and automation of business processes; (4) employ IoT (Internet of Things) to help mine data for critical information; and (5) architect a cloud-based platform for next generation Scientific and Technical Information /NASA Technical Reports Server (STI/NTRS) System in coordination with the Information Management (IM) Program.
- NASA is implementing Dynamic and Evolving Federal Enterprise Network Defense (DEFEND) capabilities as defined by the Department of Homeland Security. DEFEND will provide increased cybersecurity services and flexibility for NASA to deploy specific solutions the Agency can use to safeguard its networks.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

Key mission enabling activities planned for FY 2021 include:

Deliver more efficient and cost effective operations and services:

- The final phase of transforming mission services and capabilities to a more effective and efficient enterprise delivery and support model will begin for the following Mission Support offices: Office of General Counsel (OGC), Office of the Chief Information Officer (OCIO), and Office of Strategic Infrastructure (OSI).
- Continue implementation of enterprise business model to streamline NASA procurements by establishing a nationalized NASA Procurement IT Website. Anticipated savings in FY 2021 due to employing the new enterprise model and streamlining approaches is approximately $850K.

Reduce mission risk through technical capabilities:

- The Agency will continue to reduce backlogged maintenance through multiple small projects to improve the condition and reliability of buildings and infrastructure systems to prevent outages, delays, or damage to critical mission hardware or missions (e.g., Artemis). These projects include water pumps and piping upgrades, energy management control system automation, water and sewer lift station repairs, as well as multiple electrical, fire and safety upgrades.
- NASA plans to develop Identity, Credential, and Access Management (ICAM) solutions to support international partner collaboration efforts. Expanding existing remote identity proofing capabilities, trusted partner agreements, and access control plan capabilities will provide further support and capabilities for foreign and domestic partners. These solutions will enable greater assurance in partner identities and help manage access risks.
- NASA will enhance its cyber security posture by: (1) continuing to work diligently with Department of Homeland Security (DHS) on Continuous Diagnostics and Mitigation (CDM) program implementation; (2) conducting annual Supply Chain Risk Management assessments; (3) optimizing its Security Operation Center (SOC); (4) integrating cybersecurity risk into the

Agency Enterprise Working Group’s risk management practice to ensure cybersecurity is a pivotal requirement in Mission projects at NASA; and (5) assessing all systems per the National Institute of Standards and Technology (NIST) guidelines and addressing any deficiencies. NASA's cybersecurity program will also sustain its Agency logging solution.

- The Computing program plans to complete the build-out of robust computing capabilities to enable transformational operations, such as one or more Google Cloud Platform environments including integrations with NASA IT infrastructure. Computing will continue the effort initiated in FY 2020 to bring unauthorized Software as a Service into compliance with FISMA requirements.
- NASA will continue to invest in proactive maintenance initiatives (e.g., reliability centered maintenance). NASA is moving towards industry standards for reducing unscheduled maintenance by installing sensors and equipment to enable real time monitoring and reduce scheduled maintenance inspections.

Program Elements

INFORMATION TECHNOLOGY

The Information Technology (IT) program provides the information services needed to fulfill NASA’s multifaceted missions and operations. NASA's Information Technology program helps improve Agency outcomes by driving discoveries as a strategic partner, accelerating results through productivity, sharing NASA’s data and discoveries, and increasing quality, resiliency, and cost-effectiveness. The program drives advances in science, technology, aeronautics, space exploration, and mission support to enhance knowledge, education, innovation, economic vitality, and stewardship of the planet Earth. Reliable, adaptable, and secure cloud-based IT is increasingly important as NASA embarks on its Artemis program to safely return astronauts to the lunar surface by 2024.

MISSION ENABLING SERVICES

The Mission Enabling Services (MES) program provides an enterprise approach to managing NASA's business operations and mission support activities. Missions rely on these institutional services to provide the business services and skilled staff required to accomplish their objectives. Enterprise management of these areas ensures that critical Agency operations are effective, efficient, and meet statutory, regulatory, and fiduciary responsibilities. Business services include Financial Management, Human Capital Management, Procurement, Small Business, Legislative Affairs, Equal Opportunity & Diversity Management, Legal, Communications, International and Interagency Relations, and Protective Services.

INFRASTRUCTURE AND TECHNICAL CAPABILITIES

The Infrastructure and Technical Capabilities (I&TC) program enables NASA missions and ensures effective mission support. The I&TC program provides sustainment, operations and maintenance for facilities and technical capabilities. The program also provides effective oversight and management of real property, environmental program activities, aircraft operations, and logistics functions. These capabilities enable NASA to meet its statutory and regulatory responsibilities and ensures that the right infrastructure is available to meet mission requirements. This mission is accomplished through effective management of assets and capabilities; proactive coordination with NASA mission directorates; enhanced institutional planning; proactive deployment of sustainable practices; ongoing regulatory compliance; and reducing current and future infrastructure-related risks.

INFORMATION TECHNOLOGY (IT)

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**501.8**	**--**	**553.9**	**553.9**	**553.9**	**553.9**	**553.9**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Beginning in FY 2021, SSMS has a revised budget account structure. FY 2019 reflects actual budget authority that have been re-cast into the new SSMS budget structure.

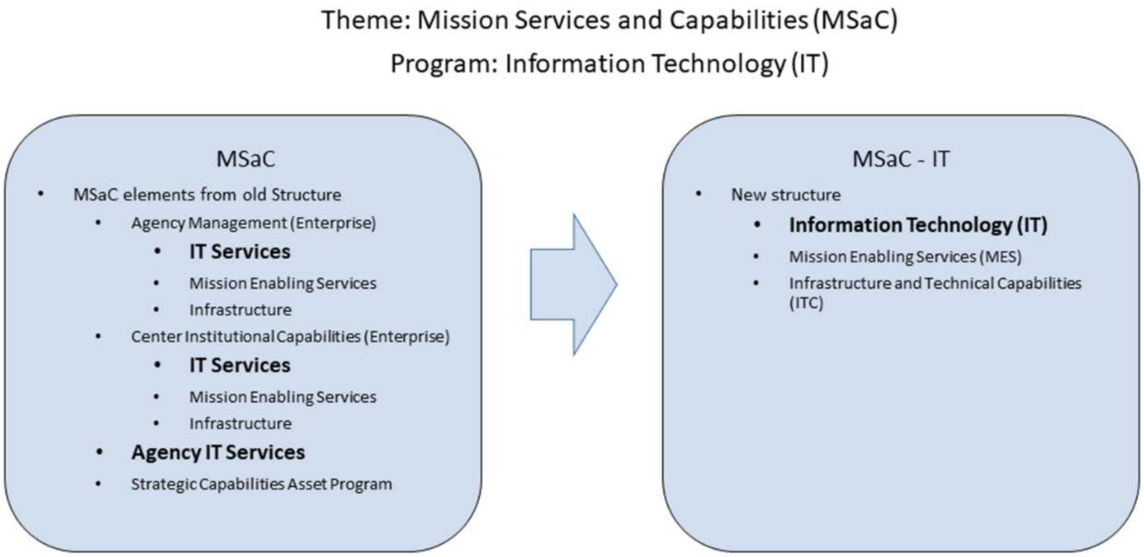
A monitor shows the status of NASA's Deep Space Network as it receives data from the Cassini spacecraft in the Charles Elachi Mission Control Center in the Space Flight Operation Center at NASA's Jet Propulsion Laboratory in Pasadena, CA.

NASA's IT program provides secure connectivity and data access for the NASA workforce and its partners, deploying over 100,000 continuous diagnostics and mitigation (CDM) tools across the corporate and mission networks and achieving Personal Identity Verification (PIV) access for 90 percent of unprivileged and 100 percent of privileged users. The program provides NASA end-users with cloud-based email inboxes and productivity and collaboration capabilities. The IT program supports over 250 applications that empower scientific research and mission support and the processing of approximately 4.3 million inquiries per year about NASA's Scientific and Technical Information (STI), providing the scientific community the information needed to achieve new discoveries, including those required for Artemis.

EXPLANATION OF MAJOR CHANGES IN FY 2021

The IT budget comprises portions of the former Center Management and Operations (CMO) and Agency Management and Operations (AMO) accounts that directly support Center and Agency IT capabilities, including assets and personnel for effective and efficient operations. Combining the funding for these capabilities into the new IT budget organization will enable NASA to transform to an enterprise approach to delivering the capabilities and services that enable NASA mission requirements. The enterprise business model approach for management of our assets and capabilities will better ensure that budget execution is aligned with Agency strategic goals. The new budget structure reflects the importance of coordinating and combining NASA's information services as part of the foundation that supports NASA's Artemis missions and other science, aeronautics exploration, and technology programs. A mapping of the prior and new budget structure follows:

INFORMATION TECHNOLOGY (IT)



The NASA Communications Services Office (CSO) budget will be transferred to the OCIO under the SSMS account to better align with its management structure. The CSO mission network provides mission-critical routed data services to programs and projects across the Agency. This activity is managed by the OCIO. However, unlike other OCIO activities which are funded in the Safety, Security, and Mission Services account, the CSO, budget is held within the Space Communications and Navigation (SCaN) program. This creates a misalignment between the budget and management structure.

ACHIEVEMENTS IN FY 2019

ENTERPRISE IT

The Applications program provided service delivery and governance for more than 250 enterprise applications and 3,000 websites. To enhance service delivery of these applications, the program created an Applications Repository that identified application capabilities for each business process area. The repository will enable rationalization of applications across the enterprise. Additionally, the Applications program implemented Phase 2 of Microsoft Office 365, which includes enhanced collaboration features (e.g., SharePoint Online and Teams) to improve team productivity and the ability to seamlessly work across geographic boundaries. Lastly, the program developed the Agency Software Management Plan to ensure timely, cost effective, and efficient procurement of software licenses.

The Communications program completed 32,136 IT service requests, supported 1.7 million minutes of video and 125 million minutes of voice conferencing, and resolved 15,440 IT service incidents. It also provided secure connectivity solutions to the International Space Station (ISS)/Space Launch System (SLS) partners, improving management and operational efficiency. By implementing enterprise cybersecurity infrastructure that improved access management for approximately 90,000 assets connected to NASA's networks, Communications reduced obsolete voice technology by migrating to Voice over Internet Protocol (VoIP) at two additional Centers. Of the total assets, 59,400 of 80,600 of NASA phones (73.7 percent) have been migrated to VoIP. Finally, Communications completed a Software Defined Networking (SDN) pilot which provides improved access management.

INFORMATION TECHNOLOGY (IT)

The Computing Services program sponsored several successful initiatives to promote better understanding of developing software in the cloud, including containerization and continuous integration, deployment, and automation. The program improved NASA's cloud service offering by increasing networking bandwidth, shortening the time to provision a user, and improving privilege management to increase user account security and reduce manual account configuration errors.

The IM program created a dashboard to visualize NASA’s usage of approximately 38 online academic journal subscriptions utilizing procurement and network traffic data (approximately 38,000 hits annually) and the Digital Object Identifier Management System (DOIMS), which provides researchers with a centralized system to create and maintain digital object identifiers (DOIs). The DOIs improve the user experience by enabling scientists to tag their publications using NASA-based capabilities.

The Transformation and Data initiative made the following information publicly accessible per the Open Data Act: over 42,900 data sets, 555 web-hosted archives of software source code, and 17 sets of routines, protocols, and tools used to interact with systems, applications, libraries, and databases. The Agency’s Digital Transformation strategy was developed to employ powerful digital practices to enhance the Agency’s efficiency, agility, and insights.

SAFEGUARDING DATA AND IT ASSETS

NASA OCIO completed the primary deployment plan of CDM Phase I tools and processes with Department of Homeland Security (DHS) support, increasing NASA’s visibility into cybersecurity risks and vulnerabilities. Once completed, the Agency will have a holistic view of NASA’s corporate and mission network vulnerability profile to enable effective cybersecurity risk management.

NASA OCIO implemented a Security Operations Center (SOC) Continuity of Operations Plan (COOP) to maintain SOC operations in the event of a disruption or catastrophic event. OCIO established a formal function to integrate cybersecurity risk management processes across the Agency into a formal enterprise risk management program.

Per Executive Order 13800, Strengthening the Cybersecurity of Federal Networks and Critical Infrastructure, NASA OCIO led efforts to fully implement the National Institute of Standards and Technology’s (NIST) Cybersecurity Framework and conducted ongoing capability assessments to improve cybersecurity operations and inform risk-based decisions on strategic, cybersecurity investments.

By establishing an Office of Cybersecurity Services (OCSS) and consolidating duplicative cybersecurity services into an efficient enterprise-wide function, NASA OCIO standardized cybersecurity service delivery. The OCIO also began deploying a consolidated Agency logging solution capability which allows the NASA SOC to process substantially more IT log data than prior local solutions. The increased capabilities provide the Communications program with web content filtering, Virtual Private Network (VPN), and firewall troubleshooting and the Agency Identity, Credential and Access Management (ICAM) program with alerts to notify of key authentication or authorization events throughout the Agency.

INFORMATION TECHNOLOGY (IT)

IT GOVERNANCE AND OVERSIGHT

The OCIO standardized the IT Portfolio data collection process, enhanced transparency, and complied with OMB reporting requirements by implementing an enterprise off-the-shelf Program Project Management (PPM) tool and configuring the tool to support the Technology Business Management (TBM) categorization of Agency IT spending, Improvements to the data collection process have provided a deep understanding of the Agency's full IT footprint and informed investment decision-making.

WORK IN PROGRESS IN FY 2020

ENTERPRISE IT

The Applications program continues to maintain 250 enterprise applications and 3,000 websites. The program will create a single, centralized case management solution for the Office of General Counsel which enables the entire NASA legal team to operate as a single enterprise, providing more efficient delivery of legal services with reduced risks associated with outdated information, different operating systems across the NASA legal offices, and divergent case management procedures. The Applications program will continue a phased implementation of managing the Agency software lifecycle to reduce risks and costs. The program will modernize NASA's heavily-utilized SAP platform (HANA), which will prepare the SAP platform for updates to NASA's financial system, contract writing system, and business intelligence platform. The program will also lead the requirements analysis for improvements to the Agency's financial systems to achieve the full functionality in budget execution and reporting.

The Communications program continues to provide voice, video, and network services to NASA Centers and missions. The program will also continue the VOIP transport project which includes installing new infrastructure and completing VOIP migration at Kennedy Space Center (KSC). Additionally, the Communications program will deploy Software Defined Networking (SDN) capabilities across the Agency to improve access management and create operational efficiencies.

The Computing Services program will complete the build-out of one or more Microsoft Azure user cloud environments, which includes integrating Azure with NASA's IT infrastructure. Additionally, Computing Services program is bringing unauthorized Software as a Service (SaaS) into compliance with the Federal Information Security Modernization Act (FISMA).

The End User Services program continues to expand utilization of its enterprise contract for end user services from 80 percent utilization to 90 percent. Additionally, the program is implementing a new information management module for change management and SpaceBars, a one-stop walk-up support office to provide IT support from friendly, skilled technicians. The EUS program will upgrade all computers to Windows 10 before Microsoft ends support for Windows 7 to standardize service delivery support and reduce cyber security vulnerabilities.

The IM program continues to maintain compliance with the Paperwork Reduction Act, Section 508 of the Rehabilitation Act, the Information Quality Act, and Federal records retention requirements. To improve performance, security, and the user experience, the IM program is modernizing STI infrastructure, enabling use of Google Cloud, and laying the groundwork for future modernization.

INFORMATION TECHNOLOGY (IT)

SAFEGUARDING DATA AND IT ASSETS

NASA IT program is developing a new enterprise-wide cybersecurity services contract to support existing Centers and Agency contracts. To ensure necessary services are available to meet mission needs in the event of a disruption or catastrophic event, NASA continues to grow and staff a 24x7 NASA SOC COOP capability at JSC. The program will further develop and implement its Agency logging solution for flexibility and agile operations to meet evolving demands.

IT GOVERNANCE AND OVERSIGHT

OCIO will enhance the PPM tool to provide integrated planned and actual IT budget data to support improved management of NASA's IT portfolio and promote efficient and effective decision-making. Additionally, OCIO is building upon the IT Program strategic roadmaps and updated CPIC processes, including leveraging IT governance, to better manage IT investments in support of NASA's mission.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

ENTERPRISE IT

The Applications program plans on completing the implementation of the centralized, standardized, and streamlined lifecycle processes for managing software licenses and consolidating Agency websites. Applications will be integrated with cross-location management and employees co-located for requirements. The program will also continue to reduce the total number of unique applications and more efficiently utilize application services and will initiate the systematic decommissioning of redundant applications and software technologies.

The OCFO will work with OCIO to initiate the FY 2020 plan for changes to the Agency's financial systems. The FY 2021 Budget provides $2 million in new funding for this initiative that will include automating standard tracking and reporting features that currently must be performed manually by the Agency.

The Communications program will continue providing voice, video, and network services to NASA centers and missions and anticipate continued growth in service requests and support to Agency missions. Additionally, the program will continue the multi-year project for Agency-wide deployment of SDN, including data center and cloud, to improve access management and operational efficiencies. Communications also plans on completing the transition to VoIP at two additional Centers.

The EUS program will continue to increase mobility and collaboration for end users to securely access and share data from any geographic location or device working towards the best cloud-based solutions. The program plans to improve "self-help" tools including the Enterprise Service Desk (ESD) knowledge base to ensure information is readily available for IT related needs. Additionally, the EUS program will implement a new configuration management system (CMS) in Service Now.

The IM program will lead the delivery of new Agency IT capabilities to catalog NASA dataset metadata and provide Agency users insight into siloed NASA datasets. The program will also establish a steady-state, federated catalog of NASA's digital assets in an Enterprise Data Inventory while providing NASA users with resource discovery, drastically boosting data re-use. Additionally, the IM program will implement and deliver an Agency Data Management Plan Policy and Agency Data Sharing Policy, which convey the direction of NASA's data governance and data management approaches.

Through the transformation and data initiative, planned achievements include implementing the Data Governance Platform for financial data; implementing/creating metadata tags using artificial intelligence for NASA Websites; implementing business application of Tableau/Power BI software for data integration; automating business processes; managing IOT; providing an isolated testing environment and internet access with analytics at JSC; and prototyping/piloting a cloud-based platform for the next generation STI/NTRS System.

SAFEGUARDING DATA AND IT ASSETS

NASA OCIO will integrate cybersecurity risk into the Agency Enterprise Working Group's risk management practice to ensure cybersecurity is a pivotal requirement in Mission projects at NASA. Additionally, the OCIO will assess all systems per the National Institute of Standards and Technology (NSIT) guideline and address any deficiencies. NASA's cybersecurity program will also sustain its Agency logging solution.

IT GOVERNANCE AND OVERSIGHT

NASA OCIO will work to modernize IT systems, identify redundancies, and reduce deferred technical refresh and modernization. By full implementation of revised CPIC processes in the new enterprise IT operating model, OCIO will strengthen IT portfolio management and oversight of IT investments.

Program Elements

ENTERPRISE IT

The Applications program anticipates and aligns customer requirements with solutions that best meet Agency needs by delivering secure, sustainable applications quickly and cost effectively, establishing a platform-centric architecture and empowered Enterprise Service Providers, enhancing Agency Software Management to reduce software license costs, and continuous portfolio rationalization.

The Communications program is NASA's enterprise service provider for fully managed network and communications services supporting institutions, programs and projects located at the NASA Centers. The program is also responsible for maintaining, operating and continually evolving communications services to improve delivery capabilities, strengthen NASA's cybersecurity posture, and reduce costs.

The Computing Services program brokers commercial cloud computing services for the NASA community and provides oversight of NASA's compliance with the Federal Data Center Optimization Initiative. Customers of cloud computing services include the science and mission communities across all phases of data acquisition, processing and science/engineering analysis.

The EUS program provides high quality, reliable, cost-effective service desk, end user computing services, collaboration, content management systems and services in support of all NASA Federal and contractor employees. Specific service types supported by the program are laptops, desktops, mobile devices, print, enterprise email, instant messaging, help desk services, support, software patching and distribution, and other end user support capabilities.

The IM program provides NASA with framework, guidelines, and services to ensure secure and efficient access, use, analysis, and preservation of the Agency's information resources. The program also ensures NASA's compliance with several Federal statutes relating to information access and integrity.

The Transformation and Data initiative engages the brightest minds across the Agency to guide NASA's data strategy, technology infusion, and strategic investment decisions, and identifies emerging information technologies to best support NASA's needs in a rapidly changing world.

SAFEGUARDING DATA AND IT ASSETS

NASA OCIO is responsible for Agency cybersecurity policy and the implementation and management of enterprise cybersecurity and privacy services. The budget is aligned to the NIST Cybersecurity Framework to evaluate cybersecurity gaps and investments against the NIST cybersecurity functions: Identify, Detect, Protect, Respond, and Recover. This alignment allows the Agency to make strategic investments to develop, modernize, and enhance Agency cybersecurity capabilities to address the greatest areas of risk to the Agency, its missions, and supporting functions.

IT GOVERNANCE AND OVERSIGHT

NASA OCIO provides Agency-level capabilities for intentionally managing IT and meeting Agency and Federal requirements. IT Governance & Oversight efforts involve collaborating with stakeholders across the Agency to formulate plans and manage budgetary data to meet legal mandates, OMB requirements and guidance, Executive Orders, and regulations. These efforts also include the E-Government activities and Federal CIO Council Committees in which NASA participates.

MISSION ENABLING SERVICES

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**690.8**	**--**	**705.0**	**693.7**	**693.7**	**693.7**	**693.7**

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Beginning in FY 2021, SSMS has a revised budget account structure. FY 2019 reflects actual budget authority that have been re-cast into the new SSMS budget structure.

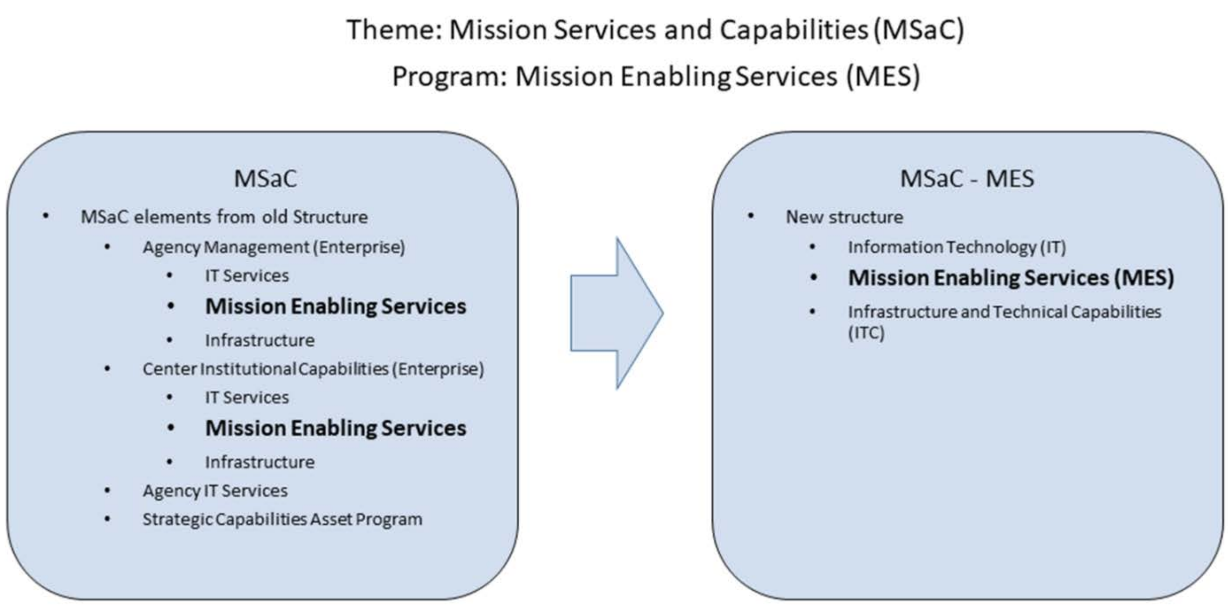
As illustrated in the image above, there are no geographical boundaries in providing Mission Enabling Services to meet Mission needs.

Mission Enabling Services (MES) provide an enterprise approach to managing NASA's business operations and protective services with no geographical boundaries in the delivery of services. An enterprise approach allows NASA to manage its business services in a unified approach thereby providing consistent processes and systems across the Agency. Missions rely on these institutional capabilities to provide the skilled staff required to accomplish their objectives. Enterprise management of these areas ensures that critical Agency operations are effective, efficient, and meet statutory, regulatory, and fiduciary responsibilities. These mission enabling services and related processes are testament to the complexity of the support needed to successfully implement and complete requisite missions. MES will continue to provide support to all NASA missions including critical support to the Artemis program. Business services include Financial Management, Human Capital Management, Procurement, Small Business Programs, Legislative Affairs, Diversity and Equal Opportunity, General Counsel, Communications, International and Interagency Relations, and Protective Services.

EXPLANATION OF MAJOR CHANGES IN FY 2021

In FY 2021, NASA will complete the transformation to an enterprise model for the delivery of Mission Enabling Services which include the following enterprise functions: Financial Management, Human Capital Management, Procurement, Small Business Programs, Legislative Affairs, Diversity and Equal Opportunity, General Counsel, Communications, International and Interagency Relations, and Protective Services. The enterprise model provides standardized services to customers and employees regardless of geographic locations. The model also reduces and eliminates duplicative capabilities, provides opportunities for employees to work across geographic boundaries, and offers greater flexibility to adjust to evolving demands and meet surge requirements.

To fully realize the benefits of the new model, NASA has developed a budget account structure that better enables the offices to deliver services and products in an enterprise model. Prior to FY 2021, enterprise budgets were managed with a combination of funding from the Center Management and Operations and Agency Management and Operations budget account themes. Budget authority and reporting under the new structure is completely aligned under one theme (Mission Services and Capabilities). This new structure is vital to NASA's efforts to realize more efficient and effective mission support operations and ensure alignment with Agency strategic goals. A mapping of the prior and new budget structure follows:



ACHIEVEMENTS IN FY 2019

NASA embarked on transforming the delivery and support model for mission services to an enterprise model, enabling the Agency to meet mission requirements while conducting day-to-day technical and business operations more effectively. In October 2018, three Mission Support offices began to deliver services in an enterprise model: Office of Chief Human Capital Officer (OCHCO), Office of Chief Financial Officer (OCFO), and Office of Legislative and Intergovernmental Affairs (OLIA).

NASA's OCHCO successfully operated utilizing an enterprise business model. This included taking full budget authority of funding realigned to OCHCO and pursuing major transformation initiatives, while maintaining the goal of providing world-class services to the Agency. During this timeframe, the OCHCO transitioned all position staffing and classification services to an enterprise model to enhance efficiencies and increase effectiveness. By consolidating and centralizing these services at the NASA Shared Services Centers (NSSC), the Agency is now well-positioned to minimize duplication of effort (including resources) and standardize processes which will reduce costs related to this function.

MISSION ENABLING SERVICES

NASA's Office of Procurement (OP) completed transformation of the organization, which included realignment of the workforce and budget from the individual NASA Centers to one enterprise Procurement Office. The transformation included the development of an enterprise delivery model where requirements, that were once decentralized, are consolidated into portfolios that are now procured and managed regionally or centrally at one or more of the NASA buying locations. This new model allows for the development of streamlined enterprise procurement strategies, smart buyers, shared resources, and lower operating costs.

The Agency celebrated the success of the Apollo missions through a series of events aimed at inspiring the next generation of human space flight and honoring the astronauts who achieved this monumental task. In December 2018, the Agency marked the achievement of Apollo 8 orbiting the Moon with a collaboration with the Smithsonian National Air and Space Museum and the Washington National Cathedral. Throughout 2019, NASA supported a series of events across the country to mark the 50th anniversary of Apollo 9, Apollo 10, Apollo 11, and Apollo 12. The focal point of our activities was a three-day festival on the National Mall in Washington, D.C., in conjunction with the National Air and Space Museum and a two-hour NASA TV broadcast from the National Mall, the refurbished Apollo Mission Control Center in Houston TX, and other locations across the country.

NASA's Office of General Counsel (OGC) significantly advanced the development of Artemis through innovative, coordinated legal support across Headquarters and multiple field Centers for the many procurements that enable NASA to work with our industry partners. The NASA legal team played an integral role in the acquisition strategies and implementation of the contracts for the Power Propulsion Element, Gateway Logistics Services, Human Landing System, Habitation modules, and Commercial Lunar Payload Services, which collectively will create the Gateway architecture for deep-space exploration and will enable a sustainable U.S. human and robotic presence on the Moon and progress towards human exploration of Mars and beyond.

NASA's OP and Office of Small Business Programs (OSBP) formed an integrated enterprise service delivery model that will transform how NASA procures goods and services. This model creates a more efficient and effective organization of the NASA Center small business specialists (SBSs).

NASA's OSBP established the NASA Industry Forum (NIF) to increase communication with our industry partners and share best practices. The NIF held two meetings in FY 2019.

NASA exceeded its FY 2019 small business goal of 16 percent by achieving approximately 17 percent. NASA exceeded its FY 2019 small disadvantaged business goal of 5 percent by achieving 8 percent. Total prime and subcontracting dollars combined increased from $5.2 billion in FY 2017 to $5.5 billion in FY 2018.

WORK IN PROGRESS IN FY 2020

In FY 2020, five additional Mission Support offices began the implementation and transformation to deliver services in an enterprise model: Office of Procurement (OP), Office of Small Business Programs (OSBP), Office of Diversity and Equal Opportunity (ODEO), Office of Communications (OCOMM), and Office of Protective Services (OPS).

A key element in our talent strategy at NASA is our ability to quickly, fairly, and accurately acquire the best candidate for our jobs. During FY 2020, the OCHCO will replace NASA's long standing and aged talent acquisition and assessment system, NASA STARS, with USAStaffing/USAHire. This Government off-the-shelf product will bring our hiring process forward by a decade, allowing NASA to assess candidates using industry best practices. Additionally, this move will assist NASA in avoiding continued costs associated with maintaining the current system.

The unveiling of the Artemis spacesuits will garner national and international media attention and present an opportunity to share the Agency's plan to send the first woman and the next man to the Moon.

The International Space Station 20th Anniversary in 2020 will present opportunities to tell the public through media and other means about how the International Space Station has contributed to our journey to the Moon and Mars.

NASA has launched a Unity Campaign to enhance the effectiveness of NASA organizations and personnel in achieving NASA's priorities, including the Artemis program with local implementation plans developed that align with the Agency's enterprise strategy for the campaign. NASA expects to achieve measurable results, including increased employee engagement, workplace and workforce inclusiveness, and enhanced organizational performance.

Maturation of the enterprise service delivery model and organization structure with a focus on the development of a centralized IT Procurement Office to achieve consistency in IT requirements to enable greater commonality in implementing IT solutions leading to improved FITARA scorecard performance, reduced duplication in IT contracting, and improved IT buying expertise.

The Office of Protective Services (OPS) continues to upgrade the hardware infrastructure on the National Security Systems (NSS) to comply with the methodology for secure data processing and testing of diverse software and hardware on the NSS 'test bed'. These upgrades will ensure that security posture is maintained and that the new configurations will enhance the standard. OPS continues to work with all programs that require access to classified information.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

OCHCO plans to implement an Agency-wide Human Space Flight Pathways Program for students/interns. The Pathways Program is an integral aspect of NASA's workforce pipeline and succession planning. The Program's goal is to ensure NASA's early career workforce has the necessary breadth and depth of experience to support the Agency's priorities (e.g., Artemis).

ODEO will lead the development of a new NASA Diversity and Inclusion (D&I) strategic plan to achieve the Agency Priority Goal 4.4.2 to Sustain or improve NASA's Inclusion Index scores on the annual Federal Employee Viewpoint Survey (FEVS) as measured by the New Inclusion Quotient (New IQ) results.

OGC plans to have completed its transformation into a single legal enterprise with field Center Chief Counsel lines of reporting realigned to HQ along with Center Office of Chief Counsel budgets and resources.

OPS will ensure full coverage of Communications Security (COMSEC), National Security Systems, Intelligence Analysis, and Special Security Officer support for Artemis, commercial crew endeavors, and other NASA priorities.

MISSION ENABLING SERVICES

Program Elements

OFFICE OF THE CHIEF FINANCIAL OFFICER

The Office of the Chief Financial Officer (OCFO) provides leadership for the strategic planning, performance reporting, budget analysis, justification, control, and reporting of all Agency fiscal resources; develops the Agency's detailed strategic plan and performance reports; leads the Agency's planning, programming, budgeting, and execution process; oversees all financial management activities relating to the programs and operations of the Agency; and monitors and reports the financial execution of the Agency budget. The OCFO manages the Agency's budget and financial operations, directs the preparation and submission of annual financial and budgetary reports, and coordinates Agency financial management activities with other federal agencies. The OCFO was established in accordance with the Chief Financial Officers Act of 1990 (CFO Act), Public Law 101-576.

OFFICE OF CHIEF HUMAN CAPITAL OFFICER

The Office of the Chief Human Capital Officer (OCHCO) provides services and innovative solutions to ensure they meet the needs of our mission today and tomorrow. From creating a learning culture to implementing technology that supports work/life balance, OCHCO supports and strengthens the human foundation of NASA. Game-changing programs help Agency leaders understand workforce investments, anticipate workforce needs and easily acquire talent for the task. Game-changing programs include streamlining and modernization of the Human Capital Information Technology (HCIT), simplification of position description (PD) classification, centralized training administration, implementing a flexible and agile workforce approach through the Strategic Workforce Plan (SWP), and replacing our aging talent acquisition system. NASA's talent needs are always evolving with mission activities that test the limits of human capability. Leaning forward to be a global leader in human capital excellence, OCHCO enables the people of NASA to push the boundaries of achievement by supporting NASA's mission first and its people always.

OFFICE OF PROCUREMENT

The Office of Procurement (OP) explores and executes innovative, effective, and efficient acquisition business solutions to optimize capabilities and operations that enable NASA's mission. NASA spends approximately 85 percent of its budget on acquiring goods and services through approximately 750 procurement and small business professionals across the Agency. In FY 2019, Agency spend was $19.6 billion via approximately 36,000 procurement actions (e.g., awards, modifications) while managing more than 23,000 instruments (e.g., contracts, Purchase Orders, Task Orders, and Delivery Orders).

MISSION ENABLING SERVICES

OFFICE OF SMALL BUSINESS PROGRAMS

The Office of Small Business Programs (OSBP) promotes and integrates small businesses into NASA's industry base of competitive contractors that pioneer the future of space exploration, scientific discovery, and aeronautics research. OSBP provides integration, policy, initiatives, and oversight needed to ensure compliance with law and regulation to increase the Agency's small business industry base while offering the best technical solutions and value to support the Agency's mission. Conducts, sponsors, and participates in small business outreach activities which assist small businesses, including small disadvantaged, women-owned, Historically Underutilized Business Zones (HUBZone), veteran-owned, and service-disabled veteran-owned as well as Historical Black Colleges and Universities (HBCU)/ Minority Serving Institutions (MSI) in supporting the NASA mission.

OFFICE OF LEGISLATIVE AND INTERGOVERNMENTAL AFFAIRS

The Office of Legislative and Intergovernmental Affairs (OLIA) provides executive leadership, direction, and coordination of all communications and relationships, both legislative and non-legislative, between NASA and the United States Congress as well as state and local governments.

OFFICE OF DIVERSITY AND EQUAL OPPORTUNITY

The Office of Diversity and Equal Opportunity (ODEO) leads diversity and civil rights policies, programs, and services, which enable the universe of available talent to contribute inclusively and equitably to NASA. NASA's ODEO programs empower and advance NASA as a leader and model Agency for Diversity and Inclusion and for Equal Employment Opportunity, as well as promote External Civil Rights Compliance in NASA-funded science, technology, engineering, and mathematics and other related programs.

OFFICE OF THE GENERAL COUNSEL

The Office of the General Counsel (OGC) provides legal services Agency-wide including establishing and disseminating legal policy and interpreting new statutes and cases to enable diverse and cutting-edge Agency activities and to ensure they are conducted in accordance with all statutory and regulatory requirements. The OGC is also responsible for developing the ethics and patent program requirements, establishing metrics, and developing quality standards. As a functional office, the General Counsel serves in an advisory capacity to the Administrator, Enterprise Associate Administrators and Center Directors across nearly 20 core legal disciplines. The Office of the General Counsel provides litigation expertise to the Agency and acts as the Agency representative before the U.S. Patent and Trademark Office and other administrative forums. NASA attorneys also function as leaders and trusted advisors on matters of policy and legal risk, upholding NASA values and enabling the NASA mission.

OFFICE OF COMMUNICATIONS

The Office of Communications (OCOMM) delivers NASA's incredible work to billions of people around the world with compelling storytelling on a variety of platforms thereby strengthening the NASA brand. NASA communicates via various methods including news and media engagement, digital services and products (e.g., web, multimedia, social media), non-technical publications, exhibits, as well as speaking

MISSION ENABLING SERVICES

and public engagement activities and events, to promote effective and consistent NASA communications by ensuring synergy and strategic focus and working collaboratively with other Agency organizations.

OFFICE OF INTERNATIONAL AND INTERAGENCY RELATIONS

The Office of International and Interagency Relations (OIIR) provides executive leadership and coordination for all NASA international and interagency activities and partnerships, and for policy interactions between NASA and other U.S. Executive Branch offices and agencies.

OFFICE OF PROTECTIVE SERVICES

The Office of Protective Services (OPS) is the focal point for policy formulation, oversight, coordination, and management of Agency physical security, intelligence, counterintelligence, counterterrorism, emergency management, continuity of operations, fire services, National Security, communications security (COMSEC), classified information security, personnel security, identity and credential management, electronic physical access management, insider threat, and protective services training programs. OPS provides services at 20 locations across the country, to ensure the safety and security of people, property, and information.

INFRASTRUCTURE & TECHNICAL CAPABILITIES

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**536.8**	**--**	**693.1**	**693.0**	**693.0**	**693.0**	**693.0**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Beginning in FY 2021, SSMS has a revised budget account structure. FY 2019 reflects actual budget authority that have been re-cast into the new SSMS budget structure.

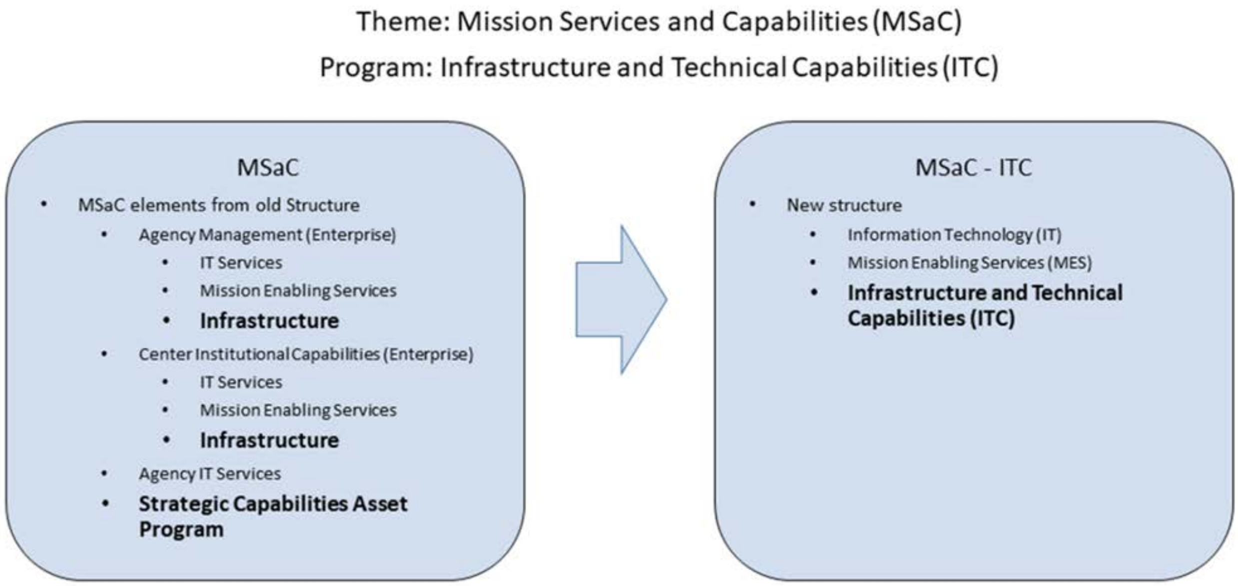
Preparing to test the Orion capsule in extreme temperature conditions (-250 to +300 degrees Fahrenheit) at the Space Environments Complex (SEC) at Glenn Research Center (GRC).

The NASA Infrastructure and Technical Capabilities (I&TC) program addresses agency-wide operating requirements that are not fully funded by a single NASA Mission Directorate. The program maintains facilities, utilities, structures and technical capabilities. It also provides oversight and management of real property assets, environmental program activities, aircraft operations, and logistics functions. Critical to supporting NASA's missions is the underlying infrastructure and skilled workforce that keep the Centers and facilities operating effectively and efficiently.

EXPLANATION OF MAJOR CHANGES IN FY 2021

The I&TC budget is established from portions of the former Center Management and Operations (CMO) and Agency Management and Operations (AMO) budgets. I&TC comprises the resources that directly support Center and Agency institutional capabilities. Specific capabilities (e.g., vacuum chamber test facilities) are also aligned under this single budget line to optimize their utilization and respond to emerging mission requirements. This single I&TC budget structure will improve the management of fiscal resources, which will enable more efficient, adaptable and effective operations and services. A mapping of the prior and new budget structure follows:

INFRASTRUCTURE & TECHNICAL CAPABILITIES



ACHIEVEMENTS IN FY 2019

Key mission enabling accomplishments in FY 2019 include:

- NASA approved the Master Plan Facility Development Concepts at three Centers, which demonstrated an ability and intent to dramatically reduce the cost of stewardship at the Centers over a 20-year period.
- NASA continued to expand the use of Condition-Based Maintenance (CBM) and initiated a tiered maintenance program. These efforts included installing remote sensing and asset monitoring technology on critical assets. This resulted in increased reliability and availability of these assets. Examples include the following:
    - The Agency tracked 1,522 Predictive Testing and Inspection (PT & I) “finds,” resulting in the Agency finding and repairing 1,522 potential failures early with a potential cost avoidance of 66 percent per finding.
    - Glenn Research Center (GRC) had six CBM "finds" that resulted in a 60 percent cost avoidance on the repairs of non-instrumented assets.
    - Langley Research Center (LaRC) had more than 150 CBM "finds" since FY 2014 that were detected, and maintenance action scheduled before the asset failed and interrupted mission work. This resulted in a cost avoidance of over $4.5 million. Maintenance costs, on CBM instrumented assets, were reduced by 6 percent.
- Significant progress was realized in developing an Agency Master Plan that links the Agency's strategic objectives to investments in critical assets needed to meet mission objectives. In addition, there were divestments of assets no longer required which resulted in reduced infrastructure costs. Center Master Plans will directly tie to the Agency Master Plan once completed thereby ensuring strategic alignment at all levels.

INFRASTRUCTURE & TECHNICAL CAPABILITIES

NASA completed multiple repairs, system refurbishments and mission critical upgrades of aging equipment and infrastructure to restore reliability and reduce safety and mission risks. NASA's technical capabilities continued to be available for programs and projects with an overall availability of 99.8 percent. Notable milestones included:

- The Pegasus transportation barge was lengthened by 100 feet to enable transport of Space Launch System components.
- The 25-foot Space Simulator supported the Mars 2020 development testing required to launch a spacecraft to investigate the Martian astrobiological environment and surface geological processes.
- The Flight Simulation Facility at LaRC supported the Aeronautics Research Mission Directorate with development and testing to enable the Low Boom Flight Demonstrator's to meet their research objectives of supporting the development of practical commercial supersonic vehicles.
- Aircraft Operations enabled over 8,000 flight hours without incurring any mishaps. Over 4,200 aircraft sorties were safely conducted supporting human exploration, science and aeronautics research, such as aircraft technology development projects (i.e., X Projects) and astronaut training.

WORK IN PROGRESS IN FY 2020

Key mission enabling activities underway in FY 2020 include:

The I&TC program will continue sustainment projects that do not qualify for CECR funding to revitalize, replace, upgrade or refurbish infrastructure and technical capabilities. Replacing systems that are far past their design life will reduce operating costs and reduce the risk of infrastructure failure. Notable examples include:

- Repair or replace air handler units and cooling systems that pose the highest risk to the Agency's missions. Many are over 40 years old and have obsolete parts.
- Replace outdated facility fire safety, emergency and electrical equipment across all Centers to reduce safety risks to personnel.
- Initiate retro-commissioning projects across the Agency to increase building performance, reduce energy costs and meet energy use reduction goals, using Enhanced Use Lease proceeds.
- Expand the condition-based maintenance program and utilize a Reliability Centered Maintenance Program approach to improve effectiveness and reduce costs.

NASA will perform numerous tests and evaluations to reduce risk associated with NASA’s efforts to build the modern, advanced launch vehicle required for Artemis. Activities will include:

- Continue development of Thermal Protection Systems for Artemis Orion and planetary science missions at the Arc Jet Complex at the Ames Research Center (ARC).
- Conduct Thermal vacuum and electromagnetic interference testing for the Orion EM-1 vehicle at the Space Environments Complex (SEC) at GRC.
- Continue developing the external Vision System (XVS) and synthetic vision technologies for improved flight training and aviation safety at the Flight Simulation Facility (FSF) at LaRC. XVS will enable pilots of supersonic aircraft to safely operate future low-boom, supersonic configurations (without forward-facing windows).

- Thermal vacuum testing planned for the Science Mission Directorate Lucy mission in Chamber A at Johnson Space Center (JSC).
- Thermal vacuum and acoustic testing planned for Commercial Crew and Cargo Program at the Space Environments Complex at GRC.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

Key mission enabling activities planned for FY 2021 include:

In FY 2021, NASA will begin implementing a more centralized approach to providing I&TC services, incorporating best practices and leveraging expertise independent of geographic location. By sharing integrated resources across Centers, NASA will improve efficiencies, effectiveness and reliability across the Agency. Notable examples include:

- Continue replacement of over aged electrical controls and address identified safety risks of arc flash events.
- Continue to support lease and out grants to our partners in support of key NASA missions (e.g., Artemis), while leveraging resources from these partnerships to reduce risks of infrastructure failures due to overaged infrastructure components.
- Planned testing across the Agency including continued support for:
  - Artemis Orion through thermal vacuum and acoustics and vibrations testing in the SEC;
  - Artemis Orion through heat shield risk reduction testing and Thermal Protection Shielding development for the Science Mission Directorate Dragonfly mission at the Arc Jet Complex at ARC;
  - Artemis Orion, Commercial Crew and Cargo Program launch, and other space environmental testing in thermal, vacuum, and acoustic chambers; and
  - Space radiation environment impacts on electronic and related aerospace materials systems using external, ground-based, high-energy radiation sources.

Program Elements

AIRCRAFT MANAGEMENT

The Aircraft Management Program provides capability leadership, oversight, and coordination of NASA's aviation assets, including Unmanned Aircraft Systems to enable NASA's missions in science, technology, aeronautics, and space exploration. NASA policy sets the highest standards and best practices of aviation safety. Program-Independent Flight Operations Offices provide oversight of Center aircraft flight operations and ensure aircraft operations can meet unique missions worldwide in a safe manner. These offices include a Chief of Flight Operations, an Aviation Safety Officer, a Chief of Maintenance and a Chief of Quality Assurance to ensure oversight of qualified personnel operating aircraft that are airworthy and mission ready.

INFRASTRUCTURE & TECHNICAL CAPABILITIES

ENVIRONMENTAL MANAGEMENT

The Environmental Management Program encompasses the development, implementation and oversight of Agency policies for environmental planning, compliance, restoration, pollution prevention, energy and water conservation and sustainability while preserving natural, cultural and historic resources in balance with enabling the NASA missions. The program enables compliance with applicable Federal, state and local environmental laws and regulations, as well as NASA policy in day-to-day operations and mission support. Specifically, Environmental Management covers NASA's programs for local environmental policy development, Environmental Management System (EMS) implementation, environmental permitting and compliance, recycling, sustainable acquisition, hazardous materials and waste management, pollution prevention, energy and water management systems and reporting, renewable energy, natural resources, historic properties and National Environmental Policy Act (NEPA) program support.

FACILITIES SERVICES

The Facilities Services program encompasses the institutional facilities support activities throughout the Agency. The budget supports utilities, operations and maintenance, real estate, and facilities engineering to include civil construction designers, engineers and project managers. I&TC funds the civil servants and procurements that operate and manage NASA's institutional infrastructure. NASA recently deployed a cost model that forecasts the funding requirements to sustain its inventory of facilities at the current condition. NASA manages a portfolio of assets with over $2.4 billion in deferred maintenance. The I&TC budget supports a strategy to reduce the growth of backlogged maintenance and systematically improve the reliability of NASA institutional infrastructure from transformers and substations to buildings, horizontal infrastructure and test capabilities.

NASA Centers manage their activities focused on planned maintenance, routine operations such as grounds, central plant operations and utilities, as well as unscheduled breakdown maintenance. This budget reflects NASA's strategy and priority to reduce backlogged maintenance for important buildings systems such as electrical, environmental (heating and cooling), plumbing, utilities and roofs over several years. The Artemis missions will require increased reliability of NASA's infrastructure and this budget reduces schedule and technical risk through systematic upgrades of existing, outdated systems. Due to the age of most of NASA's facilities (over 82 percent of NASA's infrastructure and facilities are beyond their constructed design life), many of these systems are due for replacement. NASA is focused on replacing aging systems to reduce risk to mission requirements and future operating costs.

LOGISTICS MANAGEMENT

The Logistics Management program encompasses the development, implementation, and management of agency-wide logistics policies, processes, services, system innovation, and facilitates the implementation of Government and Industry best practices for NASA's Centers and facilities. Logistics Management provides functional management, oversight and coordination over the Agency's personal property equipment, supply and material, warehouse and receiving operations, property disposal, and artifact property disposition. The program also provides oversight for contractor-held property management; mail and freight management; transportation management; life cycle logistics and supply chain management; policy compliance and logistics contracts; and Agency library management. Logistics Management ensures the readiness of material and equipment for NASA's scientific, aeronautics, and space exploration mission requirements at 10 NASA Centers and three component facilities. The program includes receiving and inspecting supplies/materials as well as issuing and moving those materials so that products critical to NASA's space exploration mission arrive at the desired locations in an efficient manner.

TECHNICAL CAPABILITIES MANAGEMENT

The Technical Capabilities Management program provides the centralized and strategic management of a portfolio of specific capabilities to enable NASA's missions in science, technology, aeronautics, and space exploration. Examples of these capabilities are provided below:

- The high-enthalpy test capability at the NASA Arc Jet Complex, located at ARC, provides simulated high-temperature, high-velocity environments and supports the design, development, test, and evaluation of TPS materials, vehicle structures, aerothermodynamics, and hypersonic aerodynamics experienced by a vehicle during atmospheric entry.
- Flight simulators are of critical importance to NASA's research in fundamental aeronautics and aviation safety. These capabilities provide scientists and engineers with tools to explore, define, and resolve issues in vehicle design and mission operations. The capabilities include the motion simulators and development laboratories used in the research and development of flight and crewed operations at the ARC Vertical Motion Simulator and the LaRC Flight Simulation Facility.
- Space environments test capabilities and facilities whose primary use is related to spacecraft and instrument development and qualification, space technology development, human-rated space environments, and launch environments. Capability components include: vacuum, thermal/vacuum, and thermal chambers; vibration tables; acoustic labs; cleanrooms; and electromagnetic interference and electromagnetic compatibility, magnetic, optical, X-ray, solar spectrum, and ionizing radiation facilities. Located at most NASA Centers, testing performed with these capabilities ensures the equipment, sub-systems, and assembled spacecraft will survive the harsh noise and vibrations experienced during launch and the ultra-low pressure and ultra-low or ultra-high temperatures experienced in space environments.
- The external radiation testing capability procures the necessary time and facility support at non-NASA facilities to meet the requirements of Agency programs and projects. The test facilities provide controlled sources of electrons, heavy ions, neutrons, protons, and other relevant types of high-energy radiation that NASA uses to simulate the impact of the natural space radiation environment on a wide range of electronic and material systems. These facilities are highly specialized and are operated by national laboratories, private companies, and universities at both domestic and foreign locations. Test activities support a wide range of assessment, development, and flight activities.

ENGINEERING, SAFETY, & OPERATIONS

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Agency Technical Authority	175.3	--	**184.0**	184.0	184.0	184.0	184.0
Center Engineering, Safety, & Operations	850.4	--	**873.9**	873.9	873.9	873.9	873.9
Total Budget	**1025.7**	**--**	**1057.9**	**1057.9**	**1057.9**	**1057.9**	**1057.9**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Beginning in FY 2021, SSMS has a revised budget account structure. FY 2019 reflects actual budget authority that have been re-cast into the new SSMS budget structure.

Mechanical technicians perform engine maintenance on NASA’s crawler-transporter 2 on March 26, 2019.

Engineering, Safety, and Operations (ESO) comprise two programs: Agency Technical Authority (ATA) and Center Engineering, Safety, and Operations (CESO).

ATA protects the overall health and safety of NASA's workforce and programs. An independent technical authority promotes technical excellence and provides independent mission assurance increasing the likelihood that missions, operations, and programs are executed safely and successfully.

ATA comprises work managed by the Office of the Chief Health and Medical Officer (OCHMO); the Office of Safety and Mission Assurance (OSMA), including the NASA Safety Center (NSC) and the Independent Verification and Validation (IV&V); and the Office of the Chief Engineer (OCE), including the NASA Engineering and Safety Center (NESC) and JPL Technical Authority.

CESO provides funding for the ongoing management and operations of NASA Headquarters, nine Centers, and component facilities. CESO funding supports NASA's ability to provide highly skilled staff and specialized capabilities to Mission Directorates; and, significantly contributes to the accomplishment of Agency goals and objectives.

CESO includes Center unique institutional operations that do not fall under one of NASA's 11 enterprise functional offices; and, encompasses a diverse set of activities essential for safe and effective operations.

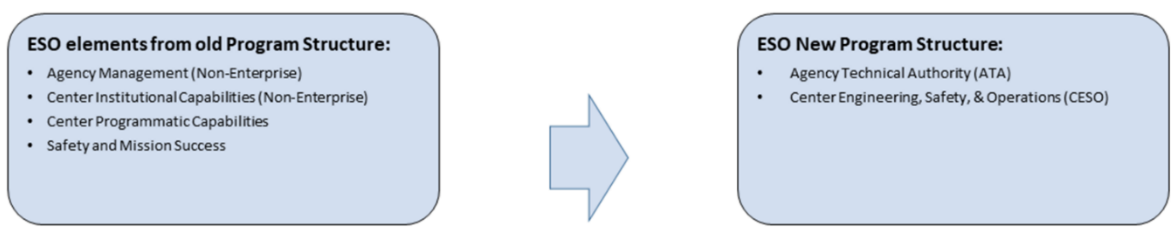
ENGINEERING, SAFETY, & OPERATIONS

These activities provide for ongoing operations of NASA's field Centers and major component facilities to ensure a safe, healthy, and environmentally responsible workplace.

EXPLANATION OF MAJOR CHANGES IN FY 2021

The ESO budget is comprised of content from the Center Management and Operations (CMO) and Agency Management and Operations (AMO) budget that is not beneficial in an enterprise business model.

Engineering, Safety and Operations (ESO):



ACHIEVEMENTS IN FY 2019

Key mission enabling accomplishments in FY 2019 include:

Delivered more efficient and cost-effective operations and services:

- The Office of the Chief Human Medical Officer supported both the Gateway and Human Landing System (HLS) programs in rapidly developing and vetting traceable, tailored health and medical requirements.
- The Marshal Space Flight Center (MSFC) awarded a new Medical Services contract that implements an agency model to determine if insurance use is feasible for personal medical services.
- The Chief Engineer's Academy of Program/Project and Engineering Leadership (APPEL) conducted 155 courses and trained 3,250 NASA engineers. APPEL courses have successfully (1) Developed project management skills which enable teams to deliver projects within budget and on schedule; (2) Included topics such as leadership techniques, earned value management, decision making skills, and effective communications which drive mission reliability, crew safety and project team integrity; and (3) Included relevant case studies and lessons learned that provide attendees with a realistic understanding of learning from a historical perspective.
  Upgraded the Optics Coatings Lab cleanroom (GSFC) to enable high reflectance coatings and to meet the environmental requirements for precision cleaning, coating and inspection of optical mirrors and components, critical for mission success.

ENGINEERING, SAFETY, & OPERATIONS

Reduced mission risk through technical capabilities:

- With support from the NASA Safety Center (NSC), OSMA implemented an oversight role for institutional safety through audits, investigation, assessments, and outreach activities that contributed to Agency-level safety performance metrics.
- Created a Level One board to review and determine health and medical technical risks were completed in a timely manner via the Health and Medical Technical Authority (HMTA).
- IV&V found a total of 117 severity 1 and 2 issues in-phase with the developer's activities 97 percent of the time with 98 percent of problems accepted by the missions and the issue corrected minimizing the cost of software development, reducing potential rework, and increasing the security, safety and success posture of these missions.
- OCHMO led the Agency effort to provide former astronauts with diagnosis and treatment for spaceflight associated medical conditions.
- The GSFC Flight Software Sustaining Engineering Lab was expanded to support new on-orbit flight sustainment activities (GEDI, DSCOVR) in a centralized location and support continued growth for in-house development.
- The NESC completed 53 independent assessments and support activities touching all of NASA's Mission Directorates ensuring mission success for multiple programs. The results included: Flight testing to gather data furthering a joint NASA-DoD investigation into pilot physiological episodes; Testing and analysis to determine the cause of a Commercial Crew Program commercial partners' propulsion system test failure; and In-depth peer review of mathematical models used for analysis of the Space Launch System Mobile Launcher.

WORK IN PROGRESS IN FY 2020

In FY 2020, highlights of work in progress include:

Deliver more efficient and cost-effective operations and services:

- Enhance occupational safety services to include Annual Facility Safety Inspections, Annual Laboratory Safety Inspections, Facilities Drawing Reviews, Integration and Test Safety Operations, Construction Safety Inspections, Facility Adjacency Studies, Cryogenic Safety Analyses, Emergency Response, and Safety Program Analyses.
- Planned investments at multiple Centers include research and engineering laboratory repairs, upgrades, and new equipment that preserve and strengthen core technical capabilities.
- OCE plans a new engineering research and analysis initiative focused on rebuilding the Agency's core engineering capability under a unified structure that will support future missions.
- Leverage digital tools to save the agency time and money while increasing safety though the infusion of Model Based Mission Assurance for the Gateway program.

Reduce mission risk through technical capabilities:

- OCHMO will continue HMTA center presence in support of Moon-to-Mars (M2M) initiatives.
- IV&V will continue to provide software expertise to 17 projects, including 15 NASA missions, Commercial Crew Program (CCP), one multi-agency mission, and across eight NASA Centers to ensure mission software operates to meet mission requirements.

ENGINEERING, SAFETY, & OPERATIONS

- OCE activities will include independent Entry, Descent, and Landing (EDL) modeling and simulation for the CCP and integrated ascent trajectory and separation analyses for the ESD SLS and Orion programs.
- Provide enhanced operational safety (e.g. critical lifts, explosives safety) for successful Artemis I Crew Service Module environmental qualification testing at GRC Plum Brook Station.
- Establish and implement Safety and Mission Assurance (S&MA) guidelines for Unmanned Aircraft Systems (UAS)/Urban Air Mobility (UAM) operations.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

Key mission enabling activities planned for FY 2021 include:

Deliver more efficient and cost-effective operations and services:

- OSMA will work to improve the effectiveness and efficiency of the Agency's institutional safety by focusing workforce, audits, and assessments on areas of concern using a risk-informed approach.
- Continue to support the maintenance of the Center Management System, Configuration Management support, Audits & Assessments, Program/Project Review Support, GIDEP, Metrology and Calibration, In-house Software Assurance Assessment and Electro Static Discharge programs.
- Acquire aircraft ground support equipment and calibration devices permitting Langley Research Center (LaRC) to perform additional in-house maintenance on the Center’s C-20B aircraft.
- Implement electrical safety and fall protection upgrades and enhanced process safety implementation at GRC.
- Planned investments to upgrade or replace outdated/end-of-life systems in research and engineering labs at GRC, to mitigate program risks.

Reduce mission risk through technical capabilities:

- OCHMO will conduct independent assessment and pathfinder activities in support of Artemis design and development; generate operational requirements and products necessary to support Artemis initial and evolving operations; and, provide technical content regarding human spaceflight standards to support HLS and Gateway programs.
- IV&V will continue to support elements of Artemis which includes the Orion crew capsule, the Space Launch System (SLS) rocket, the Exploration Ground System (EGS), the lunar Gateway, and the Human Landing System (HLS).
- The Environmental Gas Lab at MSFC will support mission program requirement. The Lab will focus on both environmental compliance measurements and laboratory compliance. Added focus of the lab will be on evaluating maintained cryogen systems, gas systems, clean rooms and flow benches.
- Centers will provide engineering assessment and safety oversight pertaining to the technical readiness and execution of NASA program and projects.

ENGINEERING, SAFETY, & OPERATIONS

Program Elements

AGENCY TECHNICAL AUTHORITY

ATA develops policy and procedural requirements. This program makes recommendations to the Administrator, mission directorates, Center Directors, and program managers who ultimately are responsible for the safety and mission success of all NASA activities, and the safety and health of the workforce (including Astronauts).

ATA resources provide the foundation for NASA's system of checks and balances, enabling effective application of the strategic management framework and the technical authorities defined in NASA's Strategic Management and Governance Handbook. ATA provides training and maintains a competent technical workforce within the disciplines of system engineering, including system safety, reliability and quality, as well as space medicine.

CENTER ENGINEERING, SAFETY, AND OPERATIONS

CESO provides strategic leadership and planning for the Agency and Center as well as enables the Agency's scientific and engineering activities by providing center engineering assessment and safety oversight pertaining to the technical readiness and execution of NASA programs and projects. It also sustains NASA's analysis, design, research, test services, lab services and fabrication capabilities to enable efficient implementation of the programs and projects conducted at the Centers.

CESO provides a key component of NASA's overall approach to risk management by providing center level independent technical authority. Center engineering, safety and mission assurance, and health and medical organizations: (1) provide, support, and oversee the technical work, and (2) provide formally delegated technical authorities.

These center level technical authorities in concert with the agency level authority provide independent oversight and review of programs and projects in support of safety and mission success. Cognizant technical authorities formally review and concur on technical and operational matters involving safety and mission success risk. These technical authorities concur based on the technical merits of each case and agreement that the risks are acceptable. This assures that NASA conducts its mission activities safely in accordance with accepted standards of professional practice and applicable NASA requirements.

AGENCY TECHNICAL AUTHORITY

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**175.3**	**--**	**184.0**	**184.0**	**184.0**	**184.0**	**184.0**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Beginning in FY 2021, SSMS has a revised budget account structure. FY 2019 reflects actual budget authority that have been re-cast into the new SSMS budget structure.

Agency Technical Authority (ATA) programs protect the health and safety of the NASA workforce; and, increase the likelihood that programs, projects, and operations will be safely and successfully completed. ATA capabilities provide expert technical excellence, mission assurance, and technical authority Agency-wide.

The ATA comprises work managed by the Office of the Chief Medical Officer (OCHMO); the Office of Mission Assurance (OSMA), including the NASA Safety Center (NSC) and the Independent Verification and Validation (IV&V); and, the Office of the Chief Engineer (OCE), including the NASA Engineering and Safety Center (NESC).

Elements of ATA programs reflect recommendations outlined in studies and by advisory boards and panels. The ATA program is focused to improve the probability of safety and mission success for programs, projects, and operations and to protect the health and safety of the workforce. The program develops policy and procedural requirements and provides recommendations to the Administrator, mission directorates, Center Directors, and program managers who are ultimately responsible for the safety and mission success of all NASA activities.

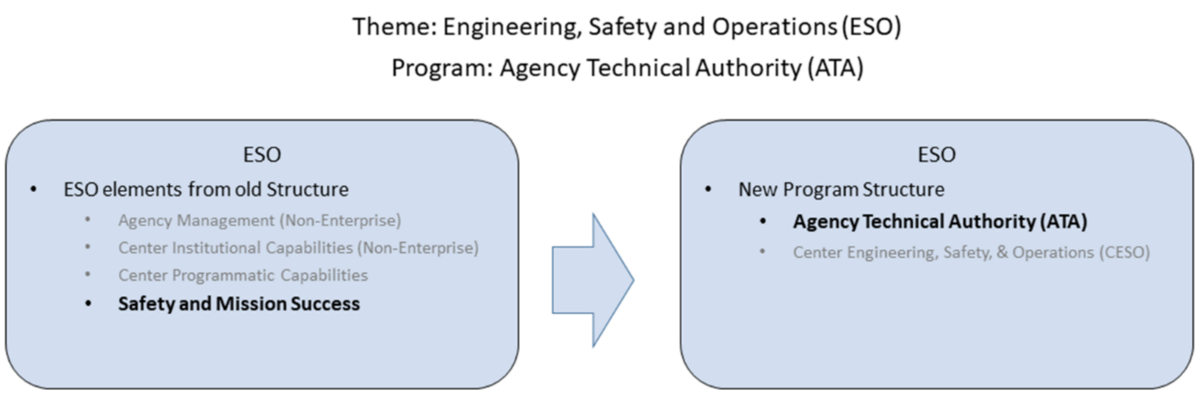
ATA resources provide the foundation for NASA’s system of checks and balances, enabling effective application of the strategic management framework and the technical authorities defined in NASA’s Strategic Management and Governance Handbook. ATA provides training and maintains a competent technical workforce within the disciplines of system engineering, system safety, reliability and quality, and space medicine.

Programmatic resources are used to evaluate the implications on safety and mission success, including health and medical aspects of new requirements and departures from existing requirements. Discipline experts analyze the criticality of the associated risks and evaluate the risks acceptability through an established process of independent reviews and assessments. The information and advice from these experts provide critical data required to develop authoritative decisions related to the application of requirements on programs and projects.

AGENCY TECHNICAL AUTHORITY

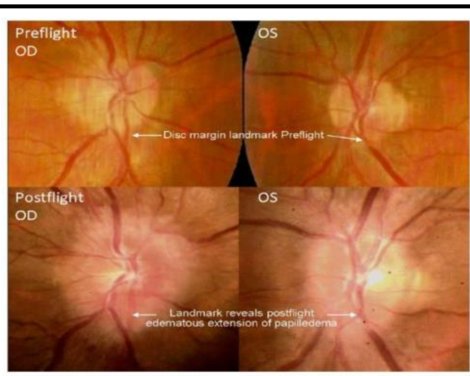
EXPLANATION OF MAJOR CHANGES IN FY 2021

The ATA program replaces the former AMO Safety Mission Success (SMS) element and includes OSMA, IV&V, OCE and OCHMO. A high-level depiction of the prior budget structure mapped to the new budget structure follows:



CHIEF HEALTH AND MEDICAL OFFICER

The ATA OCHMO program provides policy and independent oversight and advances expert health and medical capabilities in support of current and future NASA missions. Moreover, the program promotes employee physical and mental health and well-being; and, ensures the safe and ethical conduct of NASA-sponsored human and animal research.



The human system is impacted in nearly every component of the vehicle. On long duration missions, astronauts undergo a fluid shift in the brain that increases the blood in the head and thorax, resulting in vision changes, illustrated in the image above. The Health and Medical Technical Authority (HMTA) required a seat angle design for the vehicle that would not cause untoward health impairment to the crew.

ACHIEVEMENTS IN FY 2019

OCHMO achievements in FY 2019 include the following highlights:

- Created a Level One board to review, evaluate and disposition health and medical technical risks in a timely manner via the Health and Medical Technical Authority (HMTA). OCHMO streamlined health and medical standards and placed them in an evidence-based context that is understandable and implementable by engineering.
- Supported both the Gateway and Human Landing System (HLS) programs in rapidly developing and vetting traceable and tailored health and medical requirements.
- Supported both X-plane programs by tailoring the health and medical standards into technical requirements for ARMD to ensure the safety of pilots.
- OCHMO led the Agency's effort to update 14 CFR Part 1230, Protection of Human Subjects, which took steps to protect the health and medical rights of human subjects by

clarifying the roles and responsibilities of NASA Institutional Review Boards (IRBs).

- OCHMO led the Agency effort to provide former astronauts with diagnosis and treatment for spaceflight associated medical conditions. Extensive collaboration was conducted with DOL, DHA and the VA to ensure that governmental health programs provided healthcare to former astronauts.

WORK IN PROGRESS IN FY 2020

In FY 2020, OCHMO's works in progress include:

- A rapid review and evaluation of astronaut medical cases will continue to improve NASA's control outcomes and understanding of medical risks. OCHMO allows NASA to ensure that crewmember certifications remain valid, thereby preventing the loss of millions of dollars invested in training per astronaut for a Commercial Crew or any other human spaceflight mission.
- The certification of continuing medical education activities and flight surgeon education will support ongoing medical and health discipline, professionalism, and licensure. To maintain clinical currency, OCHMO will continue to sponsor university-based physician training programs. Biomedical research programs, in support of human space flight, are guided by NASA-developed health and medical standards.
- The program administration of the HMTA, engages in all crewed programs from development through de-commissioning. OCHMO continues to provide required direct health and medical technical support, insight, and oversight. This promulgates the Human-Rated Spacecraft and X-Plane requirements that further promotes mission success and healthy personnel. Moreover, OCHMO ensures that NASA's safety culture is interwoven within human spaceflight missions.
- Continuous collaboration and communication with commercial and international partners, sharing health and medical knowledge and best practices with space agencies around the world.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

In FY 2021, OCHMO planned key achievements include:

- Conduct extensive independent assessments and pathfinder activities in support of Artemis design and development. This will result in OCHMO generating operational requirements and products necessary to support the initial and evolving operations to return to the lunar surface in 2024.
- Provide technical requirements regarding human spaceflight standards (based on tailored health and medical standards) to support Gateway and HLS.
- Direct new funding in FY 2021 ($10 million above the 2019 Operating Plan level) to address need for HMTA to assess human factors in NASA missions, ensuring crew health and safety.

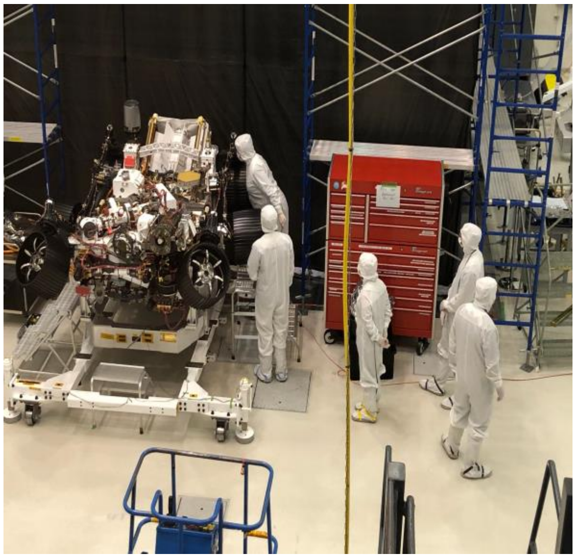
AGENCY TECHNICAL AUTHORITY

Program Elements

OCHMO promulgates Agency health and medical policies and standards to support the medical technical capabilities of the Agency. It assures the physical and mental health and well-being of the NASA workforce, as well as the safe and ethical conduct of NASA-sponsored human and animal research.

OCHMO ensures that bioethics principles and NASA's policies and practices related to the use of human and animal subjects in research are in accordance with all relevant Federal regulations and guidelines. The program oversees NASA's processes for reviewing the use of human and animal subjects in research.

OCHMO administers the HMTA, which engages in all crewed programs from development through de-commissioning. The HMTA provides required guidance, insight, and oversight, while translating health and medical standards into tailored technical requirements for all Human-Rated programs across the Agency.



Planetary Protection engineers inspecting the Mars 2020 rover and getting ready to take wipe samples to assess contamination.

SAFETY AND MISSION ASSURANCE

The ATA Office of Mission Assurance (OSMA) program assures the safety and enhances the success of all NASA activities through the development, implementation and oversight of agency-wide safety, reliability, maintainability and quality assurance policies and procedures. OSMA includes the Mission Support Division, Safety and Assurance Requirements Division, and NASA Safety Center, as well as the Independent Verification and Validation Facility (IV&V).

ACHIEVEMENTS IN FY 2019

OSMA's significant achievements in FY 2019 include:

- Technical leadership provided for the update of the U.S. Government Orbital Debris (OD) Mitigation Standards, as directed by Space Policy Directive 3, as well as the establishment of the Presidential Memorandum on the Launch of Spacecraft Containing Space Nuclear Systems (NSPM-20). OSMA performed orbital debris reviews of all NASA-sponsored missions and completed the nuclear safety evaluation of the Mars 2020 mission.
- Conducted significant tests and modeling activities benefitting the reliable use of electronic parts in space. OSMA established an initiative to develop model-based mission assurance capabilities, in addition to ongoing activities to advance hardware and software quality assurance and reliability and safety engineering capabilities.
- The NSC maintained and updated the training program covering 262 courses available to the Agency. OSMA updated five NASA directives and standards as part of a continued move towards more risk-informed assurance policies.

- IV&V achievements include software assurance provided to 16 major projects at eight NASA Centers by finding critical errors in software development artifacts in-phase with the software development activities.
- IV&V found a total of 117 Severity 1 and 2 issues in-phase with the developer's activities 97 percent of the time with 98 percent of problems accepted by the missions and the issue corrected.

WORK IN PROGRESS IN FY 2020

In FY 2020, OSMA works in progress include:

- Leveraging digital tools to save the agency time and money while increasing safety though the infusion of Model Based Mission Assurance for Gateway as part of NASA's Digital Transformation initiative.
- Advancing guidance for the use of a wide variety of Electrical, Electronic, Electromechanical, and Electro-Optical component grades and spanning CubeSats to large-scale aerospace projects in collaboration with academia, industry, and other Government agencies. Addressing component-level issues related to the dynamic availability of piece parts, varying security of the supply chain, and assuring access to radiation test facilities for high-reliability space applications.
- Conducting research on non-destructive testing techniques for additive manufactured parts to determine variances caused by the manufacturing technique. OSMA is participating in the development of industry consensus standards to ensure the proper inspection of additively manufactured parts for use in innovative spacecraft hardware.
- IV&V will continue to provide software expertise to 17 projects, including 15 NASA missions, Commercial Crew Program, one multi-agency mission, and across eight NASA Centers. These missions include elements of Artemis: the Orion crew capsule, the Space Launch System (SLS) rocket, the Exploration Ground System (EGS), the lunar Gateway, and the Human Landing System (HLS). IV&V efforts are in full support of the Artemis I exploration mission to be launched in 2020.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

In FY 2021, highlighted planned achievements will include:

- The program aims to enhance the quality and velocity of decisions by establishing an objectives-driven, case-based assurance framework and to provide NASA programs and projects with increased flexibility to determine how to best meet stakeholder objectives. This will be supplemented by several workforce engagement activities to enhance the employees' ability to support new and innovative acquisition and development approaches.
- OSMA will work towards the improvement of the effectiveness and efficiency of the Agency's institutional safety by focusing the workforce, audits, and assessments on the areas of concern using a risk-informed approach. The program will coordinate with other offices to consolidate Center reporting requirements; and expects to complete a multi-year study to enable the safe, continued operations of layered pressure vessels.
- IV&V will continue to provide software expertise to 17 projects, including 15 NASA missions, Commercial Crew Program, one multi-agency mission, and across eight NASA Centers. The

missions include elements of the Artemis: the Orion crew capsule, the SLS rocket, the EGS, the lunar Gateway, and the HLS.

Program Elements

OSMA establishes and maintains an acceptable level of technical excellence and competence in safety, reliability, maintainability, and quality engineering areas. The program assesses and communicates risk associated with noncompliance and/or compliance with safety requirements to appropriate decision makers.

The program conducts a schedule of reviews and assessments that focus on the life cycle decision milestones for crucial NASA programs and projects, safety, reliability, and quality processes. Embodied in this program is a structured development of methodology and investigation into system attributes that improve the probability of mission success.

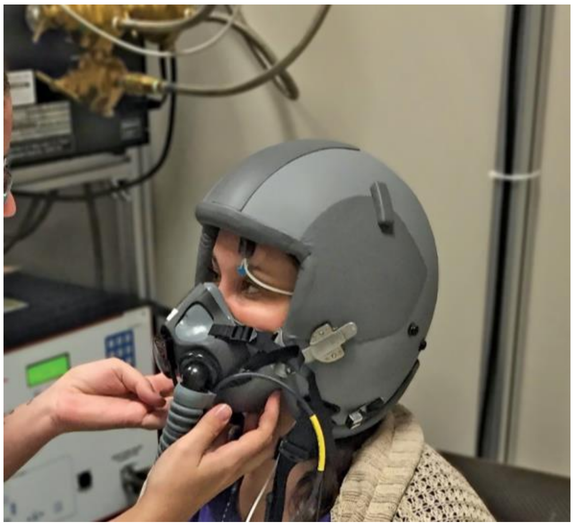
The NASA Safety Center, an OSMA component, consolidated Agency-wide efforts in the areas of technical excellence, knowledge management, audits and assessments, and mishap investigation support.

The OSMA IV&V program provides software expertise, services, and resources necessary to improve the prospects of security, safety and mission success. It independently analyzes mission software on NASA's most critical software systems and identifies software problems in early stages, minimizing the cost of software development and potential rework.

AGENCY TECHNICAL AUTHORITY

CHIEF ENGINEER

The ATA Office of Chief Engineer (OCE) program ensures that NASA's development efforts and mission operations are planned and conducted on a sound engineering basis with proper controls and management of technical risks. The program implements checks and balances among key organizations to ensure that decisions have the benefit of different points of view and are not made in isolation.



Langley Research Center employee fitted with an aviator's helmet and MBU-20/P series oxygen mask with a forehead-mounted physiological monitor prior to hypoxia induction at a Naval Medical Research Unit in Dayton, Ohio.

ACHIEVEMENTS IN FY 2019

In FY 2019, highlighted achievements will include:

- Significant progress made in the test and verification phases of five human spaceflight programs.
- NESC completed 53 independent assessments and support activities touching all of NASA's Mission Directorates. The results included: Flight testing to gather data furthering a joint NASA-DoD investigation into pilot physiological episodes; Testing and analysis to determine the cause of a Commercial Crew Program commercial partners' propulsion system test failure; and In-depth peer review of mathematical models used for analysis of the Space Launch System Mobile Launcher.
- The Academy of Program/Project and Engineering Leadership (APPEL) conducted 155 courses and trained 3,250 NASA engineers.

WORK IN PROGRESS IN FY 2020

In FY 2020, work in progress will include:

- Engineering Technical Authority will continue to support the Agency's most important programs, ensuring independent technical insight and assessment of programs at key programmatic milestones, such as:
    - International Space Station (ISS): Certification of Flight Readiness (COFR) Reviews for Crew and Logistics Visiting Vehicle Missions;
    - X-57 (Maxwell) Systems Test & Airworthiness Reviews;
    - X-59 (QueSST) Aircraft Final Assembly Complete;
    - Commercial Crew Program (CCP) - Boeing and SpaceX Crewed Flight Tests;
    - Artemis - Orion Thermal Vacuum Testing;
    - Artemis - SLS Core Stage Hot-Fire Testing;
    - James Webb Space Telescope (Webb) completion of pre-environmental test sunshield deploy and stow; and
    - Webb completion of Observatory environmental testing.

- The NESC plans to:
    - Conduct over 50 independent assessments of NASA's highest risk challenges maintaining prioritization of ISS, Commercial Crew Program, Orion/SLS, Science Missions, and Space Technology.
    - Continue independent Entry, Descent, and Landing (EDL) modeling and simulation for the CCP and integrated ascent trajectory and separation analyses for the ESD SLS and Orion programs.
    - Continue the development of a Launch Vehicle Aerodynamic Buffet Flight Test to reduce uncertainties in SLS launch vehicle design loads.
- OCE will initiate a new engineering research and analysis initiative focused on rebuilding the Agency's core engineering capability, under a unified structure, to support future missions.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

OCE will engage in collaborative efforts with OSMA, OCHMO, and OCE to strengthen the Agency's Technical Authority capability. The offices will work collaboratively, conducting safety reviews and independent technical assessments of NASA's missions (e.g., Artemis, ISS, Commercial Crew, Orion/SLS, Webb, robotic missions, and Space Technology investments).

Program Elements

As the Engineering Technical Authority, OCE ensures that NASA's development efforts and mission operations are planned and conducted on a sound engineering basis with proper controls and management of technical risks. OCE implements checks and balances among key organizations to ensure that decisions have the benefit of different points of view and are not made in isolation. Further, OCE establishes and maintains program/project management and engineering policy and technical standards, creating the foundation for excellence of the Agency's program and project management and engineering workforce, system-engineering methodology, and system of engineering standards.

OCE manages the NESC, which is responsible for enabling rapid, cross-Agency response to mission critical engineering, and safety issues at NASA and for improving the state of practice in critical engineering disciplines. Established in FY 2003 in response to the recommendations of the Space Shuttle Columbia Accident Investigation Board, the NESC performs independent testing, analysis, and assessments of NASA's high-risk projects to ensure safety and mission success. As an Agency-wide resource with a reporting path that is independent of the Mission Directorates and independently funded from OCE, the NESC helps ensure safety and objective technical results for NASA.

OCE sponsors the Academy of Program/Project and Engineering Leadership to develop program and project management and systems engineering skills. This academy provides a formal professional development curriculum designed to address four career levels from recent college graduate to executive. The office enables technical collaboration and information sharing through the NASA Engineering Network.

CENTER ENGINEERING, SAFETY, & OPERATIONS

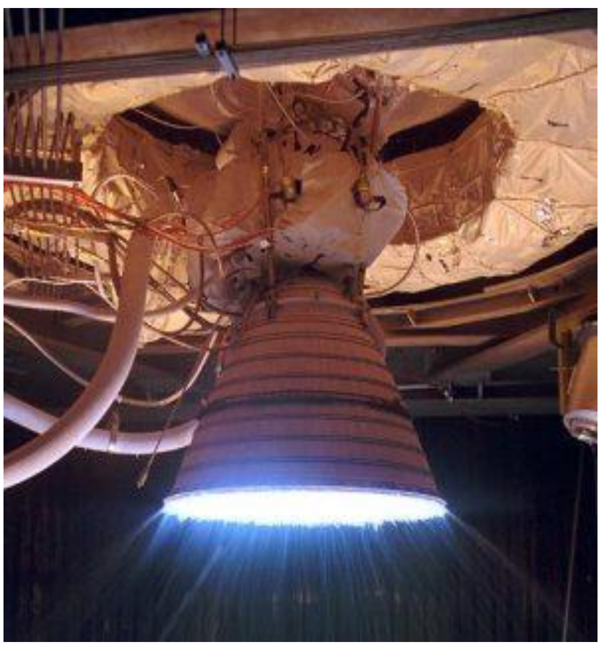
FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**850.4**	**--**	**873.9**	**873.9**	**873.9**	**873.9**	**873.9**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Beginning in FY 2021, SSMS has a revised budget account structure. FY 2019 reflects actual budget authority that have been re-cast into the new SSMS budget structure.



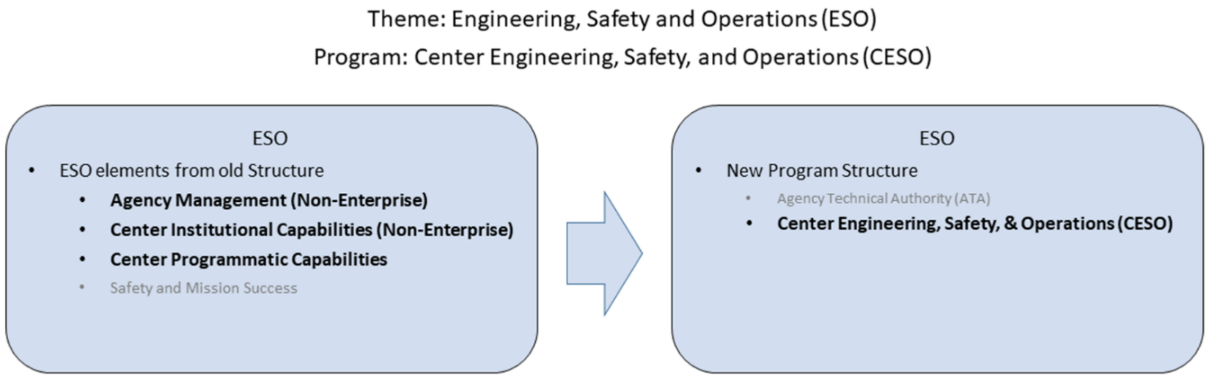
Full-scale rocket engine firing in the In-Space Propulsion Facility test chamber at GRC.

NASA's Center Engineering, Safety, and Operations (CESO) program provides strategic management and crucial policy direction at the Agency and Center level in addition to center level technical authority. Independent oversight at the center of the highly technical programs and projects is a key part of NASA's overall system of checks and balances and contributes to overall mission excellence.

EXPLANATION OF MAJOR CHANGES IN FY 2021

The CESO budget line item directly supports Headquarters corporate capabilities and the Center management, science and engineering, engineering technical authority, and safety and mission assurance technical authority capabilities that are critical to programmatic mission success. It comprises the portions of the former Center Management and Operations (CMO) and Agency Management and Operations (AMO) accounts that are not enterprise functions. Center provided capabilities are crucial due to the complexity of the support needed to successfully and safely implement and complete requisite missions. A high-level depiction of the prior budget structure mapped to the new budget structure follows:

CENTER ENGINEERING, SAFETY, & OPERATIONS



ACHIEVEMENTS IN FY 2019

Key mission enabling accomplishments in FY 2019 include:

- Expanded the Goddard Space Flight Center (GSFC) Flight Software Sustaining Engineering Lab to support new on-orbit flight sustainment activities in a centralized location and support continued growth for in-house development.
- Awarded a new Medical Services contract at Marshall Space Flight Center (MSFC) that implements an agency model to determine if insurance use is feasible for personal medical services. Contract savings over a five-year period are estimated to be approximately $5 million.
- Received the Voluntary Protection Program (VPP) Star site award at ARC from the Occupational Safety and Health Administration (OSHA). The prestigious OSHA VPP Star recognizes sites in both the private industry and Federal agencies that have implemented effective safety and health management systems and have maintained injury and illness rates below those in their respective industries.
- Upgraded Optics Coatings Lab cleanroom at GSFC to enable high reflectance coatings and to meet the environmental requirements for precision cleaning, coating and inspection of optical mirrors and components, critical for mission success.
- Implemented Process Safety Management upgrades at GRC for Cryogenic Testing in the In-Space Propulsion Complex at Plum Brook Station.
- Enabled scientific research through the use of ionizing and non-ionizing radiation sources and devices while maintaining compliance with NRC regulations at GSFC.

WORK IN PROGRESS IN FY 2020

Key mission enabling activities underway in FY 2020 include:

- Make critical strategic investments in laboratory equipment to develop cross-cutting technologies for advanced flight software systems and on-board science data processing.
- Keep flight software maintenance test beds fully functional to allow for efficient and effective responses to operational needs, and to study and simulate operational scenarios.

CENTER ENGINEERING, SAFETY, & OPERATIONS

- The Engineering Cost Office at MSFC will perform cost estimates and analyses to support SLS Core Stage, Exploration Upper Stage, and RS-25 procurements as well as provide cost estimates for Nuclear Thermal Flight Demonstrators. The organization will continue to support the Solar Cruiser Concept Study Report and enable the Artemis Program by providing cost estimates and analyses for the Human Landing System (HLS).
- The Partnerships and Formulation Office at MSFC, using a Commercial Space Launch Act (CSLA) Agreement, will provide the Saturn V test stand to Blue Origin for their long-term use to test/qualify their BE-4 and BE-3U flight engines.
- LaRC will host the Safeguard with Autonomous Navigation Demonstration (SAND) Challenge in May 2020. This opportunity will allow small businesses to compete in an autonomous unmanned aerial vehicle competition.
- The Advanced Concepts Office at MSFC will support the BorgSat proposal to study the Earth's aurora.
- Provide support to the National Space Council Users Advisory Group.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

In FY 2021, CESO will support:

- Senior Agency and Center leadership and management, executive staff and administrative support, student programs, and developmental assignments.
- Center institutional operational safety support to protect personnel and assets, aviation safety, emergency preparedness, nuclear safety, construction safety, and other safety services.
- Analysis, design, research, test services, and fabrication capabilities to enable efficient implementation of the programs and projects.
- Support calibrations, function tests, adjustments/alignments, repairs, and other support events at the Metrology and Calibration Laboratory (MCL) at MSFC. MCL support is critical to program and projects meeting their test schedules. With the continued focus on meeting test schedule dates for SLS, ISS, and others, this support is critical for the Agency meeting their goals.
- Implementation of an enhanced Enterprise Risk Management System at ARC to provide improved sustainment of Center capabilities that support critical milestones for the Artemis Program including the Vertical Motion Simulator, which is essential for the success of Artemis. The Vertical Motion Simulator enables 6 degree of freedom man-in-the-loop flight simulation.
- Outfitting of the new Detector Development Lab cleanroom at GSFC to keep pace with emerging detector technologies and improve the cost efficiency of detector development. Modernize the Toxic Gas Monitoring System for areas containing highly toxic gases. Existing system is more than 25 years old with non-serviceable and obsolete components.
- Maintenance of the Center Management System, Configuration Management support, Audits & Assessments, Program/Project Review Support, GIDEP, Metrology and Calibration, In-house Software Assurance Assessment and Electro Static Discharge programs.
- Provide support to the National Space Council Users Advisory Group.

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Construction of Facilities	297.3	--	**464.4**	455.6	455.6	455.6	455.6
Environmental Compliance and Restoration	74.9	--	**74.7**	74.7	74.7	74.7	74.7
Total Budget	**372.2**	**373.4**	**539.1**	**530.3**	**530.3**	**530.3**	**530.3**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Construction of Facilities	297.3	--	**464.4**	455.6	455.6	455.6	455.6
Environmental Compliance and Restoration	74.9	--	**74.7**	74.7	74.7	74.7	74.7
Total Budget	**372.2**	**373.4**	**539.1**	**530.3**	**530.3**	**530.3**	**530.3**
Change from FY 2020			**165.7**				
Percentage change from FY 2020			**44.4%**				

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Kennedy Space Center (KSC) Central Campus Headquarters Building (Phase 1) consolidated administrative offices and shared services into a new 200,000-square-foot facility (shown here). Completed in FY 2019, this new building enables deconstruction of more than 400,000 square feet, and reduces operations, maintenance and energy costs by $400 million over ten years. This building was constructed to be certified at a Leadership in Energy and Environmental Design (LEED) Silver level.

NASA designs and implements its construction of facilities projects, facility demolition projects, and environmental compliance and restoration activities through its Construction and Environmental Compliance and Restoration (CECR) account.

Construction of Facilities (CoF) funds capital repairs and improvements to NASA’s infrastructure to provide NASA programs and projects with the research, development, test and evaluation facilities required to accomplish their missions.

More than 83 percent of NASA's constructed infrastructure is beyond its design life, requiring significant risk management efforts to mitigate risk to current and future missions. Apollo and Space Shuttle era legacy infrastructure is especially inefficient and costly to maintain and operate, and suffers from reliability issues as we approach a new era to support lunar and Mars manned missions. As NASA's Office of Inspector General (OIG) noted in its annual NASA's Top Management and Performance Challenges (2019), "while NASA strives to keep these facilities operational, the Agency faces a deferred maintenance backlog of $2.65 billion as of 2019. This has resulted in unscheduled maintenance rather than scheduled maintenance costing up to three times more to repair or replace equipment after it has failed." To address these challenges, NASA's CoF programs focus on modernizing NASA's infrastructure to consolidate into fewer, more efficient, sustainable facilities, and repairing failing infrastructure to reduce overall maintenance costs.

The CoF Program repairs the facilities that have suffered either continuous degradations, recent failures, or deterioration from reduced maintenance over time. As a result of prioritizing time-critical repairs, a number of construction projects required to meet immediate needs are displacing renewal or new construction projects for obsolete facilities; projects that are more cost effective in the long run. The CoF renewal program also helps shrink the Agency's footprint by consolidating related functions into fewer, more energy efficient facilities.

The CoF Theme comprises two programs: Institutional CoF and Programmatic CoF. The Institutional CoF projects and activities include Facility Planning & Design, Discrete Projects, Minor Revitalization & Construction (Minor CoF), Demolition of Facilities, and Energy Savings Investments. The Programmatic CoF projects are Mission Directorate-funded discrete or minor projects for construction of specialized capabilities as required for testing and development that directly support specific NASA missions.

NASA categorizes construction projects by size of the project as well as whether a project supports NASA's energy investments or demolition goals. For example, Discrete projects are those repairs or facility replacement projects with an estimated cost of $10 million or more. Minor CoF are projects focused on repairing or modifying facilities and infrastructure, with an estimated cost between $1 million and $10 million. Energy Savings Investments projects reduce energy consumption, expand renewable energy to increase energy reliability and resiliency, and maximize utility cost avoidance. Demolition projects eliminate obsolete and unneeded facilities. Facilities Planning and Design projects enable the advanced planning and design activities required to execute construction projects. CECR does not fund routine maintenance and repairs at NASA Centers with estimates of $1 million or less, or some day-to-day facility repair activities at NASA field centers. These activities are accomplished with funding in the Safety, Security, and Mission Services account.

NASA has an inventory of more than 5,000 facilities and structures with a current renewal pace of approximately every 314 years. The Agency's ability to renew these facilities is correlated to the amount of the construction budget that is directed towards new construction or distributed system (e.g., utilities) recapitalization. The Agency's FY 2021 Budget will decrease the renewal pace to approximately every 110 years by replacing multiple obsolete facilities with two modern and efficient facilities and recapitalizing portions of multiple horizontal infrastructure systems such as potable water system, propellant distribution systems and distributed institutional power. Overall, NASA's CoF budget funds the Agency's highest priority institutional construction projects and continues to replace obsolete and deteriorating facilities that directly support the Artemis mission.

The Environmental Compliance and Restoration (ECR) program mitigates environmental risk at NASA installations, NASA-owned industrial plants supporting NASA activities, current or former sites where NASA operations have contributed to environmental problems, and other sites where the Agency is legally obligated due to more than 200 past releases of pollutants including emerging contaminants such as polyfluoroalkyl substances (PFAS). At every Center, the ECR program is investigating contaminated sites, remediating contaminated soil, water and other media, and monitoring continued compliance with remedial objectives. The ECR Program ensures NASA compliance with restoration program requirements including the Resource Conservation and Recovery Act (RCRA), Comprehensive Environmental Response, Compensation, Liability Act (CERCLA), and state regulatory requirements and multiple consent orders and legal obligations. The remediation program at the Santa Susana Field Laboratory (SSFL) site in California consumes approximately 42 percent of the ECR annual budget.

CoF and ECR activities make NASA’s assets ready, available, and appropriately sized to conduct NASA’s current and future missions, and ensures that NASA facilities are compliant with current environmental regulations. The CoF and ECR programs support NASA's Strategic Plan and the Annual Performance Plan goals related to sustainability and reducing the Agency's overall footprint.

Explanation of Major Changes in FY 2021

NASA’s new Artemis Moon to Mars exploration program is a generational challenge and mission to inspire the imagination of our Nation. The new technologies, systems, and operational tempo needed to return to the Moon, establish the cis-lunar Gateway, and start human exploration of Mars will challenge NASA program capabilities and require robust, reliable, and resilient Earth-bound facilities and infrastructure to safely and successfully support this new exploration enterprise.

In FY 2021, CECR’s CoF program reflects a focus on projects supporting multiple missions including Artemis, with emphasis on reducing the highest institutional risks to our Nation’s next generational space enterprise. For FY 2021, the major CoF projects added specifically to support the Artemis mission are (1) Repair Building 103 Roof Systems at the Michoud Assembly Facility (MAF) and (2) Modifications to Launch Infrastructure at the Kennedy Space Center (KSC). New CoF projects also directly support Science and Space Operations mission. Funding increases for Facility Planning & Design and Demolition are requested to ensure efficient execution of new and ongoing CoF projects.

Achievements in FY 2019

During 2019, NASA continued to make outstanding progress in execution of the CECR Program, with significant achievements in all programmatic areas including CoF and ECR. Major achievements are highlighted below, with detailed accomplishments identified in later sections of this document.

Facility Planning & Design - NASA completed the designs for multiple Discrete projects, including the new construction Aerospace Communications Facility at the Glenn Research Center (GRC); and Repair and Revitalization projects such as the Repair Lewis Field Storm Sewer System Phase 2 of 5 (GRC), Shoreline Protection (Wallops Flight Facility), and the Restore Coastal Shoreline Phase 2 (KSC). Upon the completion of these designs, construction was initiated.

New Construction - NASA completed multiple new construction projects. The Central Campus Headquarters Building (Phase 1) at the KSC opened in 2019. With approximately 200,000 square feet of administrative office, cafeteria, and shared services space, the facility cuts in half the square footage previously used for these same activities. The new building serves as the flagship facility housing key support functions for NASA's multi-user spaceport. It capitalizes on chilled beam heating, ventilation and air conditioning technology that reduces operating costs. Marshall Space Flight Center's (MSFC) new Building 4221 houses the Center's Human Exploration Development and Operations Offices, its Science and Technology Office and the NASA Engineering and Safety Center - all of them critically involved in the Agency's mission to conduct sustainable human exploration of the Moon and prepare for human exploration of Mars. These two buildings enabled significant consolidation, reductions to overall square footage of constructed assets, and reductions in deferred maintenance. Both of these buildings incorporate the adaptability, flexibility, and expandability to accommodate both current needs and anticipated future growth over their multi-decade lifespan. With the completion of these facilities, NASA has increased its inventory of sustainable facilities to more than 3.5 million square feet. An additional project at the Ames Research Center (ARC) completed the power, water, and data infrastructure needed for the new 10-megawatt Modular Supercomputing Facility (MSF). The MSF facility will serve the next generation computing needs of the entire Agency.

Repair and Revitalization - NASA completed multiple Discrete major repair and/or upgrade projects. NASA completed improvements to the 9-foot x 15-foot Low Speed Wind Tunnel at the GRC. The project modified the tunnels' aerodynamic turning vanes and baffles to enable testing of state-of-the-art quiet turbine engines. Also at GRC, NASA completed repairs to the Central Compressed Air System, which provides needed repairs to the air dehydration systems, and replaced the antiquated electrical switchgear, controls, and valve actuators. The Central Process System provided high pressure air and other commodities to the major test facilities at GRC. Its operation is critical to ensuring successful aerospace testing.

NASA also finished infrastructure upgrades to the Industrial Area Chiller Plant at the KSC. These upgrades ensure sufficient availability of chilled water to support the increased tempo of activity in the various facilities as required for execution of the Space Launch System program. Also, at KSC, NASA completed repairs and updates to the Hazardous Processing Industrial Area clean room in the Multi-Payload Processing Facility. This clean room is required to support the Multi-Person Crew Vehicle (Orion) and potential commercial partner applications.

NASA's Deep Space Network Aperture Enhancement Project completed multiple phases of the antennae infrastructure in both Canberra and Madrid, making both of these complexes more efficient and operationally effective. NASA's Launch Services Program completed the Hanger AE and Payload Hazardous Servicing Facility Chillers and Boiler Replacement Project at the Cape Canaveral Air Force Station to improve energy efficiency and lower operating cost.

In FY 2019, NASA also complete 18 minor projects across all Centers. These projects, focused on repair of electrical systems, steam systems, distributed gas systems, roofs, roads and mechanical systems, were required to ensure personnel safety, ensure availability of technical capabilities, maintain programmatic schedules, and reduce operational costs.

Energy Savings Investments - NASA completed multiple significant Energy Savings Investments projects, including construction of a high-efficiency boiler at the MSFC, and installation of expanded energy monitoring and control system projects in two buildings at GRC.

Demolition - NASA continued to reduce the footprint of its portfolio of constructed assets through demolition efforts. In FY 2019, 30 facilities, with a net reduction of more than 68,000 square feet of building space, were demolished.

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

Environmental Compliance and Restoration (ECR) - Multiple NASA sites continued their cleanup activities for soil and groundwater. The SSFL program completed demolition activities for structures and implemented abatement activities for the remaining Test Stands.

WORK IN PROGRESS IN FY 2020

Facility Planning & Design - Emerging institutional risks, such as arc flash and pressure systems degradation, are being identified and quantified, and advanced planning for mitigation measures has begun.

New Construction - Within the CoF Program, NASA's planned FY 2020 projects include replacement of obsolete buildings and repairs to technical assets. Work will start on the Flight Electronics Integration Facility at the Jet Propulsion Laboratory. This state-of-the-art facility will enable development of robust, next-generation avionics systems, and will provide for advanced technical and performance requirements such as highly specific electrostatic grounding to prevent damage to flight hardware during manufacturing. NASA will also start construction of the Flight Dynamics Research Facility at the Langley Research Center (LaRC). This state-of-the-art flight dynamics experimental testing facility will consist of a vertical wind tunnel to support vehicle development and risk reduction for entry capsules and launch abort systems, enable risk reduction for planetary probes and entry vehicles, and provide support for Aeronautics activities. Enhanced capabilities include higher Reynolds numbers and dynamic pressures, lower flow turbulence for improved flow quality, closed flow path with variable flow control and mechanical cooling capabilities, and increased flexibility and cost effectiveness, and optimization of systems for operational and maintenance efficiency. Both of these projects were driven by Center Master planning processes which identified priority investments in technical facilities to help meet Agency research and development and flight hardware integration needs for aeronautics and space exploration missions.

Repair and Revitalization - Major repairs planned for FY 2020 include the High-Pressure Industrial Water 66-inch water pipe and ancillary equipment at the Stennis Space Center (SSC). This project ensures ability to provide the water required for fire suppression, test stand deflector cooling, and diffuser operations during rocket engine testing. NASA will also continue with modifications to the infrastructure at Launch Complex 39B at the KSC. This project will update the Environmental Control System (ECS) to support future crewed launch missions, and update the Converter Compressor Facility (CCF) to increase operational efficiency and augment delivery of helium and nitrogen to the launch site. NASA will continue the Space Communication and Navigation (SCaN) program's Deep Space Network Aperture Enhancement Project and will be working towards having the DSS-56 antenna in Madrid completed and operational by the end of the fiscal year. At Goldstone, Deep Space Network Aperture Enhancement Project will continue with the site excavation and progress on the hybrid RF-Optical design work. Several infrastructure repair project will be initiated in FY 2020 at multiple Centers, and repair projects that could not be funded in FY 2020 will be deferred.

Energy Savings Investments - To help reduce energy usage, work continues on energy savings projects. NASA will install a photovoltaic system at White Sands Test Facility and execute various energy efficiency projects at MSFC and Johnson Space Center.

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

Demolition - NASA plans to demolition 36 facilities with a corresponding reduction of approximately 600,000 square feet.

Environmental Compliance and Restoration - NASA plans to continue with investigation and mitigation of chemical releases into the environment from past activities; work to restore soil and water in order to protect human health and the environment; and preserve natural and cultural resources for future missions. Public review continues for the SSFL draft Supplemental Environmental Impact Statement (SEIS), which will assess the impacts associated with a range of soil clean-up alternatives. Following completion of the SEIS, NASA will prepare a Record of Decision and submit work plans to the State for the soil clean-up. Operation of the groundwater treatment system is expected to resume following reconstruction of piping system from recent fire damage. Multiple Centers will continue clean-up of groundwater and soil contamination and investigations as necessary. The Agency will continue operations of treatment systems and groundwater and soil monitoring at Armstrong Flight Research Center (AFRC), ARC, Goddard Space Flight Center (GSFC), LaRC, MAF, SSC, and Wallops Flight Facility.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

Detailed descriptions of planned projects can be found in the different sections for Construction of Facilities and Environmental Compliance and Restoration. Summary key planned achievements include the following:

New Construction - The FY 2021 Budget includes two repair-by-replacement projects for facilities that are integral to Center Master Plans. The first project is the Engineering and Mission Operations Facility at the ARC that will provide a consolidated engineering hub to serve aerospace systems and spaceflight projects. This facility is focused on consolidating and modernizing inherited, antiquated facilities that were built before 1958. The 60,000-square-foot project will enable demolition of 10 obsolete buildings and more than 90,000 square feet.

The second new construction project is the Vehicle and Aerospace Ground Equipment Maintenance Facility at the AFRC. This 25,000-square-foot facility will consolidate and replace five old and degraded buildings scattered across the Center, representing 33,000 square feet of demolition. This new state-of-the-art, sustainable facility will maintain all of the Centers' government vehicles and aircraft ground equipment, and will function as a central ground support hub. It includes equipment bays, lifts, a shop, testing areas, a wash bay, a technical library a training room and administrative space. The facility is integral to supporting AFRC's mission to conduct world-class flight research including NASA aircraft and future high-profile X-Planes.

Repair and Revitalization - Multiple Discrete and Minor repair and revitalization projects are planned. Key projects supporting Artemis include Phase 1 of a multi-phased replacement of the Building 103 roof at the MAF. This 43-acre building is utilized for assembly of the Space Launch System stages and components. Also supporting Artemis, NASA plans to continue the infrastructure modifications necessary to support the Space Launch System (SLS) and Orion launch processing operations at the KSC. This project will build on the FY 2020 project work and implement infrastructure modifications necessary to support launch. These timely upgrades and infrastructure modifications from previous shuttle configurations are required to support the anticipated Artemis processing and launch manifest.

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

NASA plans to revitalize the mechanical systems in the Structures, Dynamics, and Thermal Vacuum Laboratory, Building 4619 at the MSFC. This facility is mission-critical for support of core NASA programs including Space Launch System, Orion, International Space Station, and Solar Probe Plus. This building houses MSFC's high bay test facility used for thermal conditioning and structural load testing for the Space Launch System.

NASA plans to continue with the phased repair of the potable water systems at the Stennis Space Center. Originally installed in 1964, the approximately 65 miles of potable water distribution pipe is now extremely pitted, fragile and brittle, with 95 reported water leaks and significant breaks occurring during FY 2010-2017. The project will mitigate single points of failure and enhance the level of safety and security for NASA's engine testing programs.

NASA plans to restore the motion reliability of the Virtual Motion Simulator (VMS) at the ARC. This one-of-a-kind research and development facility is used for aerospace simulation studies and experiments, and is the only motion-based simulator capable of meeting the requirements for the development, testing, and certification of the Lunar and Mars Human Landing System, which must meet manual control handling qualities requirements. The project replaces the motor drives and other key components that provide the complex motion capability of the VMS.

NASA plans to complete the third phase to upgrade the Compressor Station at the LaRC. This effort will ensure the Center's continued ability to safely and reliably provide high pressure air (approximately 6,000 pounds per square inch) to the research facilities and technical assets across the Center (e.g., 8-foot High Temperature Tunnel, National Transonic Facility, Transonic Dynamic Tunnel, and 14-foot x 22-foot Tunnel). Continuing this phased work is critical; a NASA Safety Center study previously recommended replacing all Compressor Station compressors and associated ancillary systems at LaRC as they are well beyond their design life, unreliable, and expected to continue to fail in an unpredictable manner.

Energy Savings Investments - Energy improvements projects on several of the buildings located at the ARC and the Stennis Space Center, and a solar photovoltaic systems installation project with energy storage at the Jet Propulsion Laboratory is planned. Calculations indicate that these projects should provide a return-on-investment payback within 10 years.

Demolition - Demolition of more than 25 facilities with a corresponding reduction of more than 150,000 square feet, including funding for the demolition of the Indian River Bridge at the KSC.

Environmental Compliance and Restoration - Key planned accomplishments include the continued demolition, groundwater clean-up, finalization of soil clean-up plans, continued operation of groundwater treatment systems, and continued long term monitoring of air and groundwater at SSFL in accordance with the State of California. Additionally, continued investigation and clean-up of groundwater and soil contamination at KSC under State of Florida requirements as well as ongoing clean-up programs at the MSFC, White Sands Test Facility, and the Jet Propulsion Laboratory will continue.

CONSTRUCTION OF FACILITIES

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Institutional CoF	218.9	--	**395.1**	455.6	455.6	455.6	455.6
Exploration CoF	31.9	--	**22.3**	0.0	0.0	0.0	0.0
Space Operations CoF	17.6	--	**23.9**	0.0	0.0	0.0	0.0
Science CoF	19.7	--	**23.1**	0.0	0.0	0.0	0.0
Aeronautics CoF	9.2	--	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**297.3**	**--**	**464.4**	**455.6**	**455.6**	**455.6**	**455.6**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Building 4619 at Marshall Space Flight Center (MSFC) is shown above. Its mission-critical laboratories require temperature and humidity control to operate their test equipment. The building's Apollo-era HVAC system is expensive to repair, difficult to maintain, and prone to failures that impact mission test activities. The project to revitalize its mechanical systems will allow it to reliably support the laboratory testing critical to the Space Launch System (SLS), Orion, the International Space Station (ISS), and Solar Probe Plus.

NASA's Construction of Facilities (CoF) program includes both institutional and programmatic construction projects. These projects reduce facility-related risk to mission success, increase sustainability, and improve technical infrastructure capabilities in support of NASA missions.

Institutional CoF provides for the design and construction of facilities projects that enable NASA's infrastructure to meet mission needs. New Construction or repair-by-replacement projects replace and/or consolidate inefficient, deteriorated buildings with energy efficient, high-performance facilities. Repair and Revitalization projects generally include system and component repairs or upgrades to NASA's horizontal infrastructure and facilities in order to improve reliability.

Energy Savings Investments aid the Agency in reducing operational costs for utilities and improve the Agency's energy independence. Demolition projects eliminate facilities that are no longer needed. Together these activities reduce operating costs, reduce the Agency facility footprint, and develop an energy-efficient infrastructure to enable NASA's missions.

Programmatic CoF are Mission Directorate-funded discrete or minor projects for construction of specialized capabilities that directly support NASA's missions. These projects provide facilities for critical technical capabilities to manufacture, test, process, or operate hardware for NASA programs. NASA Mission directorate funds are transferred into the CECR account to fund these construction projects.

The CoF program mitigates institutional risks that are associated with real property assets. NASA defines institutional risk in NASA Procedural Requirement (NPR) 8000.4 as "risks to infrastructure, information technology, resources, personnel, assets, processes, operations, occupational safety and health, environmental management, security, or programmatic constraints that affect capabilities and resources necessary for mission success, including institutional flexibility to respond to changing mission needs and compliance with internal (e.g., NASA) and external requirements (e.g., Environmental Protection Agency or Occupational Safety and Health Administration regulations)." Real property assets typically include horizontal/vertical infrastructure, facilities and associated collateral equipment.

CoF projects are grouped as New Construction, Repair and Revitalization, Energy Savings Investments and Demolition.

New Construction projects construct new facilities or structures deemed necessary to meet mission needs or replace obsolete, but necessary, facilities when repair or recapitalization is not an effective life-cycle cost solution. New Construction projects must be consistent with the Agency's Master Planning process, which ensures alignment with Agency missions, Strategic Plan and Center roles. Additional specific considerations for New Construction projects include assessment of the facility condition, impact to mission, annual operational costs, life cycle cost, and extent of Agency footprint reduction.

Repair and Revitalization projects include general repairs, upgrade or recapitalization of institutional real property assets. Repair projects restore real property assets to a condition equivalent to the originally intended and designed capability. These projects can include wholesale system replacements like a mechanical system for heating, ventilation and air conditioning (HVAC) or repairing or replacing items such as boilers, roofs, chillers, or larger projects like valves and gates within a canal water impoundment system. Upgrade projects include restoration of current functional capability of the real property assets so it can accomplish its designated purpose, increase its functional capability, and/or meet new building, fire, and accessibility codes. Projects like these would be electrical system upgrades to reduce arc flash risk or meet new code requirements. Recapitalization projects within Repair and Revitalization restore systems or facilities through wholesale renovation of a facility or replacement of an infrastructure system. These projects can be one year or can be phased over many years for large distributed systems such as water mains, sewer, natural gas, etc. NASA uses a risk-informed prioritization process to select the Agency's highest risk Repair and Revitalization projects that fit within NASA's construction budget profile in a given year.

Energy Savings Investments projects provide either new construction for renewable energy and energy storage, or system upgrades that provide a return on investment that is determined to be reasonable to help reduce operating costs. These projects are intended to help reduce energy usage through various energy conservation measures that are applied locally at a building or system level or across multiple facilities.

Demolition projects are prioritized across the Agency and selected based on consideration of square foot reduction, readiness to move forward with the project, condition of the facility, maintenance and operations costs and other factors. NASA prioritizes its list of projects prior to the year of execution in order to keep abreast of any potential changing facility requirements.

CONSTRUCTION OF FACILITIES

EXPLANATION OF MAJOR CHANGES IN FY 2021

In FY 2021, the funding requested for total CoF ($167 million more than provided in NASA's 2019 Operating Plan) is required to support the new Artemis Moon to Mars exploration program. Institutional CoF includes eight major Discrete projects, including two new starts and 19 Minor CoF projects. Programmatic CoF includes new Discrete and Minor CoF projects directly serving exploration, space operations, and science mission needs

INSTITUTIONAL COF

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**218.9**	**--**	**395.1**	**455.6**	**455.6**	**455.6**	**455.6**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Photo showing the arrival of the SLS Core Stage at Stennis Space Center (SSC) via the barge, Pegasus, as it travels through the Stennis Navigational Locks and Bascule Bridge.

The Institutional CoF program ensures that NASA's physical infrastructure is in sufficient condition to enable execution of the Agency's missions. The objective of this program is to reduce the institutional risks to mission, increase infrastructure efficiency and effectiveness, and reduce operational costs. To meet this objective, Institutional CoF projects focus on the repair, upgrade, or replacement of aging real property assets. Real property assets include all horizontal and vertical infrastructure and the associated collateral equipment. Repair and Revitalization projects are prioritized with a risk-informed process that evaluates risks to mission in terms of safety, schedules, cost, and technical capability; major facility replacement projects also include an economic based analysis.

Prioritized projects address such issues as risk reduction to personnel safety from arc flash injuries, fire alarm upgrades, reliability improvement of key systems (e.g., compressor stations, heating and cooling plants), and deficiencies with power, natural gas, and potable water distribution infrastructure for NASA mission-critical facilities.

NASA maintains an ongoing effort to identify, quantify and prioritize institutional risk(s). Any significant risk to mission attributed to institutional real property is mitigated through the Institutional CoF program. Risks may be increased or decreased in criticality as the risk posture changes due to mission and/or infrastructure condition.

EXPLANATION OF MAJOR CHANGES IN FY 2021

In FY 2021, Institutional CoF projects support multiple missions, including Artemis, with emphasis on reducing the Agency's highest institutional risks. The emergence of the Artemis mission resulted in changes to CoF plan. The major institutional CoF projects added specifically in support the Artemis mission include: (1) Repair Building 103 Roof Systems at the Michoud Assembly Facility (MAF) and (2)

INSTITUTIONAL COF

the Modifications to Launch Infrastructure for SLS at the Kennedy Space Center (KSC). The funding requested in FY 2021 for Institutional CoF ($176 million more than provided in NASA's 2019 Operating Plan) is required to support the new Artemis Moon-to-Mars exploration program.

ACHIEVEMENTS IN FY 2019

NASA completed construction of several discrete CoF projects in FY 2019, including two New Construction and multiple Repair and Revitalization projects.

Construction was completed on two sustainable, Institutional CoF funded facilities: The Central Campus Headquarters Building (Phase 1 of 2) at the KSC, and Building 4221 at the Marshall Space Flight Center (MSFC). It is anticipated that both of these new buildings will be certified as Leadership in Energy and Environmental Design (LEED) Silver, and it is anticipated that the MSFC building will also be certified with three Green Globes. LEED and Green Globes, which are among the most respected green building certification programs worldwide, present the criteria and rating systems for the design, construction, operation, and maintenance of green buildings, homes, and neighborhoods with the aim to help building owners and operators be environmentally responsible and use resources efficiently. The KSC Central Campus Headquarters building replaces obsolete and inefficient facilities, enables significant consolidation, reduction in square footage, and reductions in operating costs. The MSFC Building 4221 was constructed as the second major replacement building in the Main Administrative Complex in the Center’s North Campus. It replaced Building 4201 with an energy and operationally efficient office structure to house approximately 450 people, and it will eliminate more than $4.5 million of deferred maintenance. Both new buildings incorporate the adaptability, flexibility, and expandability to accommodate current needs and anticipated future growth over their multi-decade life span. NASA continues to construct new facilities and building upgrades via major renovations to meet the Guiding Principles for High Performance Sustainable Buildings, per current Federal statutory and Executive Order requirements.

Within Repair and Revitalization, NASA completed the 9-foot x 15-foot Low Speed Wind Tunnel improvement project at the Glenn Research Center (GRC). This project modified the tunnels' aerodynamic turning vanes and baffles to reduce background noise in order to enable testing of state-of-the art quiet turbine engines. The Repair of Central Compressed Air System (Phase 2 of 2) project at GRC was also completed, providing needed repairs to the compressed air dehydration systems, and replacements to antiquated electrical switchgear, controls, and valve actuators in the Central Process Systems infrastructure. This Central Process System provided high pressure air and other commodities to the majority of the major test facilities at GRC, and therefore its operation is critical to ensuring successful aerospace testing.

NASA finished the Repair and Revitalization construction of the power, water, and data infrastructure needed for Ames Research Center's (ARC) new 10-megawatt Modular Supercomputing Facility (MSF). The MSF will provide the next generation computing needs for the entire agency, and as such, requires appropriate supporting infrastructure to ensure 24/7 operation. KSC likewise finished the infrastructure upgrades to the Industrial Area Chiller Plant and the Multi-Payload Processing Facility’s Hazardous Processing Industrial Area clean room that will support the Multi-Person Crew Vehicle (Orion) and potential commercial partner applications.

INSTITUTIONAL COF

In addition to these completed Discrete projects, NASA also completed the following Repairs and Revitalization Minor Revitalization and Construction of Facilities projects, increasing reliability and safety of multiple facilities.

- Armstrong Flight Research Center
  - Repair Mechanical Systems, Research Aircraft Integration Facility
  - Repair Paving, Various Locations
- Ames Research Center
  - Replace Substation 115-kilovolt High Voltage Cables (Phase 2 of 3)
  - Restore Electrical Reliability for Unitary Plan Wind Tunnel, N260, N238, and N243A
  - Restore Electrical Reliability of Agency Telecom Gateway, Building N254
- Glenn Research Center
  - Repair Building Exteriors, Engine Research Building West Wing, Building 23
- Goddard Space Flight Center
  - Upgrade South Island Electrical, Wallops Flight Facility
- Jet Propulsion Laboratory
  - Install Utility Metering
  - Upgrade Liquid Nitrogen Tanks (Phase 4 of 5)
- Johnson Space Center
  - Replace Compressed Air System, Central Heating and Cooling Plant, Building B24
- Kennedy Space Center
  - Repair Roads and Replace Culverts, Various Locations
  - Replace Roof, Launch Equipment Shop
  - Upgrade Heating Ventilation and Air Conditioning System, Launch Equipment Shop
- Langley Research Center
  - Upgrade Electrical Distribution System
  - Upgrade Steam System, Building B1208
- Marshall Space Flight Center
  - Revitalize Pressure and Propellant Distribution Systems, Site-wide (Phase 1 of 2)
- Stennis Space Center
  - Refurbish Hydrogen Generation System
  - Rehabilitate Natural Gas System, Site-wide

In FY 2019, NASA initiated five significant Discrete projects. Work continued on a critical shoreline restoration project through award of the Restore Coastal Shoreline (Phase 2 of 2) project at KSC that is needed to protect the spaceport’s launch pads. Work also started on the safety-oriented efforts at MSFC to replace and revitalize the site-wide fire protection/alarm node system. Likewise, both phases of the steam distribution replacement project at MSFC to convert buildings from steam to more efficient natural gas heating systems were initiated. Initiation of these project is critical so the work can be completed prior to the 2021, when Redstone Arsenal’s steam is no longer available. Also, GRC started its project to repair Lewis Field’s storm sewer system (Phase 2 of 3).

In FY 2019, NASA initiated construction of the following Minor CoF projects:

- Armstrong Flight Research Center
  - Repair Mechanical Systems, Flight Loads Lab

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- Ames Research Center
  - Reduce Seismic Risk, Buildings N226, N244, and N245
- Goddard Space Flight Center
  - Upgrade Fire Alarms, Greenbelt Center-wide
  - Repair of North Chilled Water Plant, Building 9
  - Repair of South Chilled Water Plant, Building 94
  - Restore Electrical Infrastructure, Main Base, Wallops Flight Facility
- Jet Propulsion Laboratory
  - Multi-Mission Operations Center, Space Flight Operations Facility, Building B230
  - Office Consolidation, Building B303
- Langley Research Center
  - Upgrade Electrical Distribution System
- Marshall Space Flight Center
  - Upgrade Lightning Protection System, Site-wide
  - Water Piping, Engineering and Development Laboratory, Building 4708
- Stennis Space Center
  - Refurbish Potable Water System, Water Wells and Towers
  - Rehabilitate E-Complex Deluge System

Energy Savings Investments - NASA continued its energy investments efforts by initiating the Lighting Upgrade project at Armstrong Flight Research Center (AFRC), and completing the following projects:

- Expand Energy Monitoring and Control System, Buildings 49 and 110, GRC
- Install High Efficiency Boiler, Engineering and Development Laboratory, Building 4708, MSFC

Demolition - During FY 2019, NASA disposed of 30 facilities with approximately 68,000 square feet of unneeded assets.

WORK IN PROGRESS IN FY 2020

NASA plans to continue progress on the Institutional CoF projects that were initiated in FY 2019 and prior years. NASA also plans to initiate three discrete projects, including two New Construction and one Repair and Revitalization project.

New Construction - The two repair-by-replacement facilities include the Flight Electronics Integration Facility (FEIF) at the Jet Propulsion Laboratory (JPL), and the Flight Dynamics Research Facility (FDRF) at Langley Research Center (LaRC). The state-of-the-art FEIF will enable development of robust, next-generation avionics. It is a 95,000 square foot, five-story concrete building with two-way concrete floor and roof slabs designed for the high seismic region. This project, joint funded between the Science Mission Directorate and Institutional CoF, will provide the best state of the art facility for advanced technical and performance requirements, such as highly specific electrostatic grounding to prevent damage to flight hardware during manufacturing. The facility will consist of class 1K, 10K and 100K cleanrooms and facilities for parts storage, fabrication, integration and testing. More than 115,000 square feet of existing buildings will be demolished as a footprint offset. The FEIF initiative supports future Discovery and New Frontiers missions, future exoplanet-detection missions, future Earth science missions following on the Surface Water and Ocean Topography (SWOT) and NASA-Indian Space Research Organization (ISRO) Synthetic Aperture Radar (NISAR) missions currently in development, and a host of future Earth Science instruments.

The FDRF will support vehicle development and risk reduction for entry capsules and launch abort systems, enable risk reduction for planetary probes and entry vehicles, and provide support for Aeronautics projects. This facility consists of a single vertical wind tunnel with enhanced capabilities encompassing those of the existing 12-foot Low Speed Tunnel (12-Foot) and 20-foot Vertical Spin Tunnel (VST). These existing facilities cannot support the complex technology needs for many of the currently planned, as well as projected, NASA missions due to poor flow quality, low dynamic pressure range, and the unlikely ability to keep them technically viable (even for less demanding applications). The FDRF will use a commercial free-fall simulator facility with modifications along with the existing VST and 12-Foot test rigs and data acquisition systems. Enhanced capabilities include higher Reynolds numbers and dynamic pressures, lower flow turbulence for improved flow quality, closed flow path with variable flow control and mechanical cooling capabilities, increased flexibility and cost effectiveness, and optimization of systems for operational and maintenance efficiency. Four existing NASA-owned buildings in the Langley East Area (Joint Base Langley-Eustis) will be demolished.

Repair and Revitalization - Major repairs will commence on the High-Pressure Industrial Water 66-inch water pipe and ancillary equipment at the Stennis Space Center (SSC) with joint Institutional, Exploration, and Space Operations CoF funding. This project ensures ability to provide the water required for fire suppression, test stand deflector cooling, and diffuser operations during rocket engine testing.

In addition to these Discrete projects, NASA is planning to initiate the following Repair and Revitalization Minor CoF projects:

- Ames Research Center
  - Reduce Seismic Risk to Buildings N204A N206A & N239
  - Reduce Electrical Arc Flash Risk to Personnel, Phase 1 of 4
- Goddard Space Flight Center
  - Upgrade High Voltage Electrical Feeders, Phase 1 of 2
  - Wallops Island Causeway Bridge Repairs, Wallops Flight Facility
- Johnson Space Center
  - Electrical Substation Upgrades
- Kennedy Space Center
  - Relocate Indian River Bridge Utilities
- Langley Research Center
  - Utility Tunnels 1 & 2 Repairs, Phase 2 of 2
  - Utility Tunnels 3 & 4 Repairs

Energy Savings Investments - In FY 2020, NASA plans to continue its energy investment efforts by initiating the following projects:

- Implement Energy Conservation Measures and Retro-Commissioning, Various Buildings, Phase 3, Johnson Space Center (JSC)
- Implement Energy Upgrades, Various Buildings, MSFC

INSTITUTIONAL COF

Demolition - In FY 2020, NASA plans to dispose of 36 facilities with approximately 600,000 square feet of unneeded assets.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

NASA is planning an aggressive Institutional CoF program for FY 2021. Summary accomplishments planned include the following with detailed descriptions provided thereafter:

New Construction - The FY 2021 Budget funds new starts at two facilities:(1) the Engineering and Mission Operations (EMO) facility at ARC, and (2) the Vehicle and Aerospace Ground Equipment Maintenance (AGE) facility at AFRC.

Repair and Revitalization - In FY 2021, six Discrete and 19 Minor CoF projects are planned. Those projects directly supporting the Artemis program, include: repair of the Virtual Motion Simulator at ARC, electrical safety and reliability upgrades at KSC, launch infrastructure modifications at KSC, MAF Building 103 roof replacement, repair of Building 4619 mechanical systems at MSFC, repair of pressure and propellent distribution systems at MSFC, repairs to Test Complex power generation system at SSC, and canal impoundment system valve repairs at SSC. The remaining projects reflect the highest priorities that are vital to mitigating near-term infrastructure risks.

Energy Savings Investments - Planned for FY 2021 are two energy improvement projects across several buildings at ARC and SSC, and a solar photovoltaic systems installation project with energy storage at JPL. Combined these projects should provide a payback in less than 10 years.

Demolition - Planned for FY 2021 is the demolition of more than 50 facilities and roughly 300,000 square feet.

Detailed descriptions are provided below:

Discrete Construction of Facility Projects

Discrete CoF projects have initial cost estimates of $10 million or greater. These projects may comprise major repairs or replacement of failing or damaged infrastructure, or they may include recapitalization projects that replace or update outdated facilities or technical assets that impede NASA operations and mission achievement. NASA's FY 2021 Institutional CoF budget includes eight discrete repair and recapitalization projects that improve reliability of key institutional systems supporting Artemis and other missions, and reduce the highest real property related institutional risks to safety, cost, schedule, and mission success. These projects are described below.

ARC ENGINEERING AND MISSION OPERATIONS FACILITY

FY 2021 Estimate: $67.0 million; Total Project Estimate: $77.5 million

ARC’s Engineering and Mission Operations Facility will be a new, 60,000-square-foot building that will serve as the Center’s new engineering hub that will support its core competencies and NASA missions. In doing so, it will consolidate several key program functions and include new engineering collaborative spaces, laboratories, engineering offices, and support areas. This new mission engineering hub will serve both aerospace systems and spaceflight projects. It will support innovative engineering, design and development, the manufacture, assembly, and operation of complex mechanisms, avionics, materials research, instruments, and systems in support of NASA missions in ways not possible with the current facilities.

ARC's existing facilities were not originally designed or built to meet current and future mission needs and are widely distributed across the site. These obsolete and distributed facilities contribute to work inefficiencies that severely impact the robust "design-build-fly" capabilities needed by NASA's mission directorates. The new Engineering and Mission Operations Facility is the cornerstone of the ARC Master Plan's "Campus of the Future" that is focused on consolidating and modernizing antiquated facilities NASA inherited from the National Advisory Committee for Aeronautics that were built before 1958. The project will achieve LEED Silver certification to comply with Federal statutory sustainable design, energy efficiency, and renewable requirements, resulting in reduced utility and maintenance costs and worker productivity enhancements (e.g., renewable ready, natural ventilation, daylighting). The project will involve the demolition of 10 obsolete buildings and more than 90,000 square feet.

This new integrated facility will support the next generation of NASA programs and help sustain ARC's core competencies, including cost-effective space missions, entry systems, space and earth science, astrobiology and life sciences, aero sciences, and intelligent/adaptive systems. It will serve all of NASA mission directorates and core NASA programs (e.g., Orion, SLS, ISS, Stratospheric Observatory for Infrared Astronomy, and Small Spacecraft Technology). It is anticipated that ISS mission payloads and the Artemis Lunar Exploration instrument suite will be developed in this new Engineering and Mission Operations facility at ARC.

ARC RESTORE RELIABILITY TO VIRTUAL MOTION SIMULATOR

FY 2021 Estimate: $11.0 million; Total Project Estimate: $12.0 million

The Virtual Motion Simulator (VMS) is a one-of-a-kind research and development facility used for aerospace simulation studies and experiments. It is the largest, most realistic motion-based flight simulation environment in the world. Continuously degrading VMS drive system will impact the timely delivery of simulation results in support of NASA's Artemis, Urban Air Mobility (UAM), and the Electrified Aircraft Propulsion Demonstration programs. The VMS is also utilized for support to Federal Aviation Administration programs, and is mission-critical to Department of Defense (DoD) activities.

NASA plans to replace the VMS transformers, switchgears, analog control systems, motion control systems and operator interface. NASA also plans to replace the DC motors, drive, and instrumentation with A/C motors, variable frequency drives; and replace the mechanical torque tubes, brakes, gear boxes, and motor mounts. These improvements are necessary to support the development, testing, and certification of the Lunar and Mars Human Landing System (HLS), which must meet manual control handling qualities requirements. The manually controlled descent and landing on the lunar and Mars surface is probably the most critical and difficult phase of flight. The VMS is the only existing ground-based simulator capable of meeting the requirements of the NASA Human Exploration and Operations Mission Directorate. VMS also supports Aeronautics Mission Directorate activities (e.g., Advanced Air Mobility and Urban Air Mobility), external Government customers (e.g., DoD, Federal Aviation Administration, and National Transportation Safety Board), private industry, and academia.

INSTITUTIONAL COF

AFRC VEHICLE AND AEROSPACE GROUND EQUIPMENT MAINTENANCE FACILITY

FY 2021 Estimate: $16.7 million; Total Project Estimate: $18.0 million

The new AFRC Vehicle and Aerospace Ground Equipment Maintenance Facility will consolidate and replace the functions of five old and degraded buildings scattered across AFRC. This new 25,000-square-feet state-of-the-art LEED Silver facility will house and maintain all AFRC's Government vehicles and aircraft ground equipment, and function as a central ground support hub. It will include equipment bays, lifts, repair shop, testing areas, wash bay, technical library, training room, and administrative space. This repair-by-replacement project will enable demolition of 33,000 square feet consisting of four existing, degraded, 50+ year-old prefabricated buildings that have numerous problems (e.g., leaking roofs, failing HVAC systems, personnel safety and health risks) and a carport which are responsible for current inefficiencies in maintenance operations. This facility's design and consolidation of multiple facilities will enhance operations efficiency and alleviate these deficiencies while also adding a centralized, Environmental Protection Agency (EPA)-compliant hazardous material waste collection, disposal, and recycling unit. This new facility will directly support the Aeronautics Mission Directorate activities, such as current NASA aircraft (e.g., F-15, F-18) and future high-profile X-Planes (e.g., X-57 Maxwell, X-59 QueSST). The project was previously submitted in FY 2017, but it required redesign and resubmission to meet changing bid climates.

KSC MODIFICATIONS TO LAUNCH INFRASTRUCTURE FOR SLS

FY 2021 Estimate: $33.8 million: $25.0 million (Institutional CoF), $8.8 million (Exploration CoF); Total Project Estimate: $61.6 million

Jointly funded by Institutional and Exploration Programmatic CoF, NASA will continue developing the KSC infrastructure modifications necessary to support SLS and Orion launch processing operations. This project's first phase appeared in the FY 2020 Budget submit under the title "Modifications to Convertor Compressor Facility and Environmental Control Systems [ECS]." This project will build on the FY 2020 project work and implement the nitrogen system upgrades and infrastructure modifications necessary to support SLS. Additionally, ECS will be installed to ensure continuous critical temperature and humidity air supply can be maintained for SLS and Orion flight systems during processing operations. Finally, NASA will fabricate and construct the Emergency Egress System (EES) slide wire system that will support the Artemis II mission. In the event of an emergency prior to launch, EES enables flight crew egress from the mobile launch tower to a ground-based safe haven. To support the mission safety and schedule, this project will need to start in the first quarter of FY 2021. Timely upgrades and infrastructure modifications to KSC infrastructure from previous shuttle configurations are required to support anticipated Artemis processing and launch manifest. No other facilities have the size or capabilities necessary to support launch vehicle processing, assembly, and operations. Failure to implement these discrete projects seriously impact NASA's ability to transition and sustain the use of this launch complex to support SLS and implement Human Exploration and Operations Mission Directorate objectives.

LARC UPGRADE COMPRESSOR STATIONS (PHASE 3 OF 4)

FY 2021 Estimate: $14.5 million; Total Project Estimate: $57.6 million

INSTITUTIONAL COF

NASA plans to complete the third phase to upgrade the LaRC Compressor Station that provides high pressure air (HPA) site wide. It will ensure the Center's continued ability to safely and reliably provide high pressure air (approximately 6,000 pounds per square inch (psi)) to 25 research facilities and technical assets across the Center. NASA relies on this compressor station to provide the HPA needed to operate LaRC's wind tunnels. Building on the Phase 2 work funding in FY 2017, this project will replace an obsolete 6,000-psi compressor with a new compressor and update its associated ancillary systems. Continuing this phased work is critical; a NASA Safety Center study previously recommended replacing all Compressor Station compressors and associated ancillary systems at LaRC as they are well beyond their design life, unreliable, and expected to continue to fail in an unpredictable manner. This replacement will substantially increase the reliable delivery of HPA to the research facilities and technical assets across the Center (e.g., 8-foot High Temperature Tunnel, National Transonic Facility, Transonic Dynamic Tunnel, and 14-foot x 22-foot Tunnel). It supports the LaRC Master Plan by increasing the reliability of the Compressor Station's production of air and contributing to the sustainment of the Center's core capabilities serving numerous NASA programs (e.g., SLS, Orion, Commercial Crew, Entry Descent and Landing, Commercial Cargo, Hypersonic Technology Project).

MAF REPAIR BUILDING 103 ROOF SYSTEM

FY 2021 Estimate: $25.0 million; Total Project Estimate: $170.0 million

NASA is planning to replace Building 103's massive roof. Building 103 is an approximately 1.7-million-square-foot, large bay facility with a 40-foot height clearance. This environmentally controlled facility has been serving as NASA's primary large-scale aerospace manufacturing facility since the early 1960's, and it continues to support NASA exploration efforts (i.e., Orion and SLS). This five-phase project will replace the existing, deteriorated roofing system of the main SLS manufacturing facility at MAF. The replacement project will remove the entire concrete roof panel deck and replace it with a new metal deck. The roof replacement will reduce leaks, improve weather protection, and provide a more durable and energy efficient system than the current roof system. Building 103's roof system replacement is needed to address several significant deficiencies that threaten NASA's capability to manufacture large-scale aerospace components/vehicles. First, the above deck roofing system components have degraded from both age and exposure to major hurricanes and, more recently, a significant tornado. Second, the existing roof deck is composed of precast lightweight concrete panels that were installed in the 1940's and that have far exceeded their useful life. They are experiencing both web and flange cracking along with corrosion of the reinforcing steel mesh. Finally, the current deck is supported primarily with timber purlins; a recent assessment determined several purlins have deteriorated to the point that they need to be replaced. This replacement roof project will address these significant deficiencies. Moreover, it will ensure NASA's long-term capability to manufacture large-scale aerospace components/vehicles, continue to build the SLS, and support U.S. capabilities for manned spaceflight.

In FY 2017, NASA received supplemental funding to repair tornado damage to several MAF facilities including Building 103. The scope and cost of those repairs are not included in this roof replacement project.

MSFC REVITALIZE BUILDING 4619 MECHANICAL SYSTEMS

FY 2021 Estimate: $13.5 million; Total Project Estimate: $14.5 million

INSTITUTIONAL COF

Building 4619, the Structures, Dynamics, and Thermal Vacuum Laboratory, is one of MSFC's mission-critical laboratory facilities with capabilities that include structural strength and dynamics testing, experimental fluids and environmental testing, and guidance, navigation, and control simulation. This project will renovate the building's HVAC systems across all of its offices, laboratories, and high bay areas. It will remove the facility's inefficient and high-maintenance steam heating system and replace it with a modern, reliable, and energy efficient, natural gas-fired hot water boiler heating system. Much of the building's main mechanical infrastructure is original to the building, which was built in 1959. HVAC system failures (e.g., mechanical failures, water pipe ruptures) result in the loss of air conditioning (i.e., temperature and humidity control). Building 4619's laboratories require temperature and humidity control for the proper operation of their test equipment. These mechanical failures can shut down the facility's laboratories, resulting in mission delays of a week or more and can have a major impact on program requirements and mission schedules. By replacing infrastructure that is well beyond its useful life, this renovation project will realize operation and maintenance cost savings, enhance energy efficiency, and reduce the risk to supported programs' costs and schedules. The risk reduction from this project is significant as these laboratories support core NASA programs (e.g., SLS, Orion, ISS, Solar Probe Plus).

SSC REPAIR POTABLE WATER SYSTEM, BASE SIDE (PHASE 3 OF 4)

FY 2021 Estimate: $11.7 million; Total Project Estimate: $43.0 million

NASA intends to complete Phase 3 repairs to SSC's potable water system by replacing 50+-year-old iron pipe water distribution system throughout the base side of SSC. It is past its design life, prone to failures, and currently operating with a patchwork of temporary repairs. While not addressing the entire system, this phase alone will replace the vast majority of base side piping that is in danger of imminent failure, and it will eliminate 190 temporary patches to the system. Originally installed in 1964, SSC's approximately 65 miles of potable water distribution pipe is now extremely pitted, fragile, and brittle, with 95 reported water leaks and breaks occurring during FY 2010-2017. Within a six months span during FY 2018, SSC experienced 12 potable water breaks and/or significant leaks (i.e., an average of one break or leak every 15 days) with impacts including boil water orders, fire protection system impairment, Center operations interruptions, and test delays due to the inability to cool buildings or provide basic water service. Further, the existing single points of failure and degraded condition significantly increase the fire risk to property and life. This project will, however, increase the potable water system reliability and reduce the ongoing costs of responding to and fixing failing water pipes. The project will mitigate the single points of failure and enhance the level of safety and security for NASA's engine testing programs (e.g., NASA Human Exploration and Operations Mission Directorate, Space Launch System and RS-25, Space Technology, Nuclear Thermal Propulsion (NTP)).

Minor Revitalization and Construction of Facilities

FY 2021 Estimate: $133.8 million

Minor Revitalization and Construction of Facilities projects have initial cost estimates between $1 million and $10 million. These projects may include new construction, major repairs, upgrades, or replacement of failing or damaged infrastructure. The following planned FY 2021 Minor Revitalization and Construction of Facilities projects will provide critical repairs or upgrades across NASA's Centers. Not funding these projects would cause direct cost, schedule, technical, and/or personnel safety impacts to major NASA missions or programs, and/or direct impacts to NASA's commercial partners.

- Armstrong Flight Research Center
  - Repair Building Envelopes, Center-wide
- Glenn Research Center
  - Repair Electrical Distribution System (Phase 3 of 5)
  - Repair Facility Horizontal Communications Infrastructure, Plum Brook Station
  - Repair Water Distribution System, Cooling Tower Numbers 1 and 4
  - Repair Water Distribution System, Cooling Tower Numbers 3 and 6
- Goddard Space Flight Center
  - Restoration of Main Base Electrical Infrastructure, Wallops Flight Facility
  - Replace Chiller 3, Building 31,
  - Update Fire Alarm, Center-wide
- Jet Propulsion Laboratory
  - Seismic Bracing, Building 183
- Johnson Space Center
  - Central Heating and Cooling Plant Chiller Replacement
  - Replace Natural Gas System, Johnson Space Center / White Sands Test Facility, WSTF
- Kennedy Space Center
  - Upgrade Safety and Reliability of Institutional Power Systems (Phase 4 of 5)
- Langley Research Center
  - Rehab Utility Tunnel Environmental Controls
  - Repair Utility Tunnels 1 and 2 (Phase 1 of 2)
  - Upgrade Electrical Distribution System, Main Core Campus
- Marshall Space Flight Center
  - Revitalize Pressure and Propellant Distribution System (Phase 3 of 3)
  - Utility Control System Risk Reduction (Phase 1 of 2)
- Stennis Space Center
  - Repairs to Critical Test Complex Power Generation System
  - Repair Canal Impoundment System, Miter Gates, and Closure Valves

Energy Savings Investments

FY 2021 Estimate: $7.0 million

These important projects focus on improving systems efficiencies and reducing utilities expenditures. The projects that comprise this request are of the highest priority based on expected return on investment or contribution to Federal energy mandates. The group of projects listed below collectively provides an estimated 9.7-year simple payback period – the time required to recover the initial investment through annual energy cost avoidances. Implementing these projects will contribute to NASA meeting Federal statutory and executive order energy requirements and will result in an estimated annual $1.3 million in avoided utilities expenditures. Specific projects planned for FY 2021 include:

- Improve Building Energy Efficiency, Various Buildings, ARC

- Install Solar Photovoltaic Systems with Energy Storage, JPL
- Implement Energy Improvements, Various Buildings, SSC

Demolition of Facilities

FY 2021 Estimate: $25.0 million

NASA continues to meet its national fiduciary responsibilities, leveraging Agency-retained assets to increase their functionality to support mission success while disposing of unneeded Federal real estate, increasing the use of under-utilized assets, minimizing operating costs, and improving energy efficiency.

NASA will use the requested funding to eliminate inactive and obsolete facilities that are no longer required for NASA's Mission. Abandoned facilities pose potential safety and environmental liabilities at the Centers. The Agency must maintain these facilities at minimal levels to prevent increasing safety and environmental hazards, and these recurring maintenance costs impose a drain on the maintenance dollars available at the Centers. Demolishing these abandoned facilities allows the Agency to avoid non-productive operating costs required to keep abandoned facilities safe and secure. Demolition is the most cost-effective means to reduce the Agency's deferred maintenance.

NASA identifies facilities for demolition through special studies to determine whether a facility is required for current or future missions. Facilities that are no longer needed are included in a five-year demolition plan that sets project schedules based on last need, annual costs avoided, square foot reduction, return on investment, potential liability, and project execution factors. Specific planning for FY 2021 includes demolition of approximately 25 facilities with a corresponding 150,000+ square foot reduction, including funding for demolition of the Indian River Bridge at the KSC.

Facility Planning and Design

FY 2021 Estimate: $44.9 million

NASA will continue to provide funding for advanced planning and design activities, special engineering studies, facility engineering research, preliminary engineering efforts required to initiate design-build projects, preparation of final designs, construction plans, specifications, and cost estimates associated with non-programmatic construction projects. These activities include master planning, value engineering studies, design and construction management studies, facility operation and maintenance studies, condition-based maintenance studies, facility utilization analyses, engineering support for facilities management systems, engineering support for management oversight, and capital leveraging research activities. Funding also supports participation in facilities-related professional engineering associations and organizations to better leverage industry best practice. The facilities planning and design activities are crucial to implementing NASA's recapitalization strategy and supporting mission needs. These projects are also necessary to make progress toward required Federal footprint reduction, sustainability, energy, and stewardship goals.

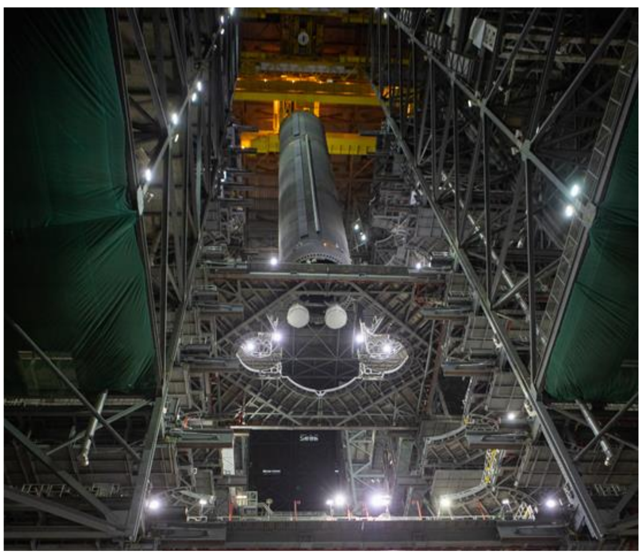
EXPLORATION COF

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**31.9**	**--**	**22.3**	**0.0**	**0.0**	**0.0**	**0.0**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.



Technicians use a crane to lower the Space Launch System (SLS) Core Stage pathfinder into High Bay 3 inside the Vertical Assembly Building (shown here) at Kennedy Space Center (KSC).

Exploration Construction of Facilities (CoF) provides construction required to support the Space Launch System (SLS), Orion, and Exploration Ground Systems (EGS) program activities. Funds required for the planning and design of out-year programmatic construction remain in the applicable program accounts.

EXPLANATION OF MAJOR CHANGES IN FY 2021

None.

ACHIEVEMENTS IN FY 2019

During FY 2019, NASA continued to make tremendous progress transitioning facilities configured for the legacy Space Shuttle and Constellation programs to facilities configured to support the SLS and Orion programs for Artemis Missions.

At Kennedy Space Center (KSC), the Exploration Ground Systems (EGS) program continued to achieve key milestones, evolving legacy Apollo and Space Shuttle infrastructure to accommodate future SLS and Orion launch processing requirements and Human Exploration and Operations Mission Directorate objectives.

New Construction - At Launch Complex 39B (LC-39B), fabrication and installation of an approximate 1.25M gallon liquid hydrogen (LH2) sphere continued, along with the installation of a vaporizer, flare stack and associated piping/valve system.

Repair and Revitalization - Within the Vehicle Assembly Building (VAB), construction began on the installation of a new Environmental Control Systems (ECS) that will maintain continuous critical

EXPLORATION COF

temperature and humidity air supply for SLS and Orion flight systems during processing operations. In addition, EGS completed installation of access platforms (20 total) in VAB's High Bay 3, and this commenced the final commissioning phase, supporting real time fit checks with mobile launcher (ML) operations.

EGS continued planning activities associated with the revitalization of KSC infrastructure as it relates to life-cycle replacement objectives at KSC. Ongoing planning continues to address multiple rehabilitation and repair projects, including the Rotational Processing Surge Facility (RPSF) fire protection.

At Michoud Assembly Facility (MAF), the SLS Program continued modifications to the facility to support tooling and manufacturing for the SLS Core Stage production. This work included the second phase to repair structural components of critical fan houses on the roof of Building 103, and replacing electrical Substation 1 with the installation of a new double ended substation. Numerous design efforts were accomplished in FY 2019 for future construction at MAF, such as the rehabilitation of East Mater Substation, Phase 1 installation of the site wide storm water drainage system, replacement of Substation 21, and rehabilitation of the industrial waste water tank facility (IWTF) and processing system.

WORK IN PROGRESS IN FY 2020

Repair and Revitalization - EGS will start upgrades to the ECS at LC-39B to support future crewed launch missions. Given the time interval between Artemis I and Artemis II missions, EGS is proactively commencing an initial construction phase in FY 2020. Augmented ECS upgrades will follow within the window of time allocated between the launches of Artemis I and Artemis II. This project will replace legacy equipment, including Apollo-era air intake filters and Shuttle-era cooling towers. These modifications are necessary regardless of future Artemis launch vehicle configurations.

A multiphase construction project at the Converter Compressor Facility (CCF) is required to increase operational efficiency and augment delivery of helium and nitrogen to the launch site. FY 2020 planned modifications (i.e., first of two phases of modifications) are necessary to ensure SLS and Orion peak flow rates are met during processing and launch at KSC. This initial phase will replace CCF helium system pumps, associated pipe configuration, and controls. The second phase is expected to begin in FY 2021.

EGS will initiate construction of three rehabilitation projects at KSC. The program will upgrade the Rotation, Processing and Surge Facility (RPSF) fire protection system to ensure safety code compliance during facility processing. EGS will also replace the aging HVAC system at the KSC Logistic Facility in accordance with the EGS life cycle replacement plan. Finally, EGS will repair and/or replace the distribution pumps, piping, and valves associated with potable water systems and sewage/drain collection systems throughout VAB high bays.

The Orion program will also refurbish the south wall of the high bay used as a clean room for Orion capsule processing in the Neil Armstrong operations and checkout building at KSC. This repair will eliminate water penetration through cracks/defects in the existing coating of the exterior surface of the high bay wall.

At the Booster Fabrication Facility Complex at KSC, the SLS Program will initiate the design for roof replacement of both the Manufacturing building and the Engineering and Administration building. This roof project includes the replacement and upgrade of all roof top mechanical installations (i.e., HVAC equipment and exhaust fans) supporting both administrative and operational areas. Construction is expected to begin in the 4th quarter of FY 2020 with a planned completion in FY 2021. An additional design project will start for upgrades to the existing obsolete substations and switchgears throughout the complex. The project will include design and installation of new exterior pad mounted medium voltage transformers and new automated dual source switchgears. The current switches are not automatic and increase the risk of unplanned outages that impact flight hardware production operations.

At MAF, work will continue on modifications to Building 103 and Building 110 to support SLS Core Stage manufacturing. In addition, numerous construction projects will be completed in FY 2020, such as the Phase 1 installation of the site wide storm drainage system, replacement of the North 50-psi steam system piping, rehabilitation of structural components of critical fan houses in Building 103, and Phase 1 of rehabilitation of the IWTF tank and processing system. Construction will also commence on upgrading the bridge crane capability for SLS between column D2 to G3 in Building 103 from 10- to 15-ton; upgrading the legacy cranes in the robotic weld tool (RWT) and inter tank (IT) Areas; rehabilitating Cell Q; and starting Phase 2 installation of the site-wide drainage system, rehabilitation of critical fan houses in Building 103, and rehabilitation of the IWTF and Process System.

Numerous designs are scheduled to be completed, including the following: repairs to roadways at MAF; elevator upgrades in buildings 103, 110 and 114; upgrade Fire Alarm Panels in the 100 and 200 series buildings; and Phase 1 of Building 103 roof replacement. The designs scheduled to start include the north condensate distribution in Building 103, Cell H activation, and rehabilitation of the center steam distribution system in Building 103.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

Repair and Revitalization - At KSC, Exploration and Institutional CoF are jointly funding critical infrastructure modifications necessary to support SLS and Orion launch processing operations via the SLS Modifications for CCF, ECS, and EES project. The CCF upgrade efforts will focus on replacing the nitrogen compression pumps, vaporizers, selected valves, and piping configurations. It will also provide rehabilitation repair due to long-term deferred maintenance, update building code compliance, and replace obsolescence infrastructure with new energy efficiency technology. An ECS will be installed to ensure continuous critical temperature and humidity air supply can be maintained for SLS and Orion flight systems during processing operations. Construction is planned at LC-39B to fabricate and install an EES. The EES provides emergency evacuation of flight crew to a safe haven via a slide wire system from the Mobile Launcher. Following completion of the KSC Booster Fabrication Facility Complex replacement roofs, the SLS Program will initiate a rehabilitation of the complex office areas. The interior remodel will include a redesigned office and cubicle layout along with new flooring, furniture, and restrooms. The SLS Program will begin the design for a replacement of the low voltage power distribution system (i.e., obsolete panel boards, disconnect switches, universal power system units, and transfer switches).

At MAF, construction will start with the activation of Cell H, rehabilitation of the center steam distribution system in Building 103, upgrade to the elevators in buildings 103, 110 and 114, replacement of the north condensate distribution system, and upgrade to the fire alarm panels in the 100 and 200 Series buildings. Several constructions projects will be completed, such as, upgrades to the bridge crane between columns D2 and G3 in Building 103 from 10- and 15-tons, upgrades to legacy cranes in the RWT and IT Areas, rehabilitation of Cell Q, Phase 2 installation of the site-wide storm drainage system, rehabilitation critical fan houses in Building 103, and rehabilitation of the IWTF and processing system. In addition, work is expected to start on the design to replace the fire system post indicator valves (PIV) and sectional control valves (SCV) as well as Phase 1 of the restroom renovations in Building 103.

Discrete Construction of Facility Projects

Discrete CoF projects have initial cost estimates of $10 million or greater. These projects may comprise major repairs or replacement of failing or damaged infrastructure, or may include new construction projects that replace or update outdated facilities or technical assets that impede NASA operations and mission achievement. Exploration CoF has one discrete project jointly funded with Institutional CoF at KSC, which is described in the Institutional CoF section (KSC Modifications to Launch Infrastructure for SLS).

Minor Revitalization and Construction of Facilities

FY 2021 Estimate: $13.5 million

These projects provide for the repair, modernization, or upgrade of facilities and collateral equipment required by Exploration activities. Repair projects restore facilities and components to a condition substantially equivalent to the originally intended and designed capability. Repair and modernization work includes the substantially equivalent replacement of utility systems and collateral equipment necessitated by incipient or actual breakdown. Modernization and upgrade projects include both restoration of current functional capability and enhancement of the condition of a facility so that it can more effectively serve its designated purpose, increase its functional capability, and/or meet new building, fire, and accessibility codes.

The minor projects below provide critical investments to support refurbishment of infrastructure to support Exploration infrastructure and ensure building, fire, and accessibility codes compliance. During the year, rearrangement of priorities may be necessary that may cause a change in some of the items to be accomplished.

- Kennedy Space Center
  - VAB Water Distribution Rehabilitation
- Michoud Assembly Facility
  - Activate Cell H (Phase 2)
  - Rehabilitate Center Steam Distribution System
  - Upgrade Elevators in Buildings 110 and 114
  - Replace North Condensate Distribution Building 103
  - Replace Fire Alarm Panels 100/200 Series buildings

SPACE OPERATIONS COF

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	17.6	--	23.9	0.0	0.0	0.0	0.0

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

NASA's Deep Space Network Aperture Enhancement Project DSS-54 antenna at Madrid is shown undergoing installation, integration, and testing.

Space Operations CoF provides construction to support Space Communications and Navigation (SCaN), the International Space Station (ISS) program, and the Launch Services Program (LSP). Funds required for the planning and design of out-year programmatic construction remain in the applicable program accounts.

EXPLANATION OF MAJOR CHANGES IN FY 2021

No major changes.

ACHIEVEMENTS IN FY 2019

New Construction - FY 2019 marked the completion of several milestones for the DAEP. In Madrid, the first quarter saw the completion of the antenna pedestals for DSS-53 and DSS-56. Meanwhile, the assembly of the steel structure for both antennas progressed and culminated in the critical lift of the main reflector assembly for DSS-56. This achievement was followed with the start of the Integration, Installation, and Test (II&T) of electronics at DSS-56. The critical lift for DSS-53's main reflector assembly was achieved later in the fiscal year.

Goldstone identified the site for the new DSS-23 antenna. This site selection is significant as the construction of this new antenna will complete the array of four 34-m Beam Wave Guide antennas at Goldstone and will add new RF-Optical hybrid capabilities for the DSN.

Repair and Revitalization - Canberra completed the Site-Wide Uninterrupted Power Supply (UPS) project and placed it into operation. The Replace Beam-Wave Guide (BWG) Chillers project was successfully completed in FY 2019. The final set of wheels for the Replace Beam Wave Guide Azimuth Tracks, 34-m Subnet project were installed, benefitting a total of six antennas at the site.

SPACE OPERATIONS COF

At Cape Canaveral Air Force Station (CCAFS), the LSP completed the Hanger AE and Payload Hazardous Servicing Facility (PHSF) Chillers and Boiler Replacement Project. The project is a functional replacement of chilled water systems and other Heating, Ventilation, and Air Conditioning (HVAC) components at Hangar AE. These PHSF components were well beyond their service life and were in severely deteriorated conditions. The improved technology in the replaced systems and components will achieve functional redundancy and a much-reduced operational cost.

At Vandenberg Air Force Base (VAFB), LSP also completed the energy efficiency upgrades to Building 840 that included an integrated HVAC system and advanced building controls to better maintain the interior environmental control. This project also included the installation of lighting controls, light-emitting diode lights, and high-efficiency variable refrigerant flow (VRF) heating/cooling systems and controls.

WORK IN PROGRESS IN FY 2020

New Construction - In FY 2020, the DAEP will be working towards having the DSS-56 antenna in Madrid completed and operational by the end of the fiscal year. At Goldstone, DAEP will continue with the site excavation and progress on the hybrid RF-Optical design work.

Repair and Revitalization - DAEP will initiate one new minor project at Goldstone to replace DSS-14 US-1, US-2, Servo Starters.

In Madrid, the Antenna Apron and Subsoil Remediation project will continue as planned. However, under direction of SCaN, the pedestal remediation project for the DSS-54 antenna will be on standby as DAEP first plans to build a replacement pedestal for the existing DSS-54 antenna along with the necessary facilities-support structures and interface components.

LSP will continue closeout activities and commissioning of the Hanger AE and the PHSF chillers and boiler replacement project at CCAFS. The Building 840 energy efficiency upgrades will continue at VAFB.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

New Construction - NASA plans to complete constructions and start operations of DSS-53 in FY 2021. Once complete, Madrid will be the first deep space communication complex to have the capability to array four antennas for an enhanced aperture.

Goldstone plans to complete the DSS-23’s antenna pedestal build by the end of 2020, which will enable the next phase of the project. The hybrid RF-Optical project design and build process will continue.

Repair and Revitalization - SCaN plans to begin two minor projects at Goldstone: replace BWG antenna drives and drive cabinets, subnet; and update Goldstone site-wide UPS 10-year lifecycle. Both projects will replace antiquated equipment for greater safety and reliability of these mission critical assets.

SPACE OPERATIONS COF

Discrete Construction of Facility Projects

Discrete CoF projects have initial cost estimates of $10 million or greater. These projects may comprise major repairs or replacement of failing or damaged infrastructure, or they may include recapitalization projects that replace or update outdated facilities or technical assets that impede NASA operations and mission achievement.

JPL 34-M DEEP SPACE NETWORK APERTURE ENHANCEMENT PROJECT (DEAP) BEAM WAVE GUIDE ANTENNAS AT GOLDSTONE AND CANBERRA

FY 2021 Estimate: $21.2 million; Total Project Estimate: $113.4 million

NASA plans to build four new 34-m BWG Antennas at each of the DSN’s communications complexes. DSS-23 will become the fourth Goldstone-operating 34-meter BWG antenna, capable of providing both RF and Optical Communications for deep space. The project includes the fabrication and installation of the antenna structures, panels, gearboxes, bearings, electric drives, encoders, beam wave guide mirrors, sub-reflectors and positioners, optical mirrors, and related servomotors. The project also includes the construction of the pedestals and all the facilities/infrastructure in and around the antennas (e.g., paved access roads, trenches, drainage, flood control devices, water main and distribution system, antenna apron, perimeter security fence, HVAC systems, electrical power distribution, fire detection and suppression system, and surveillance system assembly).

At present, existing DSN antennas are operating at capacity and are oversubscribed, with demand exceeding supply by about 50 percent. The new DAEP 34-meter beam waveguide antennas are essential to provide DSN with the needed capabilities to support NASA missions in the 2020s. Projections indicate a growing number of interplanetary spacecraft, including planetary robotic missions and precursor robotic missions for the Human Exploration and Operations Mission Directorate. NASA’s ability to support the expected growth in the number of supported crewed missions will depend on these expanded capabilities. The newly developed optical communications capability will provide much higher data rates for both robotic and crewed missions of the future.

Minor Revitalization and Construction of Facilities

FY 2021 Estimate: $2.7 million

These projects provide for the repair, modernization, or upgrade of facilities and collateral equipment required by Space Operations activities. Repair projects restore facilities and components to a condition substantially equivalent to the originally intended and designed capability. Repair and modernization work includes the substantially equivalent replacement of utility systems and collateral equipment necessitated by incipient or actual breakdown. Modernization and upgrade projects include both restoration of current functional capability and enhancement of the condition of a facility, so that it can serve its designated purpose more effectively, increase its functional capability, or meet new building, fire, and accessibility codes.

SPACE OPERATIONS COF

The minor projects below provide critical investments to support refurbishment of infrastructure to support Space Operations infrastructure and ensure building, fire, and accessibility code compliance. During the year, rearrangement of priorities may cause a change in some of the items to be accomplished.

- Goldstone: Replace BWG Antenna Drives and Drive Cabinets, Subnet
- Goldstone: Update Site-wide UPS 10-year Life-cycle

SCIENCE COF

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**19.7**	**--**	**23.1**	**0.0**	**0.0**	**0.0**	**0.0**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Construction will start on the Flight Electronics Integration Facility, shown here in the artist's rendering, in FY 2020. This state-of-the-art facility will be used to develop next-generation avionics and will integrate multiple flight hardware assembly and fabrication facilities across the Jet Propulsion Laboratory (JPL) into a single location.

Science CoF provides construction required to support NASA's programs in Earth Science, Planetary Science, Astrophysics, and Heliophysics. It also includes construction for NASA's High-End Computing Capability (HECC) Program, which the Science Mission Directorate (SMD), as the biggest user, manages for NASA. Construction for HECC directly supports the Aeronautics, the Human Exploration and Operations Mission Directorate, Science, and Space Technology Missions.

Funds required for the planning and design of out-year programmatic construction remain in the applicable program accounts.

EXPLANATION OF MAJOR CHANGES IN FY 2021

Construction of the new Astromaterials Curation Annex project at the Johnson Space Center (JSC) will provide approximately 20,000 square-feet of critical laboratory space for what will be an unprecedented increase in new astromaterial collections from sample return missions. This laboratory space is required to provide for curation, analysis, preliminary examination, and allocation of samples to the scientific community.

ACHIEVEMENTS IN FY 2019

New Construction - NASA completed the infrastructure and utilities work in FY 2019 for the Modular Supercomputing Facility (MSF) at Ames Research Center (ARC) based on the successful proof-of-concept prototype completed in FY 2016-2017. Rather than meeting computing requirements through the expansion of capability within conventional facilities, this project provides a lower cost modular container-based capability adjacent to the Advanced Supercomputing Facility at ARC. This infrastructure will enable the flexible expansion of this new energy-efficient and water-conserving modular computing technology. It enables NASA to increase supercomputing capability with minimal impact on energy and water resources. This modular approach also ensures flexibility to adjust for fast-changing technology with minimal risk and will provide the supercomputing capability necessary to meet NASA's mission requirements today and into the future.

Repair and Revitalization - In FY 2019, SMD initiated two minor Science CoF projects: JSC Asteroid Sample and Advanced Curation Facility, Building 31; and Jet Propulsion Laboratory (JPL) – Renovation of Space Flight Operations Facility (SFOF), Building 230. The JSC Asteroid Sample and Advanced Curation Facility, building 31 project constructed approximately 4,000 square feet of new laboratory suites within in the existing Planetary and Earth Sciences Laboratory. This construction project is critical to the development, testing, and refinement of organic and microbiological contamination control procedures and precision cleaning techniques required for future astromaterial samples and asteroid samples due to arrive from the Hayabusa 2 and OSIRIS-Rex missions in 2021 and 2023, respectively. The Renovation SFOF, building 230 project will provide efficient, re-configurable space for Mars 2020 and other planetary-surface mission operations. It will make required upgrades to mission-critical equipment, increasing reliability and significantly reducing operations and maintenance costs. Its start in FY 2019 will allow SMD to take advantage of the rare window of opportunity presented by Cassini mission close-out.

WORK IN PROGRESS IN FY 2020

New Construction - In FY 2020, SMD will contribute to the modernization of capabilities and NASA infrastructure by starting construction on the new Flight Electronics Integration Facility (FEIF) at JPL. The FEIF will be a state-of-the-art facility for developing robust, next-generation avionics and is an important revitalization project that will integrate multiple flight hardware assembly and fabrication facilities into a single location. While supporting a more efficient workflow, the FEIF will greatly reduce the risk to mission flight hardware associated with the current need to transport it between multiple facilities across JPL (refer to Institutional CoF Section for further information). In FY 2020, NASA plans to complete renovation of JPL SFOF, Building 230 and construction on the JSC Asteroid Sample and Advanced Curation Facility, Building 31. Work on the Asteroid Sample and Advanced Curation Facility will continue in FY 2021 with construction of Building 31 Annex, described below. In addition to completing these projects, NASA plans to initiate the minor the Replace/Refurbish Laboratory Infrastructure (Building N239) Phase 2 of 3 project at ARC.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

NASA's FY 2021 Science CoF budget includes one discrete and one Minor CoF project required to meet laboratory needs. The Astromaterials Curation Annex at JSC is a New Construction project and additional work to Replace/Refurbish Laboratory Infrastructure, Building N239 at ARC is a Repair and Revitalization project.

SCIENCE COF

Discrete Construction of Facility Projects

Discrete CoF projects have initial cost estimates of $10 million or greater. These projects may comprise major repairs or replacement of failing or damaged infrastructure, or they may include recapitalization projects that replace or update outdated facilities or technical assets that impede NASA operations and mission achievement.

JSC ASTROMATERIALS CURATION ANNEX, BUILDING 31

FY 2021 Estimate: $19.5 million

NASA plans to construct an approximately 20,000-square-foot, Leadership in Energy and Environmental Design (LEED)-certified annex to JSC Building 31 for Astromaterials Research and Exploration Science (ARES) and enable the demolition of more than 25,000 square feet of obsolete space across JSC. This annex will provide critical laboratory space to support NASA's core planetary science and curation requirements as we return to the Moon, return samples from asteroids, and look to Mars and beyond. NASA and our international partners will be bringing back an unprecedented amount of astromaterial samples in the coming decade. The number, diversity, and complexity of these new NASA astromaterials collections will soon exceed that of NASA's existing collections that were accumulated over the last half century (i.e., all of NASA's history). New samples from the Moon, asteroids, and Phobos will present exciting challenges to meet organic cleanliness levels and preserve cold and volatile-rich samples.

NASA faces significant analysis and curation facility challenges. JSC's Building 31 curation facilities are already at capacity. Sample curation and research staff are currently spread across four JSC buildings, and this poses a great risk to both sample security and contamination (i.e., there is an increased risk of contamination each time a sample is handled and packaged for transport). JSC's existing facilities are more than 50 years old, not designed to support today's sensitive laboratories, and do not meet the requirements for next generation analytical instruments. These aged facilities experience frequent mechanical, electrical, and structural failures that force ARES facility or instrument downtime (i.e., 50-100 times per year). Scientists using ARES facilities often get one opportunity to make measurements on small, irreplaceable samples so achieving consistent performance is mission critical.

The new Astromaterials Curation Annex will help NASA and our international partners maximize these unprecedented astromaterial research opportunities by fully leveraging multi-million dollar plant services feeding existing curatorial and analytical laboratories within the current Building 31 complex. Efficiencies will be realized by bringing all of the sample curation and research staff (more than 150 people) into a single building complex and enabling them to better share existing high-valued Agency research and analysis assets. Most importantly, NASA's missions to collect and return these samples represent a substantial taxpayer investment and the facilities on the ground have to be up to the task of properly analyzing and curating them. This new, dedicated space is required to prevent contamination from other astromaterial collections, answer fundamental questions driving these sample return missions, and maximize the scientific return from these irreplaceable samples. This project will significantly contribute to NASA's Mars 2020, OSIRIS-REx, and Artemis Moon (i.e., return of new lunar samples) programs, and will maximize the scientific return on our participation in JAXA's MMX mission.

SCIENCE COF

Minor Revitalization and Construction of Facilities

FY 2021 Estimate: $3.6 million

These projects provide for the repair, modernization, or upgrade of facilities and collateral equipment required by Science activities. Repair projects restore facilities and components to a condition substantially equivalent to the originally intended and designed capability. Repair and modernization work includes the substantially equivalent replacement of utility systems and collateral equipment necessitated by incipient or actual breakdown. Modernization and upgrade projects include both restoration of current functional capability and enhancement of the condition of a facility so that it can more effectively serve its designated purpose, increase its functional capability, and/or meet new building, fire, and accessibility codes.

NASA plans a Minor CoF project that will continue efforts to replace and refurbish laboratory infrastructure in outdated and non-compliant laboratories in Building N239 at ARC.

- Replace/Refurbish Laboratory Infrastructure, N239 Phase 3 of 3

Environmental Compliance and Restoration

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	74.9	--	74.7	74.7	74.7	74.7	74.7

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

The Mid-Plume treatment system at WSTF (pictured here) uses an ultraviolet (UV) reactor to treat the N-nitrosodimethylamine (NDMA) contaminated groundwater. Ultraviolet lamps disperse UV light into the water, breaking the chemical into harmless byproducts. To support Sustainable Remediation, the UV reactor is powered by an onsite photovoltaic system.

NASA's Environmental Compliance and Restoration (ECR) program cleans up hazardous materials and waste products released to the surface or groundwater at NASA installations, NASA-owned industrial plants supporting NASA activities, current or former sites where NASA operations have contributed to environmental problems, and other sites where the Agency is legally obligated to address hazardous pollutants. ECR program activities include projects, studies, assessments, investigations, sampling, plans, designs, construction, related engineering, program support, monitoring, and regulatory Agency oversight.

Funding also covers land acquisitions required to ensure operation of remedial treatment processes and facilities as part of remediation and cleanup measures.

For more information, go to: http://www.nasa.gov/offices/emd/home/ecr.html

Explanation of Major Changes in FY 2021

None.

Achievements in FY 2019

NASA's ECR program includes cleanup activities at all NASA Centers, with priority given to protecting human health and the environment in conformance with U.S. Environmental Protection Agency (EPA) and state regulatory agreements and requirements. NASA accomplished the following notable restoration activities in FY 2019:

ENVIRONMENTAL COMPLIANCE AND RESTORATION

- SSFL completed demolition activities for structures and implemented abatement activities for the remaining Test Stands. The site has submitted and is finalizing plans for groundwater cleanup. As a result of the expected increased volumes for soil cleanup, NASA issued a Notice of Intent to prepare a Supplemental Environmental Impact Statement (SEIS) that will assess the impacts associated with a range of cleanup scenarios. Work also focused on recovery efforts to restore power and reinstall piping for the groundwater treatment system destroyed as a result of the Woolsey Fire in November 2019. Cultural resource management continued per the Programmatic Agreement with the State Historic Preservation Office, Native Americans, and consulting parties.
- The Jet Propulsion Laboratory (JPL), in conjunction with the State of California and EPA, continued onsite and offsite groundwater contamination remediation to protect public drinking water sources per the recently completed Record of Decision.
- Kennedy Space Center (KSC) continued investigation and clean up of groundwater and soil contamination. Activities included the installation of new groundwater treatment systems, excavation and removal of contaminated soils, investigation of additional sites for potential contamination, continued sampling of more than 700 monitoring wells, continued operations of existing groundwater cleanup systems, and site closures.
- Marshall Space Flight Center (MSFC) began contaminated soil removal in the East and West Test Areas as well as implementing interim actions to address the groundwater plume operable unit.
- WSTF continued to operate the plume front and mid-plume front treatment systems to capture and treat contaminated groundwater and continued source area investigations and closure activities.
- Glenn Research Center (GRC) began clean-up operations of an abandoned wastewater treatment facility and a lead contaminated range at Plum Brook Station.
- The Agency began an investigation of per- and polyfluoroalkyl substances (PFAS) across the Centers. NASA completed surveys of the Fire Fighting and Environmental communities on the use of Aqueous Film Forming Foam and releases. Based on this survey, NASA awarded a contract to implement a consistent Preliminary Assessment of all potential releases across all NASA facilities.
- The Agency continued operations of treatment systems and monitoring at Ames Research Center (ARC), Armstrong Flight Research Center (AFRC), Goddard Space Flight Center (GSFC), Langley Research Center (LaRC), Michoud Assembly Facility (MAF), Stennis Space Center (SSC), and Wallops Flight Facility (WFF).

WORK IN PROGRESS IN FY 2020

NASA is continuing its commitment to restoration by executing the following activities in FY 2020:

- SSFL will submit for public review the draft SEIS that will assess the impacts associated with a range of soil cleanup alternatives. Following completion of the SEIS, NASA will prepare a Record of Decision and submit work plans to the State for the soil cleanup. At the recommendation of the OIG and in consultation with the interested parties, NASA is deciding whether to retain one or all of the remaining test stands at SSFL. Operation of the groundwater treatment system is expected to resume following reconstruction of the piping system that suffered fire damage. SSFL will finalize plans and begin implementation of pilot-scale groundwater cleanup actions and continue long-term groundwater and air monitoring at the site

ENVIRONMENTAL COMPLIANCE AND RESTORATION

Cultural resource management will continue per the Programmatic Agreement with the State Historic Preservation Office, Native Americans, and consulting parties.

- KSC will continue investigation and clean up of groundwater and soil contamination. Activities planned include the installation of new groundwater treatment systems, removal of contaminated soils, investigation of additional sites for potential contamination, continued sampling of more than 700 monitoring wells, and continued operations of existing groundwater cleanup systems.
- JPL will continue operations, in conjunction with the State of California and EPA, for onsite and offsite groundwater contamination remediation to protect public drinking water sources.
- MSFC will continue contaminated soil removal in the East and West Test Areas as well as implement interim actions to address the groundwater plume operable unit.
- WSTF will continue to operate the plume front and mid-plume front treatment systems to capture and treat contaminated groundwater and continued source area investigations and closure activities.
- GRC will continue cleanup operations of an abandoned wastewater treatment facility and lead contaminated range at Plum Brook Station.
- WFF will begin operation of a groundwater treatment system to address specific perfluorinated compounds.
- In support of the PFAS investigation, NASA will conduct document searches, employee interviews and site visits to implement the Preliminary Assessment. Once potential areas of concern have been identified, NASA will prepare plans for further characterization.
- The Agency will continue operations of treatment systems and groundwater and soil monitoring at AFRC, ARC, GSFC, LaRC, MAF, SSC, and WFF.

KEY ACHIEVEMENTS PLANNED FOR FY 2021

Key projects and achievements planned for the FY 2021 include:

- $31.5 million for demolition, groundwater cleanup, finalization of soil cleanup plans, continued operation of groundwater treatment systems, and continued long-term monitoring of air and groundwater at SSFL in accordance with the State of California. Cultural Resource management will continue per the Programmatic Agreement with the State Historic Preservation Office, Native Americans, and consulting parties.
- $15.9 million for the continued investigation and clean up of groundwater and soil contamination at KSC under State of Florida requirements. Key activities planned include the installation of new groundwater treatment systems, removal of contaminated soils, investigation of additional sites for potential contamination, continued sampling of more than 700 monitoring wells, and continued operations of existing groundwater cleanup systems and closure activities.
- $8.6 million for the continued cleanup program at MSFC including contaminated soil removal in the East and West Test Areas as well as implementing interim actions to address the groundwater plume operable unit.
- $7.9 million to operate and maintain systems to clean up contaminated groundwater emanating from JPL and continued operations of the Lincoln Avenue and Monk Hill drinking water treatment systems.
- $7.6 million for the continued clean up of ground water contamination and investigation of soil contamination at WSTF, including completion of closure activities, implementation of source

area facility investigations, long-term monitoring of groundwater, and continued operation of the plume front and mid-plume ground water treatment systems.
- $2.0 million for the PFAS investigation. NASA will implement planned characterization efforts, which will include sampling of groundwater surface water and sediments. Sampling efforts will direct further action.
- $1.2 million for partial funding continuation of remedial efforts at the eight other Centers and facilities, and Environmental Compliance and Functional Leadership projects.

Program Elements

RESTORATION

Restoration projects address cleanup liabilities at all NASA Centers and component facilities. As of the start of FY 2020, known liabilities totaled $1.7 billion with many of the individual cleanup projects estimated to take more than 30 years to complete. NASA policy is to address these liabilities using a "worst first" approach to ensure protection of human health and the environment and to facilitate mission readiness. Plans for FY 2020 are based on a prioritized, risk-based approach for incrementally addressing NASA's cleanup portfolio. Projects are ranked according to the relative urgency and the potential health and safety hazards related to each individual cleanup. As studies, assessments, investigations, plans, regulatory approvals, and designs progress, and as new discoveries or regulatory requirements change, NASA may adjust program priorities.

ENVIRONMENTAL COMPLIANCE AND FUNCTIONAL LEADERSHIP

Environmental Compliance and Functional Leadership projects invest in environmental methods and risk reduction practices that ensure NASA can continue to carry out its scientific and engineering missions. This includes methodologies for sustainably reducing energy intensity and greenhouse gas emissions, supporting operational activities, and meeting external reporting requirements.

INSPECTOR GENERAL

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**39.3**	**41.7**	**44.2**	**44.2**	**44.2**	**44.2**	**44.2**

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

INSPECTOR GENERAL

FY 2021 Budget

Budget Authority (in $ millions)	Op Plan FY 2019	Enacted FY 2020	Request FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Total Budget	**39.3**	**41.7**	**44.2**	**44.2**	**44.2**	**44.2**	**44.2**
Change from FY 2020			**2.5**				
Percentage change from FY 2020			**6.0%**				

FY 2019 reflects total discretionary funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specific marks from Public Law 116-93, Consolidated Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

For FY 2021, the NASA Office of Inspector General (OIG) requests $44.2 million to support the work of auditors, investigators, analysts, specialists, lawyers, and support staff located at NASA Headquarters in Washington, DC, and 12 other locations throughout the United States.

The OIG conducts audits, investigations, and reviews of NASA programs to prevent and detect fraud, waste, abuse, and mismanagement and to assist NASA managers and Congress in promoting economy, efficiency, and effectiveness in the Agency's programs and operations. OIG's operational offices are the Office of Audits (OA) and the Office of Investigations (OI).

OA conducts independent and objective audits of NASA programs, projects, operations, and contractor activities, and oversees the work of the independent public accounting firm that conducts the Agency's annual financial statement audit. In its work, OA targets NASA's top management and performance challenges and the Agency's most important projects and missions. OIG audits provide fact-based analysis with actionable recommendations that help NASA achieve its space exploration, scientific, and aeronautics goals more effectively and efficiently.

OI investigates allegations of cybercrime, fraud, waste, abuse, and misconduct related to NASA programs, projects, personnel, operations, and resources. OI refers its findings to the Department of Justice for criminal prosecution and civil litigation or to NASA managers for administrative action. Through its investigations, OI develops recommendations to reduce the Agency's vulnerability to criminal activity or administrative inefficiency. Given that NASA spends approximately 74 percent of its total resources on contracts and grants, OI's caseload includes investigations of suspected false claims submitted by NASA contractors, product substitution and counterfeit parts, and conflict of interest cases that involve NASA employees who place private gain before public service.

The OIG's FY 2021 request is for $44.2 million in two-year funding and includes the following:

- $37 million (84 percent) to fund personnel and related costs, including salaries, benefits, monetary awards, worker's compensation, permanent change of station costs, and Government contributions for Social Security, Medicare, health and life insurance, retirement, and the Thrift Savings Plan including increased rates for retirement contributions. Salaries include the required additional 25 percent law enforcement availability pay for OIG's approximately 55 criminal investigators;

- $3 million (7 percent) to fund the statutorily required annual audit of the Agency's financial statements;
- $1 million (2 percent) to fund travel, per diem, and related expenses; and
- $3 million (7 percent) to fund equipment, training, Government vehicles, special equipment for criminal investigators, transit subsidies, and information technology equipment unique to OIG.[1]

EXPLANATION OF MAJOR CHANGES IN FY 2021

For FY 2021, the budget requests $44.2 million in two-year funding, an increase of $2.5 million (6 percent) from FY 2020 enacted. Salaries and benefits and the contract with a private accounting firm to conduct the statutorily required audit of NASA's financial statements consume 91 percent of the OIG annual budget. The budget funds an additional three Full-Time Equivalent (FTE) for expanded OIG activities in support of NASA's lunar program, known as Artemis, and to cover increased costs when a new contract is awarded for the financial statement audit.

In addition, the budget funds OIG payroll and benefits, including retirement costs, a 1 percent increase in base pay for civilian employees in 2021, and increases in employee awards for FY 2021. The OIG is a personnel-driven organization with our salaries and benefits representing 84 percent of our budget. Consequently, it is critical that OIG maintain sufficient staffing to carry out the oversight mission.

Additionally, OIG plans to award a new contract to a private accounting firm for the statutorily required annual audit of NASA's financial statements. The current vendor provided its services at a lower price (compared to similar previous contracts), a reduction in costs that OIG does not expect to continue with firms currently competing for the new five-year contract. Specifically, from FY 2005 to FY 2014, the OIG paid an average annual cost of $3 million for the financial statement contract compared to the $2.4 million average cost for the contract expiring in FY 2020.

For FY 2021, OIG is requesting all funding be deemed two-year funding. This change is consistent with other NASA appropriations – that is, the OIG is the only NASA component lacking two-year budget authority – and will allow the OIG to streamline its financial, procurement, and other year-end processes within NASA's centralized systems to more efficiently carry out its oversight mission. It will also provide efficiencies in hiring for an organization that is 84 percent salaries and benefits. Two-year funding will give OIG the flexibility to more efficiently manage hiring and keep our workforce at stable levels in this era of multiple continuing resolutions. In Public Law 116-93, Consolidated Appropriations Act, 2020, the OIG received $500,000 of two-year funding.

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[1] *This number includes $500,000 for staff training and $100,000 to support the Council of Inspectors General on Economy and Efficiency (CIGIE). In accordance with Public Law 110-409, the Inspector General Reform Act of 2008, the Inspector General certifies that these amounts are sufficient to satisfy all training requirements and contributions to CIGIE.*

INSPECTOR GENERAL

ACHIEVEMENTS IN FY 2019

In FY 2019, the OIG issued 15 audit products containing 79 recommendations for improvement and identifying approximately $276 million in potential savings for NASA. Audit products included reports examining NASA's:

- Management of the Space Launch System Stages Contract;
- Progress With Environmental Remediation Efforts at the Santa Susana Field Laboratory;
- Oversight of the Agency Technology Transfer Process;
- Success in Controlling Cost and Mitigating Risks for the Europa Mission;
- Actions to Identify and Account for Historic Real and Personal Property;
- Strategy for Maintaining Heliophysics Science Capabilities and Missions; and
- Cybersecurity Practices at the Jet Propulsion Laboratory.

In FY 2019, OI investigated a wide variety of criminal and administrative matters involving procurement fraud, theft, counterfeit parts, ethics violations, and computer intrusions leading to more than $75.6 million in criminal, civil, and administrative penalties and settlements with approximately $6.2 million of these funds returned directly to NASA. Overall, OI's efforts in FY 2019 resulted in 34 indictments, 24 convictions, 8 civil settlements, 32 administrative actions, and 19 suspensions or debarments. Examples of OI's work over the past year include:

- A multi-year joint investigation by NASA OIG, Defense Criminal Investigative Service (DCIS), and the Federal Bureau of Investigation (FBI) resulted in a lab supervisor of a NASA subcontractor pleading guilty to mail fraud for his participation in a decade-long scheme to defraud NASA and the Missile Defense Agency. The criminal behavior involved the fraudulent alteration of material properties test results for parts manufactured for use in rockets and military hardware. As part of the guilty plea, the supervisor admitted that he trained and directed lab technicians to falsify mechanical properties test results for extrusions (metal) used in rockets and military hardware that failed to meet industry standards. The extrusions were believed to be the cause for the loss of two NASA satellite missions valued in excess of $580 million. The supervisor also admitted that the NASA subcontractor and others made over 4,000 alterations on aluminum extrusion test results, which allowed the subcontractor to gross more than $6.8 million in total sales based on the altered test results. The supervisor was sentenced to 37 months imprisonment, two years of supervised release, and ordered to pay $170,000 in restitution. As a result of the investigation, the NASA subcontractor entered into a global settlement resolving civil and criminal claims whereby the company agreed to pay $34.1 million in combined restitution to NASA, the Missile Defense Agency, and commercial customers. The subcontractor also agreed to forfeit $1.8 million in ill-gotten gains. The NASA subcontractor and its parent company agreed to plead guilty to one count of mail fraud, and the parent company entered into a deferred prosecution agreement.
- As the result of a joint investigation by the NASA OIG, Defense Contract Audit Agency (DCAA), DCIS, Naval Criminal Investigative Service, U.S. Air Force Office of Special Investigations, and Department of Energy (DOE) OIG, a Delaware company and one of its co-owners agreed to pay $2.75 million in a civil settlement to resolve allegations the company mischarged labor costs and falsely certified work it performed by duplicating the same work on multiple Small Business Innovation Research (SBIR)/Small Business Technology Transfer contracts.

- Based on a Qui Tam filed with the Department of Justice and an investigation by NASA OIG and DCIS, a major parts supplier agreed to pay $11 million in a civil settlement to resolve claims it charged the Government for various electrical components that were not manufactured and/or screened properly. The affected components were used by NASA and other Government agencies, though no resulting failures were identified.
- Following a joint investigation by the NASA, National Science Foundation (NSF), and DOE OIGs, the University of Puerto Rico agreed to pay more than $1.77 million in a civil settlement to resolve claims it misused grant funds. Although the institution certified its labor costs to each agency, the investigation revealed the costs were charged incorrectly.
- A joint investigation by the NASA OIG, DCAA, DCIS, Department of Health and Human Services (HHS) OIG, National Science Foundation OIG, and DOE OIG revealed the University of Wisconsin-Madison participated in rebate and discount programs with supply and equipment vendors that generated rebates and discounts through purchase cards and service centers. In violation of OMB cost principles, the university failed to credit the rebates and discounts associated with these purchases to the federal awards. The university agreed to pay $1.5 million in a civil settlement to resolve claims that it violated the False Claims Act by failing to properly account for rebates and credits to reduce costs allocable to federal grants and awards.
- During the previous semiannual reporting period, four small businesses and their owner were charged with wire fraud and conspiracy to commit wire fraud for obtaining separate federal funding to conduct the same research on multiple SBIR contracts. The owner and three of the companies pled guilty to the charges and agreed to pay restitution of nearly $1.1 million. The owner entered into a pretrial diversion program and was sentenced to two years of probation and 80 hours of community service.
- Following an investigation by NASA OIG, a Kennedy Space Center contractor agreed to pay $500,000 to settle claims that it violated the False Claims Act by failing to meet Small Business Administration requirements for labor participation and work performance over a three-year period.
- As a result of a joint investigation by the NASA OIG and the Small Business Administration OIG, a small business based in Cleveland, Ohio agreed to pay $490,710 in a civil settlement to resolve allegations that it engaged in capabilities misrepresentation to secure NASA contracts, and then outsourced most of its business.

WORK IN PROGRESS IN FY 2020

In the first three months of FY 2020, the OIG has issued audit reports examining NASA's management of security operations processes and programs; plans and progress for safely transporting astronauts to the International Space Station using commercial carriers; and compliance with the Federally mandated Digital Accountability and Transparency (DATA) Act. During the remainder of the fiscal year, the OIG will examine development of Mobile Launchers; Distributed Active Archive Data Centers; Earth Science portfolio of projects and missions; storage and disposal of hazardous materials; and the Orion multipurpose crew vehicle.

Ongoing OI work includes proactive initiatives designed to identify acquisition and procurement fraud schemes. Additionally, representatives from both OI and OA are working together to use the OIG's advanced data analytics capabilities to help identify indicators of potential fraudulent activity.

INSPECTOR GENERAL

KEY ACHIEVEMENTS PLANNED FOR FY 2021

In FY 2021, the OIG will continue to focus its audit work on NASA's top management and performance challenges identified in our November 2019 report. Specifically, the OIG plans to undertake work in the following areas:

- Landing Humans on the Moon by 2024
  - Acquisition Strategy for Lunar Missions
  - Mitigation of Risks Arising from the Transition from ISS to Gateway Operations
  - Partnership with the European Space Agency in developing additional Orion Service Modules
- Improving Management of Major Projects
  - Impact of 5G Rollout on Weather Satellite Data Collection Efforts
  - Chandra X-ray Observatory
  - Astrophysics Portfolio
  - Management and Oversight of Johns Hopkins University's Applied Physics Laboratory
- Attracting and Retaining a Highly Skilled Workforce
  - Acquisition Workforce
  - Mishap Information System
- Sustaining a Human Presence in Low Earth Orbit
  - Efforts to Stimulate Commercialization of Low Earth Orbit
  - Management and Utilization of the International Space Station
  - Commercial Crew Program
  - Efforts to Mitigate the Risks from Orbital Debris
- Improving Oversight of Contracts, Grants, and Cooperative Agreements
  - Management of Universities Space Research Association contracts, grants and cooperative agreements
  - SEWP Awards and Novation Agreements
  - Review of Institutes Established by the Space Technology Mission Directorate
  - Management of International Space Station Operations and Maintenance Contracts
- Addressing Long-standing Information Technology Governance and Security Concerns
  - Agency Cybersecurity Protections
  - Management of the Deep Space Network
- Sustaining Infrastructure and Facilities
  - Construction of Facilities across NASA field sites
  - Environmental Remediation Efforts at NASA Facilities

OIG will also continue oversight in a variety of Financial Management and Quality Control areas to include:

- Improper Payments Information Act Compliance;
- Desk and Quality Control Reviews of Selected Single Audit Reporting Packages;
- Oversight of Financial Statement Audit;
- Reviews of Selected NASA Exchange Audits;
- Risk Assessment of Purchase and Travel Card Programs;
- Management of Non-reimbursable Agreements; and

- Federal Information Security Modernization Act.

Critically, as part of a broader antifraud effort, FY 2021 funding will support an increase in the number of public audit reports produced and will help provide support in a new area of oversight – auditing small grantees.

From an investigative perspective, the FY 2021 request will continue support for investigations of cybercrime, fraud, waste, abuse, and misconduct related to NASA programs, projects, personnel, operations, and resources.

Given the important role of NASA's contracting practices in returning humans to the Moon on an expedited schedule, the majority of OIG's proactive initiatives focus on acquisition activities that are susceptible to procurement fraud schemes. Examples of ongoing proactive initiatives that will continue to be active throughout FY 2021 include the following:

- A project initiated to monitor and aggregate data related to NASA's Artemis program in an attempt to identify indications of fraud on the part of prime contractors and subcontractors;
- A project that will develop actionable information pertaining to individuals, businesses, or other parties that supply substandard, counterfeit, or non-conforming parts to NASA or its contractors and suppliers;
- A project initiated in conjunction with the Financial Crimes Enforcement Network (FinCEN), other OIGs, and federal law enforcement partners that will assess suspicious financial activities involving Government employees, contractors, and grant recipients in an attempt to identify potential corruption (e.g., bribery and kickback schemes, conflicts of interest);
- A project that will identify indications of construction fraud schemes (e.g., false applications for payment, change order manipulation, billing for work not performed, collusion) impacting NASA's space and research centers; and
- A Criminal and Cyber Threat Intelligence (CaCTI) project that will identify instances where sensitive procurement information and other critical data may have been improperly exfiltrated from NASA computer systems.

In FY 2020 and FY 2021, OIG intends to place additional emphasis on proactive initiatives designed to identify antitrust crimes (e.g., bid-rigging conspiracies and related fraudulent schemes) that undermine competition in Government procurement, grant, and program funding. On November 5, 2019, the Department of Justice (DOJ) announced creation of a new Procurement Collusion Strike Force (PCSF). During FY 2021, the PCSF will continue to lead a national effort to protect taxpayer-funded projects from antitrust and related crimes. Prosecutors from DOJ's Antitrust Division and participating U.S. Attorneys' Offices, along with agents from NASA OIG, the FBI, and partner OIGs, will conduct outreach and training for procurement officials and government contractors on antitrust risks in the procurement process. The partnered prosecutors and investigators will jointly investigate and prosecute cases that result from their targeted proactive efforts.

Finally, FY 2021 funding will allow for the following mission support capabilities:

- Audit leadership training at the director and program manager levels;
- Participation in anti-fraud training and fraud-risk workshops;
- Agency fraud risk exposure analysis;
- Incurred cost audits of NASA subcontractors; and

- Third-party review of OIG's IT network and systems security.

Supporting Data

FUNDS DISTRIBUTED BY INSTALLATION

FUNDS BY MISSION BY NASA CENTER

Budget Authority ($ in millions)	FY 2021*
Deep Space Exploration Systems	40.8
Exploration Technology	38.7
LEO and Spaceflight Operations	30.3
Science	200.8
Aeronautics	143.7
STEM Engagement	0.0
Safety, Security, and Mission Services	213.0
Construction and Environmental Compliance and Restoration	81.6
Ames Research Center (ARC) Total	**748.9**
Deep Space Exploration Systems	2.1
Exploration Technology	21.4
LEO and Spaceflight Operations	0.1
Science	31.5
Aeronautics	108.0
STEM Engagement	0.0
Safety, Security, and Mission Services	65.8
Construction and Environmental Compliance and Restoration	24.5
Armstrong Flight Research Center (AFRC) Total	**253.4**
Deep Space Exploration Systems	187.2
Exploration Technology	63.2
LEO and Spaceflight Operations	68.7
Science	35.8
Aeronautics	189.5
STEM Engagement	0.0
Safety, Security, and Mission Services	219.1
Construction and Environmental Compliance and Restoration	39.0
Glenn Research Center (GRC) Total	**802.4**
Deep Space Exploration Systems	9.5
Exploration Technology	113.4
LEO and Spaceflight Operations	205.7
Science	2,244.0
Aeronautics	7.8
STEM Engagement	0.0
Safety, Security, and Mission Services	399.3
Construction and Environmental Compliance and Restoration	22.1
Goddard Space Flight Center (GSFC) Total	**3,001.8**

FUNDS DISTRIBUTED BY INSTALLATION

Budget Authority ($ in millions)	FY 2021*
Deep Space Exploration Systems	8.7
Exploration Technology	30.1
LEO and Spaceflight Operations	183.7
Science	1,386.2
STEM Engagement	0.0
Safety, Security, and Mission Services	10.0
Construction and Environmental Compliance and Restoration	31.6
Jet Propulsion Laboratory (JPL/NMO) Total	**1,650.3**
Deep Space Exploration Systems	2,037.3
Exploration Technology	21.0
LEO and Spaceflight Operations	3,165.7
Science	51.4
STEM Engagement	0.0
Safety, Security, and Mission Services	353.2
Construction and Environmental Compliance and Restoration	30.9
Johnson Space Center (JSC) Total	**5,659.4**
Deep Space Exploration Systems	412.4
Exploration Technology	11.1
LEO and Spaceflight Operations	174.7
Science	264.6
Aeronautics	0.0
STEM Engagement	0.0
Safety, Security, and Mission Services	379.3
Construction and Environmental Compliance and Restoration	44.0
Kennedy Space Center (KSC) Total	**1,286.0**
Deep Space Exploration Systems	29.0
Exploration Technology	40.7
LEO and Spaceflight Operations	1.3
Science	253.2
Aeronautics	238.2
STEM Engagement	0.0
Safety, Security, and Mission Services	273.5
Construction and Environmental Compliance and Restoration	29.6
Langley Research Center (LaRC) Total	**865.5**
Deep Space Exploration Systems	2,170.0
Exploration Technology	55.0
LEO and Spaceflight Operations	144.6
Science	166.5
STEM Engagement	0.0
Safety, Security, and Mission Services	467.5
Construction and Environmental Compliance and Restoration	65.4
Marshall Space Flight Center (MSFC) Total	**3,069.0**

FUNDS DISTRIBUTED BY INSTALLATION

Budget Authority ($ in millions)	FY 2021*
Deep Space Exploration Systems	3,814.7
Exploration Technology	1,181.9
LEO and Spaceflight Operations	179.2
Science	1,671.7
Aeronautics	131.7
STEM Engagement	0.0
Safety, Security, and Mission Services	571.0
Construction and Environmental Compliance and Restoration	151.6
Office of Inspector General	44.2
NASA Headquarters (HQ) and Inspector General (IG) Total	**7,746.0**
Deep Space Exploration Systems	50.1
Exploration Technology	1.9
LEO and Spaceflight Operations	33.5
Science	0.7
STEM Engagement	0.0
Safety, Security, and Mission Services	58.3
Construction and Environmental Compliance and Restoration	18.8
Stennis Space Center (SSC) Total	**163.2**
	25,246.0

* Sums may not add to Total due to rounding.

NOTE: Funds will not be fully distributed to Centers until after final acquisition decisions are made. Thus, Center FY 2021 allocations should not be considered final or directly comparable to prior year allocations.

CIVIL SERVICE FULL-TIME EQUIVALENT DISTRIBUTION

NASA's workforce continues to be one of its greatest assets for enabling missions in space and on Earth. The Agency remains committed to applying this asset to lead or participate in emerging space technology opportunities, collaborate and strengthen the capabilities of commercial partners, and communicate the strategic plans and results of Agency programs and activities. The civil service staffing levels in the FY 2021 Budget reflect NASA's requirements for scientists, engineers, researchers, managers, technicians, and the business operations workforce. The funding requested for NASA in FY 2021 provides compensation and benefits for civil service personnel at NASA Centers, Headquarters, and NASA-operated facilities, including a 1 percent raise in 2021.

NASA continually assesses and adjusts the mix of skills in its workforce to address changing mission priorities and to leverage industry partnerships, academic partnerships, and on- and near-site support contracts to optimize operations. A knowledgeable and well-trained civil service workforce is critical for conducting mission-essential work and overseeing contracted work in research and technology. To adjust the mix of skills where appropriate, Centers explore cross-mission retraining opportunities for employees, offer targeted buyouts in selected surplus skill areas, and identify, recruit, and retain a multi-generational workforce of employees who possess skills critical to the Agency.

CIVIL SERVICE FULL-TIME EQUIVALENT (FTE) DISTRIBUTION BY CENTER

DIRECT FUNDED

	Actual	Estimate	Request				
	FY 2019	**FY 2020**	**FY 2021**	**FY 2022**	**FY 2023**	**FY 2024**	**FY 2025**
ARC	1,144	1,126	1,120	1,120	1,120	1,120	1,120
AFRC	500	511	503	503	503	503	503
GRC	1,505	1,489	1,478	1,478	1,478	1,478	1,478
GSFC	3,002	2,876	2,880	2,880	2,880	2,880	2,880
JSC	2,910	2,905	2,913	2,913	2,913	2,913	2,913
KSC	1,948	1,892	1,901	1,901	1,901	1,901	1,901
LaRC	1,741	1,771	1,758	1,758	1,758	1,758	1,758
MSFC	2,264	2,249	2,268	2,268	2,268	2,268	2,268
SSC	280	265	266	266	266	266	266
HQ	1,118	1,146	1,147	1,147	1,147	1,147	1,147
NSSC	-	-	-	-	-	-	-
NASA Total*	**16,412**	**16,230**	**16,234**	**16,234**	**16,234**	**16,234**	**16,234**
OIG	175	184	187	187	187	187	187

**Sums may not add to totals due to rounding*

NOTE: Funds will not be fully distributed to Centers until after final acquisition decisions are made. Thus, Center FY 2021 allocations should not be considered final or directly comparable to prior year allocations.

CIVIL SERVICE FULL-TIME EQUIVALENT DISTRIBUTION

CIVIL SERVICE FTE DISTRIBUTION BY CENTER

REIMBURSABLE FUNDED

	Actual	Estimate	Request				
	FY 2019	**FY 2020**	**FY 2021**	**FY 2022**	**FY 2023**	**FY 2024**	**FY 2025**
ARC	31	22	22	22	22	22	22
AFRC	35	15	15	15	15	15	15
GRC	14	3	3	3	3	3	3
GSFC	210	225	225	225	225	225	225
JSC	31	-	-	-	-	-	-
KSC	11	1	1	1	1	1	1
LaRC	17	15	15	15	15	15	15
MSFC	34	-	-	-	-	-	-
SSC	17	20	20	20	20	20	20
HQ	172	-	-	-	-	-	-
NSSC	-	179	179	179	179	179	179
NASA Total*	**572**	**480**	**480**	**480**	**480**	**480**	**480**
OIG	5	5	5	5	5	5	5

**Sums may not add to totals due to rounding*

NOTE: Funds will not be fully distributed to Centers until after final acquisition decisions are made. Thus, Center FY 2021 allocations should not be considered final or directly comparable to prior year allocations.

CIVIL SERVICE FULL-TIME EQUIVALENT DISTRIBUTION

FY 2021 FTE DISTRIBUTION BY ACCOUNT BY CENTER

	Science	Aeronautics	Exploration Technology	Deep Space Exploration Systems	LEO and Spaceflight Operations	STEM Engagement	Safety, Security, and Mission Services	Reimbursable / Working Capital Fund**	OIG	NASA-Funded Total	Agency TOTAL
ARC	141	215	86	99	27	-	552	22	-	1,120	1,142
AFRC	89	190	16	6	1	-	201	15	-	503	518
GRC	74	315	122	220	124	-	623	3	-	1,478	1,481
GSFC	1,183	-	109	36	131	-	1,421	225	-	2,880	3,105
JSC	32	-	55	792	1,201	-	833	-	-	2,913	2,913
KSC	9	-	49	593	423	-	827	1	-	1,901	1,902
LaRC	181	441	118	120	4	-	894	15	-	1,758	1,773
MSFC	133	-	100	853	204	-	978	-	-	2,268	2,268
SSC	-	-	6	66	40	-	154	20	-	266	286
HQ	20	-	8	-	-	-	1,119	-	-	1,147	1,147
NSSC	-	-	-	-	-	-	-	179	-	-	179
NASA Total*	**1,862**	**1,161**	**669**	**2,785**	**2,155**	**-**	**7,602**	**480**	**-**	**16,234**	**16,714**
OIG	-	-	-	-	-	-	-	5	187	187	192

**Sums may not add to totals due to rounding*

***Includes 179 FTE funded by Working Capital Fund; and 301 FTE funded by reimbursable customers*

NOTE: Funds will not be fully distributed to Centers until after final acquisition decisions are made. Thus, Center FY 2021 allocations should not be considered final or directly comparable to prior year allocations.

WORKING CAPITAL FUND

NASA established the Working Capital Fund (WCF) to satisfy specific recurring needs for goods and services through use of a business-like buyer and seller approach under which NASA's WCF entities provide goods or services pursuant to contracts and agreements with their customers. The overarching aim of WCF is to promote economy, efficiency, and accountability with fully reimbursed rates and by focusing on streamlining operations, measuring performance, and improving customer satisfaction.

NASA's WCF is comprised of four entities:

- NASA Shared Services Center (NSSC);
- Solutions for Enterprise-Wide Procurement (SEWP) Government-Wide Acquisition Contract;
- Information Technology (IT) Infrastructure Integration Program (I3P); and
- National Center for Critical Information Processing and Storage (NCCIPS).

WORKING CAPITAL FUNDS BUDGET SUMMARY

	Actual	Estimate	Request
Spending Authority from Offsetting Collections ($ millions)	**FY 2019**	**FY 2020**	**FY 2021**
NSSC	74	74	88
SEWP	20	27	29
I3P	360	407	398
NCCIPS	43	23	43
Total New Spending Authority	**496**	**531**	**558**
Unobligated Brought Forward, Oct. 1	14	30	38
Recoveries of Prior Yr. Unpaid Obligations	2	8	8
Total Budgetary Resources	**512**	**569**	**604**
NSSC	71	75	88
SEWP	19	27	29
I3P	361	407	398
NCCIPS	31	23	43
Total Obligations	**482**	**531**	**558**
Unobligated Balance (end-of-year)*	**30**	**38**	**46**

**Unobligated balance end-of-year is budgetary resources less obligations*

NASA SHARED SERVICES CENTER (NSSC)

NSSC opened in March 2006 to provide centralized administrative processing services and customer contact center operations for support of human resources, procurement, financial management, Agency IT, and Agency business support services. NASA established NSSC, a function under the NASA Headquarters Mission Support Directorate, as a public/private partnership. NSSC has awarded its major business management and IT services contract to CSRA (Computer Sciences Corporation merged with SRA International). Typical expenditures are related to civil service workforce, support contractor, other direct procurements, and Agency training purchases.

NSSC is located on the grounds of Stennis Space Center and operates in a manner that provides for transparency and accountability of costs and services. NASA has reduced its administrative costs through centralized processing at NSSC. The work performed by NSSC reduces duplicative efforts and increases cost efficiencies.

NSSC's revenue streams include funding from the NASA Centers, Mission Directorates, and various NASA mission support offices. During FY 2020, NSSC will continue to offer similar services as in FY 2019 expanding the scope to include one additional service, Training Administration. In addition to expanding the scope, NSSC will also be making minor expansions to existing services. During FY 2021, NSSC will continue to offer similar services as in FY 2020.

SOLUTIONS FOR ENTERPRISE-WIDE PROCUREMENT (SEWP)

SEWP refers to operations related to the Government-Wide Acquisition Contract that was established under the authority of section 5112 of the Information Technology Management Reform Act (40 U.S.C. 1412(e)), enacted in 1996, under which NASA is designated by the Office of Management and Budget (OMB) as a Federal Government Executive Agent for SEWP contracts.

SEWP was established as a WCF entity to allow all Federal agencies use of a best value tool to purchase IT product solutions and services. Under this approach, the buying power of Federal Agencies is combined to acquire best value for IT products and services more efficiently. Typical acquisitions include a wide range of advanced technologies such as UNIX-Linux and Windows-based desktops and servers, along with peripherals, network equipment, storage devices, security tools, software, and other IT products and product-based solutions.

SEWP promotes aggressive pricing using online tools to obtain multiple, competitive quotes from vendors. On average for FY 2020, SEWP quotes have a 20 percent savings for any Federal customer using SEWP contracts. In addition, SEWP offers a low surcharge to recover NASA's costs to operate the program with an average 0.36 percent fee as compared to the Government standard of 0.75 percent. SEWP revenue is generated solely from the surcharge fees on all transactions processed. For FY 2019, the Federal Government is projected to save about $19 million in fees, based on the difference between General Services Administration (GSA) and SEWP surcharge fees.

IT INFRASTRUCTURE INTEGRATION PROGRAM (I3P)

WCF operations supporting I3P began in early FY 2012. WCF enables I3P to improve the efficiency and economy in which contract services and management are provided to support NASA's IT strategic initiatives and to increase visibility into NASA's IT budget and expenditures. Under I3P, NASA has consolidated 19 separately managed contracts into 5 centrally managed ones described as follows:

- The Enterprise Applications Service Technologies contract supports Agency Applications Office (AAO) applications hosted by MSFC. The AAO operates and maintains a broad spectrum of NASA's enterprise applications, with an emphasis on fully integrating business process expertise with application and technical knowledge. A small team of civil servants and support contractors sustain operations, implement new applications and capabilities, and provide business readiness support to the stakeholders and end-users.

- The NASA Integrated Communications Services contract provides wide and local area network, telecommunications, video, and data services hosted at MSFC.
- The Web Enterprise Service Technologies contract provides public Web site hosting, Web content management and integration, and search services. GSFC and ARC host these services.
- The Agency Consolidated End-User Services contract provides program management, provisioning, and support of desktops, laptops, cell phones, personal digital assistants, office automation software, and video conferencing. NSSC hosts these services.
- The Networx Telecommunications Circuits contract provides telecommunication services including, tele-conferencing services, core circuit services, mission network services, and regional circuit services hosted at MSFC.

I3P's consolidated contracting approach benefits NASA by providing cost saving opportunities, such as the reduction in administrative burden involved with the business management of contracts and a significant reduction in procurement request transaction volume. Other I3P benefits include the streamlining budgeting, funding, and costing of I3P services; achieving transparency through the provision of detailed customer monthly billings; and providing consolidated, consistent reporting of Agency-wide consumption of I3P-related goods and services.

I3P is unique in that revenue streams and expenditures are limited to contract costs for its five service contracts. Revenue streams include funding from the NASA Centers, NASA Mission Directorates, and various NASA mission support offices. As reflected in the FY 2020 anticipated funding level, the I3P WCF will continue to offer similar services as in FY 2019. During FY 2021 NSSC will continue to offer similar services as in FY 2020 with no significant scope changes anticipated.

NATIONAL CENTER FOR CRITICAL INFO. PROCESSING AND STORAGE (NCCIPS)

NCCIPS is a federal shared services data center (as defined by the Uptime Institute) designed for sensitive and secure processing and storage. NCCIPS is a 200,000 sq. ft. secure data center facility on a 64-acre campus within the Stennis Space Center. NCCIPS offers federal customers collocation services from a state-of-the-art data center. NCCIPS offers 24x7x365 availability at a Tier III level, with complete redundancy in the electrical distribution system from the national grid to the rack level.

NCCIPS provides the following infrastructure/services:

- Four Layer Security – Buffer Zone/perimeter fencing, armed security at all gates, roving guards, and NCCIPS Guards (Internal NCCIPS Security Systems)
- Two separate National Power Grid feeds to SSC and three separate power feeds available to NCCIPS
- Power infrastructure is fully redundant from National Power Grid down to the racks on the floor
- Expert IT staff with a proven track record of uninterrupted service
- 24x7 facility operations staff monitoring
- Tier III redundant (N + 1) power from two national grids with diesel generator backup
- Robust network infrastructure with multiple, discreet communication paths
- FE-25 clean agent fire suppression

The NASA WCF provides NASA with a mechanism to collect amounts sufficient to finance continuing operations, acquire capital assets, and adjust for prior year results of operations, in addition to normal operating expense recovery at NCCIPS. NCCIPS WCF benefits NASA and its customers by:

- Enabling funds to be collected over time and (once earned) used for new equipment and technology;
- Allowing the NSSC to incorporate a level equipment replacement, maintenance and technology refresh cost into client rates;
- Helping to normalize rates charged to NCCIPS clients from year to year, as the need for facility repairs, infrastructure upgrades, and routine equipment maintenance increases, thus enabling NCCIPS clients to maintain their appropriation funding without incurring potentially large unplanned expenses;
- Facilitating NCCIPS business opportunities for new clients; and
- Reducing the probability of hardware failure within the NCCIPS operational environment.

NCCIPS' revenue streams include funding from the NASA SSC and NSSC Centers and External Federal Agencies such as Department of Homeland Security (DHS), U.S. Navy Department of Defense Supercomputing Resource Center (NDSRC), Government Services Administration (GSA), Department of Transportation Maritime (DOT-MARAD), Department of Transportation OCIO (DOT-OCIO) and Department of Housing and Urban Development (HUD). During FY 2020, NCCIPS will continue to offer similar services as in FY 2019 with no significant scope changes anticipated. During FY 2021, NCCIPS will continue to offer similar services as in FY 2020 with no significant scope changes anticipated.

BUDGET BY OBJECT CLASS

Code	FY 2021 Estimated Direct Discretionary Obligations ($ millions) Object Class	Deep Space Exploration Systems	Exploration Research and Technology	LEO and Spaceflight Operations	Science	Aeronautics	STEM Engagement	Safety, Security, and Mission Services	Construction & Environmenta Compliance & Restoration	Office of Inspector General	NASA Total
11.1	Full-time permanent	400	90	256	252	156	-	973	-	23	2,150
11.3	Other than full-time permanent	5	3	3	3	4	-	22	-	-	40
11.5	Other personnel compensation	3	-	2	1	-	-	39	-	-	45
11.8	Special Personal Services Payments	2	-	-	-	-	-	-	-	-	-
11.9	*Subtotal Personnel Compensation*	*410*	*93*	*261*	*256*	*160*	-	*1,034*	-	*23*	*2,235*
12.1	Civilian personnel benefits	189	44	83	81	60	-	320	-	10	787
13	Benefits to former personnel	2	-	-	-	-	-	1	-	-	3
	Total Personnel Compensation & Benefits	**601**	**137**	**344**	**337**	**220**	**-**	**1,355**	**-**	**33**	**3,025**
21	Travel & transport. of persons	25	9	13	23	8	-	27	-	1	106
22	Transportation of things	2	3	1,692	9		-	1	-	-	1,707
23.1	Rental payments to GSA	41	-	-	-	-	-	-	-	-	41
23.2	Rental payments to others	-	-	2	4	-	-	23	-	-	29
23.3	Communications, utilities & misc.	-	-	9	6	3	-	89	2	-	109
24	Printing & reproduction	-	-	-	1	-	-	3	-	-	4
25.1	Advisory & assistance services	658	71	90	93	27	-	261	28	-	1,228
25.2	Other services	80	74	153	126	31	-	258	61	5	788
25.3	Other purchases of goods & services from Government accounts	66	68	67	236	7	-	50	61	1	556
25.4	Operation & maintenance. of facilities	220	7	39	22	45	-	220	63	-	616
25.5	Research & development contracts	5,908	1,035	1,466	4,449	308	-	173	11	-	13,350
25.6	Medical care	-	-	-	-	-	-	8	-	-	8
25.7	Operation & maintenance of equipment	301	43	240	123	58	-	421	24	2	1,212
26	Supplies & materials	70	19	16	33	18	-	17	-	-	173
31	Equipment	91	16	13	38	31	-	65	1	1	256
32	Land & structures	578	-	6	1	1	-	17	288	-	891
41	Grants, subsidies, & contributions	121	96	37	806	62	-	22	-	-	1,144
	Other Object Classes	**8,161**	**1,441**	**3,843**	**5,970**	**599**	**-**	**1,655**	**539**	**10**	**22,218**
	NASA Total, Direct	**8,762**	**1,578**	**4,187**	**6,307**	**819**	**-**	**3,010**	**539**	**43**	**25,244**

Totals may not add due to rounding

NOTE: The table only reflects the FY 2021 request and does not include remaining funding from previous direct or supplemental appropriations.

STATUS OF UNOBLIGATED FUNDS

The table below displays actual and estimated unobligated balances of direct and reimbursable budget authority in each NASA account at the end of each fiscal year. The data is non-comparable, or based solely on an appropriation account's activity or projected activity with no adjustment to the FY 2019 or FY 2020 amounts to make them comparable to the budget structure underlying the FY 2021 request.

UNOBLIGATED FUNDS SUMMARY BY APPROPRIATIONS ACCOUNT

Budget Authority ($ millions)	Unobligated Balances Sept. 30, 2019	Estimated Unobligated Balances Sept. 30, 2020	Estimated Unobligated Balances Sept. 30, 2021
Deep Space Exploration Systems	198	251	304
Exploration Technology	67	79	91
LEO and Spaceflight Operations	98	425	752
Science	745	749	823
Aeronautics	27	39	51
STEM Engagement	9	11	13
Safety, Security, and Mission Services	781	829	877
Construction and Environmental Compliance and Restoration	319	393	467
Office of Inspector General	0	0	1
Working Capital Fund	30	38	46
Science, Space, and Technology Education Trust Fund	1	1	1
Total NASA	2,275	2,815	3,426

**Totals may not add due to rounding*

Note: Table excludes unobligated balances in NASA's legacy accounts (80-0110, 80-0111, 80-0112, and 80-0114) that were rescinded in FY 2019.

REIMBURSABLE ESTIMATES

Reimbursable agreements are agreements where the NASA costs associated with the undertaking are borne by the non-NASA partner. NASA undertakes reimbursable agreements when it has equipment, facilities, and services that it can make available to others in a manner that does not interfere with NASA mission requirements. Reimbursable agreements are executed under various legal authorities including:

- National Aeronautics and Space Act of 1958, as amended [P.L. 85–568] - Space Act Agreements (SAAs) and Enhanced Use Leasing (EUL) authority [incorporated through P.L. 108-7].
- Commercial Space Launch Act [P.L. 98-575] – authority to outsource the use of its launching facilities and services to private companies.
- National Historic Preservation Act (NHPA) [P.L. 89-665] – Leasing authority for historic property.
- Government Employees Training Act [P. L. 85-507] – authority to conduct employee training for other government organizations.
- Economy Act [P.L. 31–15359] – authority for agencies to obtain supplies or services from another agency.

The agreements are transacted in three accounts (SSMS, CECR, and OIG). Most of the work is managed by a specific NASA Center and performed by the relevant Mission Directorate or Office program at the Center (i.e., Aeronautics, Human Exploration and Operations, Exploration Technology, Mission Support, Office of STEM Engagement, and Office of Inspector General). Examples include use of NASA-operated wind tunnel test facilities and rocket test stand facilities by other Government agencies or private sector users. Some larger agreements and those that involve multiple Centers or Mission Directorates are managed by NASA headquarters. For example, NASA serves as the acquisition agent for the *GOES* series of satellites operated by the National Oceanographic and Atmospheric Administration.

The table below presents the budget authority for NASA's reimbursable work. As most reimbursable requests to NASA do not occur until the year of execution, the FY 2020 and FY 2021 estimates are based on anticipated reimbursable agreements reported by NASA Centers and headquarters units.

REIMBURSABLE BUDGET AUTHORITY BY APPROPRIATIONS ACCOUNT

($ millions)	Actual	Estimate	Estimate
	FY 2019	**FY 2020**	**FY 2021**
Safety, Security, and Mission Services (including EUL and NHPA)	1,823	2,344	1,932
Construction and Environmental Compliance and Restoration (including EUL)	22	21	21
Office of Inspector General	1	2	2
Total	**1,846**	**2,367**	**1,955**

ENHANCED USE LEASING

In 2003, Congress authorized NASA to enter into leasing arrangements at two Centers. In 2007 and 2008, Congress expanded that authority such that NASA may enter into leasing arrangements at all Centers. Enhanced Use Leasing (EUL) is currently authorized through December 31, 2021. EUL revenues help NASA maintain critical facilities and address deferred maintenance challenges as well as support Centers' revitalization plans. Additionally, NASA's EUL Authority supports important relationships with industry, academia, and non-profit organizations.

After deducting the costs of administering the leases, Centers are permitted to retain 65 percent of net receipt revenue. The balances are made available to NASA for use Agency-wide. These funds are in addition to annual appropriations. The table below depicts the estimated FY 2021 EUL expenses and revenues. The amounts identified under Capital Asset Account Expenditures may be adjusted between projects listed based on actual contract award. There are no civil servants funded from EUL income.

SUMMARY OF PROJECTED FY 2021 EUL ACTIVITY

FY 2021 EUL Expenses and Revenues ($ Thousands)	ARC	GSFC	JPL(NMO)	MSFC	SSC	KSC	Agency	Total
Base Rent	12,537.0	48.2	100.5	115.0	88.1	1,447.8	3,000.0	17,336.6
Institutional Support Income	899.5	6.0		321.7	8.9	88.9		1,325.0
Additional Reimbursable Demand Services Requested by Lessees (including overhead)	4,542.4				18.5	28.5	749.0	5,338.4
Total Lease Income (L Funds) - Program Year 2021	**17,978.9**	**54.2**	**100.5**	**436.7**	**115.5**	**1,565.2**	**3,749.0**	**24,000.0**
Institutional Support Costs	-899.5	-6.0		-29.1	-7.0	-88.9	0.0	-1,030.5
Lease Management and Administration	-1,051.5			-149.9	-1.9		0.0	-1,203.3
Tenant Building Maintenance and Repair	-1,064.9						-2,000.0	-3,064.9
Cost to Fulfill Reimbursable Demand Services (including overhead)	-4,542.4	0.0	0.0	0.0	-18.5	-28.5	-749.0	-5,338.4
Total Cost Associated with Leases - Program Year 2021	**-7,558.3**	**-6.0**	**0.0**	**-179.0**	**-27.4**	**-117.4**	**-2,749.0**	**-10,637.1**
Net Revenue from Lease Activity - Program Year 2021	**10,420.6**	**48.2**	**100.5**	**257.7**	**88.1**	**1,447.8**	**1,000.0**	**13,362.9**
Projected Balance, Capital Asset Account - Prior Program Years	**541.5**	**0.0**	**125.5**	**78.0**	**210.0**	**753.1**	**10,324.7**	**12,032.8**
Net Revenue from Lease Activity Retained at Center - Program Year 2021	**6,773.4**	**31.3**	**65.3**	**167.5**	**57.3**	**941.1**	**5,327.0**	**13,362.9**
Total Available, Capital Assest Account - All Program Years	**7,314.9**	**31.3**	**190.8**	**245.5**	**267.3**	**1,694.2**	**15,651.7**	**25,395.7**
Planned Maintenance, Various Buildings	-6,750.4					-500.0		-7,250.4
Replace Roofs on Varous Buildings								0.0
Misc. Renewable Solar Energy Expansion						-500.0		
Replace Bldg 1 main steam condensate piping								0.0
Upgrade Lighting Systems (Green Project)				-160.0				-160.0
Energy and Sustainability Upgrades, Various Buildings (Stennis)					-55.0			-55.0
Energy and Sustainability Upgrades, Various Buildings (Various Centers)							-6,934.6	-6,934.6
Capital Asset Account Expenditures	**-6,750.4**	**0.0**	**0.0**	**-160.0**	**-55.0**	**-1,000.0**	**-6,934.6**	**-14,900.0**
Capital Asset Account Ending Balance	**564.5**	**31.3**	**190.8**	**85.5**	**212.3**	**694.2**	**8,717.1**	**10,495.7**
In Kind Activity	**175.0**	**0.0**	**0.0**	**0.0**	**0.0**	**39.1**	**0.0**	**214.1**

ENHANCED USE LEASING

DEFINITIONS

Base Rent

Revenue collected from the tenant for rent of land or buildings lease.

Institutional Support Costs

Cost for institutional shared services, such as fire, security, first responder, communications, common grounds, road, and infrastructure maintenance, as well as routine administrative support and management oversight (e.g., environmental).

Total Lease Income

Total gross proceeds from EUL activities including expenses due to renting NASA property.

In-Kind Activity

Consideration accepted in lieu of rent payment (only applies to selected leases signed prior to January 1, 2009).

Reimbursable Demand Services

Services such as janitorial, communications, and maintenance that solely benefit the tenant and are provided for their convenience. There is no net income received by NASA, as these payments may only cover the costs of NASA and its vendors providing these services.

NATIONAL HISTORIC PRESERVATION ACT

The National Historic Preservation Act (NHPA) 54 U.S.C. §306121-306122 provides that:

> [(a) Notwithstanding any other provision of law, any Federal agency after consultation with the Council [the Advisory Council on Historic Preservation], shall, to the extent practicable, establish and implement alternatives for historic properties, including adaptive use, that are not needed for current or projected agency purposes, and may lease an historic property owned by the agency to any person or organization, or exchange any property owned by the agency with comparable historic property, if the agency head determines that the lease or exchange will adequately insure the preservation of the historic property.
>
> (b) The proceeds of any lease under subsection (a) may, notwithstanding any other provision of law, be retained by the agency entering into such lease and used to defray the costs of administration, maintenance, repair, and related expenses incurred by the agency with respect to such property or other properties which are on the National Register which are owned by, or are under the jurisdiction or control of, such agency. Any surplus proceeds from such leases shall be deposited into the Treasury of the United States at the end of the second fiscal year following the fiscal year in which such proceeds were received.
>
> (c) The head of any Federal agency having responsibility for the management of any historic property may, after consultation with the Advisory Council on Historic Preservation, enter into contracts for the management of such property. Any such contract shall contain such terms and conditions as the head of such agency deems necessary or appropriate to protect the interests of the United States and insure adequate preservation of historic property.]

In FY 2014, NASA established a program for leasing its historic properties based upon the NHPA authorities. Funds received from historic property leases are expended for purposes of operating, maintaining, and managing the properties, or for authorized demolition or removal of buildings. Federal workforce costs associated with executing the leasing program are funded from annual appropriations not leasing revenues.

The table below depicts the estimated amounts of anticipated NHPA expenses and revenues for FY 2021. NASA currently expects total rental income of approximately $24.4 million. Of the $24.4 million in total rental income, approximately $8.9 million represents net revenue from lease activities. The net revenue amount of $8.9 million will be used for historic building maintenance and repairs at ARC, as well as other properties throughout the Agency.

NATIONAL HISTORIC PRESERVATION ACT

FY 2021 NHPA Expenses and Revenues ($ thousands)	Ames Research Center
Base Rent	15,500.0
Security Deposit (Reissue)	-
Institutional Support Income	3,427.4
Cost to Fuflill Reimbursable Demand Services	5,560.8
Total Rental Income	**24,488.2**
Institutional Support Costs	(9,718.8)
Security Deposit (Reissue)	-
Lease Management and Administration	(284.1)
Reimbursable Demand Services Requested by Leasees	(5,560.8)
Total Cost Associated with Leases	**(15,563.7)**
Net Revenue from Lease Activity	**8,924.5**
Unobligated Proceeds Prior Years (as of 9/30/2020)	**-**
Deferred Maintenance for Buildings 2, 10, 15, 16, 17, 19, 20, 25, 26, N200, N226, N227, N234, N238 & N243	(1,663.7)
Restore Reliability of VMS Out-the-Window Cockpit Visual Infrastructure N243, Phase 2 of 2	(1,080.9)
Upgrade UPWT Main Drive Speed Control to Variable Frequency Drive - Design	(1,570.0)
Seismic Restraint of Arc Jet Steam Vacuum System Support, Phase 1 of 2 - Study	(200.0)
Reduce Fire Risk to Personnel N200	(1,000.0)
Restore Reliability of UPWT Main Drive Oil System - Design	(885.5)
Restore Reliability of UPWT 9X7 Centerbody Knuckle Sleeve	(2,524.4)
Capital Asset Account Expenditures	**(8,924.5)**
Capital Asset Account Ending Balance	**-**
In Kind Activity	**-**

NATIONAL HISTORIC PRESERVATION ACT

DEFINITIONS

Base Rent

Revenue collected from the tenant for rent of land or buildings.

Institutional Support Costs

Cost for institutional shared services such as fire, security, first responder, communications, common grounds, road, and infrastructure maintenance, and routine administrative support and management oversight (e.g., environmental).

Total Rental Income

Total gross proceeds from NHPA activities for expenses due to renting NASA property.

In-Kind

Consideration accepted in lieu of rent payment.

Reimbursable Demand Services

Services such as janitorial, communications, and maintenance that solely benefit the tenant and are provided for their convenience. There is no net income received by NASA, as these payments may only cover the costs of NASA and its vendors providing these services.

BUDGET FOR MICROGRAVITY SCIENCE

BUDGET FOR INTERNATIONAL SPACE STATION (ISS) RESEARCH

The Human Exploration and Operations Mission Directorate supports research which takes advantage of the unique environment of reduced gravity on the International Space Station (ISS). ISS Research is conducted in two broad categories: Exploration ISS Research and Non-Exploration ISS Research.

$ in millions	FY 2019 Actual	FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
Exploration ISS Research	$260	$249	$246	$241	$236	$236	$239
Non- Exploration ISS Research	$169	$155	$133	$130	$125	$124	$126
Total	**$429**	**$404**	**$380**	**$371**	**$360**	**$360**	**$366**
% of Non-Exploration to Total	39%	38%	35%	35%	35%	35%	35%

The amounts included for FY 2019 reflect actuals. FY 2020 through FY 2025 are reflective of NASA out-year planning.

FY 2019 reflects funding amounts specified in Public Law 116-006, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

The FY 2020 Operating Plan was not finalized at the time of Budget release. Therefore, only specifics marks from Public Law 116-93, Consolidate Appropriations Act, FY 2020, as well as projects in development, are included in the FY 2020 column.

Exploration ISS Research

Exploration ISS Research supports the Agency's need for improved knowledge about working and living in space to enable future long-duration human exploration missions. The Human Research Program provides research results that reduce risks to crew health and performance from prolonged exposure to reduced gravity, space radiation, and isolation during exploration missions. Research on the ISS is mitigating risks to humans in space and on Earth by conducting research in human health countermeasures, space human factors and habitability, behavioral health and performance, and exploration medicine, tools, and technologies. ISS Research investigates the underlying gravity-dependent phenomena in areas vital to the design of future space vehicles and systems: fire prevention, detection, and suppression; boiling and multiphase flow; capillary phenomena; and the response to the space environment of microbes, plants, and higher lifeforms. These applied research investigations will provide the necessary data for the future design of the following technology areas: life support systems, propellant storage, power generation, thermal control, and advanced environmental monitoring and control. Multi-User System Support (MUSS) is responsible for the integration of all ISS payloads including NASA, international partners, and non-NASA users and supports both Exploration and Non-Exploration ISS Research. This includes coordinating payload completion schedules, ISS mission schedules, and the space available on the launch vehicles. The Exploration ISS Research category in the table above includes funding for MUSS.

Non-Exploration ISS Research

NASA allocates at least 15 percent of the funds budgeted for ISS research to ground-based, free-flyer, and ISS life and physical science research that is not directly related to supporting the human space exploration program, in accordance with Section 204 of the NASA Authorization Act of 2005. The purpose is to ensure the effective use of the ISS in its capacity to support space-based basic and applied scientific research that can be advanced significantly through the use of the microgravity environment and provide broad national benefits. This budget supports basic ISS research in the fields of: physiological research, fluid physics, combustion science, atomic physics, cell science, materials science, and plant research. This research helps to sustain U.S. scientific expertise and capability in microgravity research and to identify new areas for participation by commercial entities or other government agencies. The Non-Exploration ISS Research category in the table above includes funding for the Center for the Advancement of Science in Space (CASIS), the Alpha Magnetic Spectrometer (AMS) and MUSS. CASIS is the organization selected by NASA to manage non-NASA use of the ISS U.S. National Laboratory. AMS is a particle physics and astrophysics experiment on the ISS that is searching for dark matter, anti-matter, and strange matter.

BUDGET FOR SAFETY OVERSIGHT

The following table provides the safety oversight budget request. This includes the Agency-wide surveillance functions as well as the project specific safety, reliability, maintainability, and quality assurance elements embedded within individual projects. NASA does not have a single safety oversight budget line item, but instead amounts are embedded in program, project, and mission support budgets.

BUDGET SUMMARY FOR SAFETY OVERSIGHT

	Actual	Estimate	Request				
Budget Authority ($ millions)	**FY 2019**	**FY 2020**	**FY 2021**	**FY 2022**	**FY 2023**	**FY 2024**	**FY 2025**
Safety and Mission Assurance	49.5	50.0	48.9	48.9	48.9	48.9	48.9
Institutional Operational Safety	38.0	37.7	37.4	37.4	37.4	37.4	37.4
SMA Technical Authority	51.0	52.8	53.3	53.3	53.3	53.3	53.3
Agency-Wide Safety Oversight	**138.5**	**140.5**	**139.6**	**139.6**	**139.6**	**139.6**	**139.6**
Program Specific*	**300.0**	**300.0**	**300.0**	**300.0**	**300.0**	**300.0**	**300.0**
NASA Total, Safety	**438.5**	**440.5**	**439.6**	**439.6**	**439.6**	**439.6**	**439.6**

* Estimated values

Agency-Wide Safety Oversight

Agency-level programs and activities that support the overarching NASA Safety and Mission Success program.

Safety and Mission Assurance

The Safety and Mission Assurance (S&MA) program administers and refines the pertinent policies, procedural requirements, and technical safety standards. The program participates in forums that provide advice to the Administrator, Mission Directorates, Program Managers, and Center Directors who are ultimately accountable for the safety and mission success of all NASA programs, projects, and operations. Specific program responsibilities include, but are not limited to, managing NASA’s Orbital Debris program, NASA’s Electronic Parts program, and the NASA Safety Center. The budget for the Safety and Mission Assurance is part of the Agency Technical Authority (ATA) program under the Safety, Security, and Mission Services (SSMS) mission account.

Institutional Operational Safety

NASA’s Institutional Operational Safety program is driven by the Office of Occupational Safety and Health Administration (OSHA) 29 CFR 1960, OSHA Standards, NASA Procedural Requirement (NPR) 8715.1A, NASA Occupational Safety and Health Programs, NPR 8715.3D, and NASA’s General Safety Program Requirements. The program includes: risk management, safety training, safety awareness, construction safety, the voluntary protection program, safety metrics and trend analysis, contractor insight/oversight, support to safety boards and committees, support to the emergency preparedness and fire safety programs, aviation safety, explosives and propellants safety, nuclear safety, radiation safety, confined space entry, fall protection, lifting devices, pressure vessel safety, hazard reporting and abatement systems, cryogenic safety, electrical safety requirements (lock out/tag out), facility systems safety, institutional safety policy development, visitor and public safety, institutional safety engineering, and a mishap prevention program including a reporting system and investigations. The Institutional Operational Safety program requires significant federal state and local coordination. The budget for Institutional Operation Safety is part of the Center Engineering, Safety, and Operations (CESO) program under the SSMS mission account.

S&MA Technical Authority

S&MA Technical Authority provides independent oversight of programs and projects in support of safety and mission success and is a key part of NASA's overall system of checks and balances. The S&MA Technical Authority program includes travel and labor only for all S&MA supervisors, branch chiefs or above and designated deputies. In addition, where the principal job function of a non-supervisory S&MA person consists of rendering authoritative decisions on S&MA matters relating to the design or operation of a program or project, that person's salary is included. Often, these positions are the lead S&MA managers for large programs where the decision-making process is nearly a full-time demand. This category does not include salaries for individuals who only occasionally work on an authority task; however, the program budget does include travel funds in direct support of these tasks when needed. The budget for S&MA Technical Authority is part of the CESO program under the SSMS mission account.

Program Specific

Project specific S&MA costs are included in individual project budgets. These costs include the technical and management efforts of directing and controlling the safety and mission assurance elements of the project. This incorporates the design, development, review, and verification of practices and procedures and mission success criteria intended to assure that the delivered spacecraft, ground system, mission operation, or payload meets performance requirements and function for their intended lifetimes.

PHYSICIANS' COMPARABILITY ALLOWANCE

Physicians' Comparability Allowance (PCA) Plan

Department and component:

National Aeronautics and Space Administration (NASA)

Purpose: The purpose of this document is to describe the agency's plan for implementing the Physicians' Comparability Allowance (PCA) program. Per 5 CFR 595.107, the Office of Management and Budget (OMB) must approve this plan prior to the agency entering into any PCA service agreement. Changes to this plan must be reviewed and approved by OMB in accordance with 5 CFR 595.107.

Reporting: In addition to the plan, each year, components utilizing PCA will include their PCA worksheet in the OMB Justification (OMBJ), typically in September. OMB and the Office of Personnel Management (OPM) will use this data for budget development and congressional reporting.

Plan for Implementing the PCA program:

1) Identify the categories of physician positions the agency has established are covered by PCA under § 595.103. Please include the basis for each category. If applicable, list and explain the necessity of any additional physician categories designated by your agency (for categories other than I through IV-B). List Any Additional Physician Categories Designated by Your Agency: Pursuant to 5 CFR 595.107, any additional category of physician receiving a PCA, not covered by categories I through IV-B, should be listed and accompanied by an explanation as to why these categories are necessary.

Number of Physicians Receiving PCAs by Category (non-add)	**Category of Physician Position**	**Covered by Agency** (mark "x" if covered)	**Basis for Category**
21	Category I Clinical Position	x	Difficulty recruiting and retaining: Physicians in this category perform both operational medical support that is mission-critical and provide medical subject matter expertise in the development of future programs, including Artemis, Gateway, and the Lunar Lander. Much of the work they do is inherently governmental, as it requires establishing requirements, both for spaceflight programs and for commercial offers in NASA procurements for spaceflight capabilities. These specialized physicians are often called on to evaluate commercial and international partner proposals for medical capabilities. These physicians also provide leadership in NASA's multilateral medical operations, representing NASA in multilateral fora. Civil Servant physicians are also required to provide oversight of key contract functions that support mission-critical activities.
0	Category II Research Position	N/A	N/A
0	Category III Occupational Health	N/A	N/A

PHYSICIANS' COMPARABILITY ALLOWANCE

Number of Physicians Receiving PCAs by Category (non-add)	Category of Physician Position	Covered by Agency (mark "x" if covered)	Basis for Category
0	Category IV-A Disability Evaluation	N/A	N/A
6	Category IV-B Health and Medical Admin.	x	Difficulty recruiting and retaining: Management physicians play a critical role in ensuring NASA's ability to meet its' ambitious goals of returning humans to the moon in 2024, expanding commercial access to space, and eventually sending humans out into the solar system. These physicians occupy positions that are primarily comprised of inherently governmental activities, including: supervision of other civil servant physicians; oversight of significant projects and programs, such as the Johnson Space Center (JSC) Clinic; providing independent oversight of NASA's health and medical activities through the Health and Medical Technical Authority; developing and assessing the risk associated with NASA standards that are applicable to all human spaceflight programs and NASA's commercialization activities; and serving as Chief Medical Officer at the Agency, Center, and Program levels to make ultimate determinations that affect Agency action and resources.

2) Explain the recruitment and retention problem(s) for each category of physician in your agency (this should demonstrate that a current need continues to persist). § 595 of 5CFR Ch. 1 requires that an agency may determine that a significant recruitment and retention problem exists only if all of the following conditions apply:
- Evidence indicates that the agency is unable to recruit and retain physicians for the category;
- The qualification requirements being sought do not exceed the qualifications necessary for successful performance of the work;
- The agency has made efforts to recruit and retain candidates in the category; and
- There are not a sufficient number of qualified candidates available if no comparability allowance is paid.

Number of Physicians Receiving PCAs by Category (non-add)	Category of Physician Position	Recruitment and retention problem
21	Category I Clinical Position	NASA physicians who receive PCA are located at JSC in Houston, Texas; Goddard Space Flight Center in Greenbelt, Maryland; and Headquarters in Washington D.C. Physician salaries in the Houston area and across the country continue to rise and the General Schedule (GS) salaries that JSC may offer are consistently lower than private sector salaries and those offered by our prime contractors. According to the 2019 Medscape Physician

PHYSICIANS' COMPARABILITY ALLOWANCE

Number of Physicians Receiving PCAs by Category (non-add)	Category of Physician Position	Recruitment and retention problem
		Compensation Report, the average physician compensation in the South-Central geographical area was $300,000. In 2020, the maximum GS salary payable for GS employees is $166,500. In addition, significantly higher physician pay scales under Title 38 in the Veterans Administration (VA) and Department of Defense (DoD) provide a potential incentive for NASA physicians to continue their government service and receive higher pay by transferring to those agencies. Further, NASA is now competing with commercial space companies that are attempting to expand their human spaceflight capabilities and need physicians experienced in human spaceflight. NASA physicians are supporting more critical program activities simultaneously than at any time in the past. This includes supporting the NASA Health and Medical Technical Authority, International Space Station crew (operating 24/7), Commercial Crew, Orion, Gateway, and Lunar activities, the active astronaut corps, and the operation of the Lifetime Surveillance of Astronaut Health program, which includes all retired astronauts. The implementation of the TREAT Act means that they will also be providing life-long care for former astronauts. Physicians who are board-certified in Aerospace Medicine and who have operational experience are a rare and valuable commodity. There is a shortage of aerospace medicine specialists nationwide and other government and military organizations are actively recruiting qualified physicians. Many of the JSC physicians with aerospace medicine training and experience are also board-certified in other clinical specialties including internal medicine, emergency medicine, and psychiatry. The double board-certified physicians are an especially rare commodity and their dual areas of expertise are extraordinarily valuable to NASA. The training period after medical school, including on-the-job training at NASA after hire, is nearly a full decade. Retaining such physicians after they are hired and have completed NASA Flight Surgeon training requirements is critical to the success of the human space flight program. All of these factors affect NASA's ability to attract and retain qualified physicians. Without offering PCA, NASA would not be able to recruit and retain qualified physicians.
0	Category II Research Position	N/A

PHYSICIANS' COMPARABILITY ALLOWANCE

Number of Physicians Receiving PCAs by Category (non-add)	Category of Physician Position	Recruitment and retention problem
0	Category III Occupational Health	N/A
0	Category IV-A Disability Evaluation	N/A
6	Category IV-B Health and Medical Admin.	NASA faces challenges recruiting and retaining physicians who are willing and able to serve in physician management and leadership roles. Because physicians are at the top of the GS pay scale, and previously, NASA had only one PCA category, there has been no pay incentive to accompany the increase in responsibility and authority. In 2019, NASA placed four physicians who occupy significant medical management and leadership positions into a separate PCA category that provides the opportunity for additional pay. Physician leaders are in even greater demand than skilled aerospace physicians. Additional PCA for those holding these critical roles helps to attract the best physicians to these roles and retain them in leadership and management positions. Over the past few years, NASA has been unable to fill critical branch and division leadership positions that require physicians, and as a result has been unable to develop a robust succession management plan to ensure that physician leaders are developed and retained to fill critical Agency roles such as Chief Medical Officer and Chief Health and Medical Officer. Providing enhanced PCA for those physicians willing to step up to roles of increased responsibility will encourage young physicians to apply for these challenging roles and ensure a cadre of skilled physician leaders for the future.

3) Explain how the agency determines the amounts to be used for each category of physicians.

Number of Physicians Receiving PCAs by Category (non-add)	Category of Physician Position	Basis of comparability allowance amount
21	Category I Clinical Position	The PCA amounts paid are the minimum needed to deal with the recruitment and retention problems. The amount \$22,000 - \$24,000 is offered to many of our physicians in this category (or \$14,000 per regulations, depending on tenure), and we have determined that amount is justified via two means: (1) Market Data relevant to the most applicable field of practice, Emergency Medicine, includes the following:

PHYSICIANS' COMPARABILITY ALLOWANCE

Number of Physicians Receiving PCAs by Category (non-add)	Category of Physician Position	Basis of comparability allowance amount
		- According to a March 2019 publication by Doximity, a reputable source, Single Board-Certified Emergency Medical Physicians in America make an average of $336,000 per year. According to a September 2018 publication by the Houston Medical Journal, a reputable source, the average salary for an Emergency Medical Physician in the Houston Metropolitan Area makes $350,000 per year. Double Board-Certified physicians can easily make more. References to that data include: Glassdoor Inc., (2018, August); Kane, L., MA. (2018, April); and Medscape Physician Compensation Report 2018 (2018, July). (2) NASA Centers have had success hiring candidates with the offers of $14,000 - $24,000 of PCA; therefore, a higher amount of PCA would not be justifiable for physicians in this category.
0	Category II Research Position	Currently no physician positions in this category
0	Category III Occupational Health	Currently no physician positions in this category
0	Category IV-A Disability Evaluation	Currently no physician positions in this category
6	Category IV-B Health and Medical Admin.	The PCA amounts paid are the minimum needed to deal with the recruitment and retention problems. Similar research and rationale went into making initial offers for PCA for Physicians in this category; however, we have determined that $14,000 - $24,000 has not been satisfactory in recruiting NASA physicians to take on the additional work burdens of Health and Medical Administration duties and retaining them in such a position. The maximum amount of PCA Allowed by law, $30,000 will be required to satisfy this recruitment and retention effort.

4) Does the agency affirm that the PCA plan is consistent with the provisions of 5 U.S.C. 5948 and the requirements of § 595 of 5 CFR Ch. 1?

Yes

BUDGET FOR PUBLIC RELATIONS

The NASA budget for Public Affairs is funded within the Safety, Security, and Mission Services account under Mission Enabling Services. These budgets include the dissemination of information to the news media and the public concerning NASA programs. Content includes support for public affairs/public relations, Center newsletters, internal communications, guest operations (including bus transportation), public inquiries, NASA TV, the nasa.gov portal (see: http://www.nasa.gov), and other multimedia support.

NASA PAO BUDGET SUMMARY, BY CENTER

	Actual	Estimate	Request				
Budget Authority ($ millions)	**FY 2019**	**FY 2020**	**FY 2021**	**FY 2022**	**FY 2023**	**FY 2024**	**FY 2025**
ARC	4.6	4.6	4.6	4.6	4.6	4.6	4.6
AFRC	1.3	1.3	1.3	1.3	1.3	1.3	1.3
GRC	4.5	4.5	4.5	4.5	4.5	4.5	4.5
GSFC	4.6	4.6	4.8	4.8	4.8	4.8	4.8
HQ	14.4	14.4	14.4	14.4	14.4	14.4	14.4
JSC	5.2	5.2	5.2	5.2	5.2	5.2	5.2
KSC	10.3	10.3	10.3	10.3	10.3	10.3	10.3
LaRC	2.7	2.7	2.7	2.7	2.7	2.7	2.7
MSFC	5.1	5.1	5.1	5.1	5.1	5.1	5.1
SSC	1.8	1.8	1.9	1.9	1.9	1.9	1.9
NASA Total	**54.5**	**54.5**	**54.9**	**54.9**	**54.9**	**54.9**	**54.9**

Sums may not add to Total due to rounding.

CONSULTING SERVICES

NASA uses paid experts and consultants to provide advice and expertise beyond that which is available from its in-house civil service workforce. Management controls ensure that there is ample justification for consulting services before these services are obtained. Much of the Agency's expert and consultant support is for the NASA Advisory Council and the Aerospace Safety Advisory Panel. NASA uses experts and consultants to provide expertise on the selection of experiments for future space missions. The use of these experts and consultants provides the Agency with an independent view that promotes the selection of experiments likely to have the greatest scientific merit. Other individuals provide independent views of technical and functional problems to provide senior management with a wide the range of information to support making major decisions. Historically, each mission directorate engages a few consultants supporting primarily programmatic and Aerospace Safety Advisory Panel issues.

NASA CONSULTING SERVICES BUDGET SUMMARY

	Actual	Estimate	Request
	FY 2019	**FY 2020**	**FY 2021**
Number of Paid Experts and Consultants	33	33	33
Annual FTE Usage	6.0	6.7	6.7
(Cost in $ millions)			
Salaries	0.7	0.7	0.7
Benefits Costs	0.2	0.2	0.2
Travel Costs	0.2	0.2	0.2
Total Costs	**1.1**	**1.1**	**1.1**

FY 2019 are actual obligations. FY 2020 and FY 2021 are estimated Budget Authority

A broader definition of consulting services could include the total object class Advisory and Assistance Services as shown in the Supporting Data Budget by Object Class section of this volume. Advisory and Assistance Services includes: (1) Quality Control, Testing & Inspection Services; (2) Management and Professional Support Services; (3) Studies, Analysis, and Evaluations; and (4) Engineering and Technical Services; and (5) IT Services.

	Actual	Estimate	Request
(Cost in $ millions)	**FY 2019**	**FY 2020**	**FY 2021**
Quality Control, Testing & Inspection Services	36.9	39.6	49.1
Management and Professional Support Services	709.9	763.1	945.6
Studies, Analysis, & Evaluations	92.2	99.1	122.8
Engineering and Technical Services	9.2	9.9	12.3
IT Services	73.8	79.3	98.2
Total Costs, Advisory & Assistance Services	**922.0**	**991.0**	**1,228.0**

FY 2019 are actual obligations. FY 2020 and FY 2021 are estimated obligations

CONSULTING SERVICES

DEFINITIONS

Consultant

A person who can provide valuable and pertinent advice generally drawn from a high degree of broad administrative, professional, or technical knowledge or experience. When an agency requires public advisory participation, a consultant also may be a person who is affected by a particular program and can provide useful views from personal experience.

Expert

A person who is specially qualified by education and experience to perform difficult and challenging tasks in a particular field beyond the usual range of achievement of competent persons in that field. An expert is regarded by other persons in the field as an authority or practitioner of unusual competence and skill in a professional, scientific, technical, or other activity.

These definitions are located under 5 CFR 304.102. The appointments are made under 5 U.S.C. 3109, and the use of this authority is reported to Office of Personnel Management (OPM) annually.

E-GOV INITIATIVES AND BENEFITS

E-GOVERNMENT FUNDING CONTRIBUTIONS AND SERVICE FEES BY INITIATIVE

NASA will provide funding contributions in FY 2021 for each of the following E-Government initiatives:

Initiative	2021 Contributions (Includes In- Kind) (In Thousands)	2021 Service Fees* (In Thousands)
E-Rulemaking	0	10,633
Grants.gov	73,000	0
E-Training	0	1,583,625
Recruitment One-Stop	0	129,375
Enterprise HR Integration	0	357,500
E-Payroll	0	3,950,075
E-Travel	0	89,520
Integrated Award Environment (IAE)	0	719,644
Financial Management LoB	124,236	0
Human Resources Management LoB	68,478	0
Geospatial LoB	225,000	0
Budget Formulation and Execution LoB**	120,000	0
Federal PKI Bridge	0	172,349
NASA Total	**$610,714**	**$7,012,721**

**Service fees are estimates as provided by the E-Government initiative Managing Partners*

***Final FY 2021 commitments have yet to be finalized by Managing Partners (OMB MAX)*

After submission of the budget, NASA will post FY 2021 Exhibit 300 IT business cases on the IT Dashboard located at: https://www.itdashboard.gov

The E-Government initiatives serve citizens, businesses, and federal employees by delivering high-quality services more efficiently at a lower price. Instead of expensive “stove-piped” operations, agencies work together to develop common solutions that achieve mission requirements at a reduced cost, which makes resources available for higher priority needs. Benefits realized by NASA through these initiatives in FY 2021 are described below:

eRulemaking (Managing Partner EPA) FY 2021 Benefits

NASA has benefited from the eRulemaking initiative by being able to better provide the public with one-stop access to the Agency’s information on rulemakings and non-rulemaking activities via the Regulations.gov website.

NASA uses the Federal Docket Management System (FDMS) to post its rulemakings so that the public can gain access to, review, and comment on these rulemakings. NASA relies on Regulations.gov to retrieve public comments on its rulemakings. NASA’s use of the FDMS and Regulations.gov substantially improves the transparency of its rulemaking actions and increases public participation in the regulatory process. Direct budget cost savings and cost avoidance has resulted from the FDMS and Regulations.gov.

E-GOV INITIATIVES AND BENEFITS

Grants.gov (Managing Partner HHS) FY 2021 Benefits

The Grants.gov initiative benefits NASA and its grant programs by providing a single location with broader exposure to publish grant (i.e., funding) opportunities and application packages, making the process easier for applicants to apply for funding with multiple agencies. All 26 major Federal grant-making agencies post 100 percent of their synopses for discretionary funding opportunity announcements on Grants.gov.

In addition, Grants.gov provides a single site for the grantee community to apply for grants using a standard set of forms, processes, and systems. This gives grantees greater access and ability to apply for Federal funding. Through the continued use of Grants.gov, NASA can reduce operating costs associated with online grant posting and application evaluation. Additionally, the Agency is able to improve operational effectiveness through the use of Grants.gov by increasing data accuracy and reducing processing cycle times.

e-Training (Managing Partner OPM) FY 2021 Benefits

The e-Training initiative provides access to premier electronic training systems and tools that support the training and development of the Federal workforce. The initiative supports Agency missions through efficient one-stop access to e-Training products and services. The availability of an electronic training environment enhances the ability of the Federal government and NASA to attract, retain, manage, and develop highly skilled professionals needed for a flexible and high-performing government workforce.

The e-Training initiative benefits NASA by reducing redundancies and achieving economies of scale in the purchase, development, and deployment of e-learning content and in the management of learning technology infrastructure. The System for Administration, Training, and Educational Resources at NASA (SATERN) is a web-based talent management tool that serves as NASA's training system of record for over 100,797 active civil servants and contractor accounts tracked within the system. This centralized approach allows NASA to reduce and leverage training costs by eliminating unique systems, standardizing training processes, and maintain valid data. In 2018 NASA migrated SATERN to a software as a service (SaaS) cloud hosted solution.

Through SATERN, employees can view required training, launch online content, view training history, and self-register for approved courses and conferences. In addition, the system allows NASA officials to identify groups and individuals who have not met basic training requirements and ensure accountability for mission critical and Federally mandated training and development. SATERN also offers employees access to career planning tools, individual development plans, and competency management assistance. Currently, SATERN offers learners access to more than 2,500 online courses and 18,000 online books and training videos. SATERN is available at all times and can be accessed from work or at home.

Recruitment One-Stop (Managing Partner OPM) FY 2021 Benefits

USAJOBS simplifies the Federal Job Search Process for Job Seekers and Agencies. The USAJOBS.gov website provides a place where citizens can search for employment opportunities throughout the Federal Government. USAJOBS is a fully operational, state-of-the-art recruitment system that simplifies the Federal job search process for job seekers and agencies. Through USAJOBS.gov users have access to:

- A centralized repository for all competitive service job vacancies;
- Job vacancies;

- A resume repository used by agencies to identify critical skills;
- A standardized online recruitment tool and services;
- A standard application process; and
- Intuitive job searches including e-mail notifications for jobs of interest.

Integration with Recruitment One-Stop allows NASA to better attract individuals who can accomplish the Agency's mission. The USAJOBS interface allows job seekers to view and apply for all NASA employment opportunities, as well as those from other Federal agencies.

In 2005, NASA adopted the USAJOBS resume as the basic application document for all NASA positions, except for astronaut positions. To date NASA has not identified any specific savings, either in terms of budgeted savings or cost avoidance. Although the Agency believes that implementation of Recruitment One-Stop has resulted in significant intangible benefits in terms of providing better vacancy information to applicants, it has not resulted in any specific cost savings to NASA. The numerous intangible benefits Recruitment One-Stop provides to NASA and other agencies include:

- Decreasing hiring time for managers;
- Providing an integrated solution to agency applicant assessment systems;
- Providing a cost-effective marketing and recruitment tool;
- Realizing cost savings over commercial job posting boards;
- Reducing the delay associated with filling critical agency vacancies; and
- Enhancing competition with the private sector for the best and brightest talent for Federal service.

Enterprise HR Integration (Managing Partner OPM) FY 2021 Benefits

The Enterprise HR Integration (EHRI) Program supports the strategic management of human capital by providing agency customers access to timely and accurate Federal workforce data. In support of this objective, EHRI has the following goals: 1) Streamline and automate the exchange of Federal employee human resources (HR) information Government wide; 2) Provide comprehensive knowledge management and workforce analysis, forecasting, and reporting across the Executive Branch; 3) Maximize cost savings captured through automation; and 4) Enhance retirement processing throughout the Executive Branch.

A key initiative of EHRI is the electronic Official Personnel Folder (eOPF), a web-based application capable of storing, processing, and displaying the OPFs of all current, separated, and retired Federal Employees. Specific EHRI/eOPF benefits to NASA include improved convenience in searching for information, better security and safety for electronic files, decreased costs, streamlined business processes, and the ability to have a central repository of OPF records for the Agency. NASA deployed the eOPF capability of electronic transfer of eOPFs between agencies in FY 2010. Specific NASA employee benefits include secure online access to OPFs, automatic notification when documents are added, exchange of retirement and HR data across agencies and systems, and the elimination of duplicate and repetitive personnel data in personnel folders. NASA completed its implementation to eOPF in March 2008, and transitioned personnel actions processing to the NASA Shared Service Center.

E-Payroll FY 2021 Benefits

The E-Payroll Initiative standardizes and consolidates government-wide Federal civilian payroll services and processes by simplifying and standardizing human resources (HR)/payroll policies and procedures and better integrating payroll, HR, and finance functions. Since 2004, the Department of Interior (DOI) has served as NASA's payroll provider, DOI's system (Federal Personnel and Payroll System (FPPS)), processes NASA's HR and Payroll transactions and supplies all key delivery aspects of its payroll operation functions. The E-Payroll initiative benefits NASA by permitting the Agency to focus on its mission related activities rather than on administrative payroll functions. Payroll processing costs are reduced through economies of scale and avoiding the cost of duplicative capital system modernization activities. The initiative also promotes standardization of business processes and practices and unified service delivery.

E-Travel (Managing Partner GSA) FY 2021 Benefits

NASA completed migration of its travel services to ETS2 - Concur Government Edition (CGE) (formerly HP Enterprise Services (FedTraveler)). Completed in 2014, this migration has allowed NASA to provide more efficient and effective travel management services. ETS2 is a streamlined, adaptable, world-class travel management service that continually applies commercial best practices to realize travel efficiencies and deliver a transparent, accountable, and sustainable service that yields exceptional customer satisfaction.

Integrated Award Environment (Managing Partner GSA) FY 2021 Benefits

The Integrated Award Environment (IAE) initiative is designed to streamline the process of reporting on subcontracting plans and provides agencies with access to analytical data on subcontracting performance. Use of the IAE common services allows agencies to focus on specific needs such as strategy, operations, and management while leveraging shared services for common functions. Furthermore, use of a government-wide business focused service environment reduces funding and resources for technical services and support for acquisition systems originally housed by individual agencies.

Through adoption of the tools and services provided by IAE, NASA improves its ability to make informed and efficient purchasing decisions and allows it to replace manual processes. If NASA did not use IAE systems, the Agency would need to build and maintain separate systems to record vendor and contract information and to post procurement opportunities. Agency purchasing officials would not have access to databases of important information from other agencies on vendor performance and could not use systems to replace paper-based and labor-intensive work efforts.

Integrated Award and Environment – Loans & Grants FY 2021 Benefits

All agencies participating in the posting and/or awarding of Contracts and Loans & Grants are required by the Federal Funding Accountability and Transparency Act (FFATA) of 2006 and the Digital Accountability and Transparency Act of 2014 (DATA Act) reporting requirements to disclose award information on a publicly accessible website. On December 14, 2007, OMB launched USASpending.gov (see: http://www.USASpending.gov) to meet the FFATA statutory requirements. NASA analyzes the past and present total funding amounts of each proposing entity, as well as its total number of awards to assist in assessing each grant proposer's risk level and score during the 2 CFR 200 required pre-award risk assessment process. This information is submitted and housed in USASpending.gov by funding agency. Understanding the total dollar amounts managed and the number of awards, provides insight on a proposer's experience with managing federal funds.

Federal PKI Bridge - FY 2021 Benefits

The Federal Public Key Infrastructure (FPKI) is the primary, secure mechanism that allows for electronic business transactions across Government and between Government and industry. It is the backbone and trust anchor for HSPD-12 and PIV Cards and is critical to enabling cyber security via identity management. The FPKI enables secure physical and logical access using strong credentials, such as the PIV card, and allows NASA documents to be digitally signed, sent, encrypted, and archived in digital media without fear that they will be compromised, spoofed, or altered. A number of core government-wide documents mandate NASA's use of the FPKI.

LINES OF BUSINESS

Financial Management LoB (Managing Partners DOE and DOL) FY 2021 Benefits

NASA's contribution to FMLoB supports efforts to transform Federal financial management, reduce costs, increase transparency, and improve delivery of agencies' missions by operating at scale, relying on common standards, shared services, and using state-of-the-art technology. NASA benefits from the FM LOB because it provides a forum in which Federal agencies can share information and weigh pros and cons of various initiatives (e.g., shared services). A shared services solution may be an alternative considered by NASA as part of its financial system improvements.

Human Resources Management LoB (Managing Partner OPM) FY 2021 Benefits

The HR LoB vision is to create government-wide, modern, cost-effective, standardized, and interoperable HR solutions to provide common core functionality to support the strategic management of Human Resources through the establishment of Shared Service Centers (SSCs).

NASA works in partnership with one of the approved service providers, the Department of Interior's Business Center (IBC). Through this partnership, NASA shares and receives "best-in-class" HR solutions. The Business Center (IBC) delivers NASA-developed solutions to their customer agencies, enabling improved efficiencies and system integrations at a fraction of the cost and delivery time than similar solutions could have been produced by the Interior Business Center. NASA achieves the benefits of "best-in-class" HR solutions through implementation and integration of IBC and NASA-developed HR solutions. NASA's participation in HR LoB provides the Agency opportunities to implement modern HR solutions and benefit from best practices government-wide strategic HR management. NASA participates in the ongoing development of a 10-year Federal Human Resources Strategic Plan with the HRLOB managing partner (OPM) and member agencies.

Geospatial LoB (Managing Partner DOL) FY 2021 Benefits

The Geospatial LoB serves the agencies' missions and the Nation's interests by developing a more strategic, coordinated, and leveraged approach to producing, maintaining, and using geospatial data and services across the Federal Government.

As a science agency, the work of NASA's science and mission professionals is inherently different from duties and functions performed by operational agencies. These differences lead NASA to organize and manage data to best facilitate science activities. Scientific inquiry often leads scientists to use different schemas for analyzing data and information produced from remote sensing data (e.g. a common grid or projection). NASA will continue to apply the elements of Federal Geographic Data Committee standards where these are appropriate. In FY 2008, NASA signed an MOU with the Department of Labor to continue its active participation in the Geospatial LOB.

Budget Formulation & Execution LOB (Managing Partner Education) FY 2021 Benefits

The Budget Formulation and Execution LoB (BFELoB) provides significant benefits to NASA and other partner agencies by encouraging best practices crossing all aspects of Federal budgeting – from budget formulation and execution to performance to human capital needs. To benefit all agencies, BFELoB continues to support the idea of shared service budget systems. As NASA currently has its own budgeting tools, the Agency has not chosen to move to a new budget system; however, a shared service budget system is an option in the future.

COMPARABILITY ADJUSTMENT TABLES

FY 2019 Budget Structure Crosswalk to FY 2021 Budget Structure

Budget Authority ($ in millions)

	FY 2019 Structure[1]	FY 2021 Structure[1]
NASA TOTAL	**$19,892.2**	**$19,892.2**
Deep Space Exploration Systems	**$4,558.8**	**$4,698.8**
Exploration Systems Development	**$3,669.8**	**$3,669.8**
Advanced Exploration Systems (Title Change to Exploration Research & Development)	**$889.0**	**$1,029.0**
Lunar Orbital Platform - Gateway	$504.2	$504.2
Adv Cislunar and Surface Capabilities	$116.5	$116.5
Exploration Advanced Systems (Title Change to Advanced Exploration Systems)	$268.2	$268.2
Human Research Program		$140.0
Exploration Research and Technology	**$1,002.7**	**$862.7**
Exploration Research and Technology	**$1,002.7**	**$862.7**
Early Stage Innovation and Partnerships	$108.4	$108.4
Technology Maturation	$216.5	$216.5
Technology Demonstration	$332.7	$332.7
Human Research Program	$140.0	
SBIR and STTR	$205.0	$205.0
LEO and Spaceflight Operations	**$4,624.6**	**$4,548.1**
International Space Station	**$1,462.2**	**$1,462.2**
Space Transportation	**$2,108.7**	**$2,108.7**
Space and Flight Support (SFS)	**$903.7**	**$827.2**
Space Communications and Navigation	$634.1	$457.7
Space Communications Networks	*$523.4*	*$346.9*
Next Generation Capability	$100.0	
Communications Service Office (CSO)	$76.5	
Human Space Flight Operations	$135.4	$135.4
Launch Services	$86.6	$86.6
Rocket Propulsion Test	$47.6	$47.6
Communications Services Program		$100.0
Communications Services Program		*$100.0*
Next Generation Capability		$100.0
Commercial LEO Development	**$150.0**	**$150.0**
Commercial LEO Development Program	$150.0	$150.0
Commercial LEO Development	*$150.0*	*$150.0*
Commercial LEO Development Project	$150.0	$150.0
Science	**$5,895.0**	**$5,895.0**
Earth Science	**$1,784.2**	**$1,784.2**
Earth Science Research	$451.4	$451.4
Earth Systematic Missions	$788.1	$788.1
Ice, Cloud, and land Elevation Satellite (ICESat-II)	*$23.1*	
GRACE FO	*$11.3*	
Surface Water and Ocean Topography	*$114.3*	*$114.3*
NASA-ISRO SAR	*$131.9*	*$131.9*
Landsat 9	*$162.4*	*$162.4*
Sentinel-6	*$59.6*	*$59.6*
Other Missions and Data Analysis	*$285.6*	*$320.0*
ICESat-2		$23.1
GRACE Follow-On		$11.3
Earth System Science Pathfinder	$235.0	$235.0
Earth Science Multi-Mission Operations (Title Change to Earth Science Data Systems)	$196.9	$196.9
Earth Science Technology	$59.7	$59.7
Applied Sciences	$53.1	$53.1
Planetary Science	**$2,234.7**	**$2,234.7**
Planetary Science Research	$258.0	$298.2
Planetary Science Research and Analysis	*$210.3*	*$210.3*

COMPARABILITY ADJUSTMENT TABLES

Other Missions and Data Analysis	*$47.7*	*$87.9*
Advanced Multi-Mission Operation System		$40.2
Planetary Defense	$150.0	$150.0
Lunar Discovery and Exploration	$218.0	$218.0
Discovery	$381.2	$381.2
New Frontiers	$130.2	$130.2
Mars Exploration	$601.5	$601.5
Outer Planets and Ocean Worlds	$285.6	$285.6
Technology (Title Change to Radioisotope Power)	$210.2	$170.0
Technology (Title Change to Radioisotope Power)	*$210.2*	*$170.0*
Advanced Multi-Mission Operation System	$40.2	
Astrophysics	**$1,185.4**	**$880.8**
Astrophysics Research	$259.2	$259.2
Cosmic Origins	$491.4	$186.8
James Webb Space Telescope	*$304.6*	
Physics of the Cosmos	$136.8	$136.8
Exoplanet Exploration	$52.4	$52.4
Astrophysics Explorer	$245.6	$245.6
Heliophysics	**$690.7**	**$690.7**
Heliophysics Research	$242.7	$242.7
Living with a Star	$247.8	$247.8
Parker Solar Probe	*$107.2*	
Solar Orbiter Collaboration	*$62.3*	*$62.3*
Other Missions and Data Analysis	*$78.2*	*$185.4*
Parker Solar Probe		$107.2
Solar Terrestrial Probes	$91.0	$91.0
Heliophysics Explorer Program	$109.2	$109.2
James Webb Space Telescope		**$304.6**
Aeronautics	**$633.9**	**$633.9**
Education	**$0.0**	**$0.0**
Safety, Security, and Mission Services	**$2,749.7**	**$2,826.2**
Center Management and Operations	**$1,949.6**	
Center Management and Operations	$1,949.6	
Agency Management and Operations	**$800.1**	
Agency Management	$359.5	
Safety and Mission Success	$175.8	
Agency IT Services (AITS)	$238.1	
Strategic Capabilities Asset Program	$26.7	
Mission Services & Capabilities		**$1,535.6**
Information Technology (IT)		$567.9
Information Technology (IT)		*$567.9*
Communications Service Office (CSO)		$76.5
Mission Enabling Services		$404.2
Mission Enabling Services		*$404.2*
Infrastructure & Technical Capabilities		$563.5
Infrastructure & Technical Capabilities		*$563.5*
Engineering, Safety, & Operations		**$1,290.6**
Agency Technical Authority		$175.8
Agency Technical Authority		*$175.8*
Center Engineering, Safety, & Operations		$1,114.8
Center Engineering, Safety, and Operations		*$1,114.8*
Construction & Envrmtl Compl Restoration	**$388.2**	**$388.2**
Inspector General	**$39.3**	**$39.3**
NASA TOTAL	**$19,892.2**	**$19,892.2**

1/ - Reflects FY 2019 President's Budget Request funding amounts

NOTE: Chart represents changes in budget structure and does not reflect funding changes.

COMPARABILITY ADJUSTMENT TABLES

FY 2020 Budget Structure Crosswalk to FY 2021 Budget Structure Budget Authority ($ in millions)	FY 2020 Structure[1]	FY 2021 Structure[1]
NASA TOTAL	**$22,615.7**	**$22,615.7**
Deep Space Exploration Systems	**$6,396.4**	**$6,396.4**
Exploration Technology	**$1,146.3**	**$1,146.3**
LEO and Spaceflight Operations	**$4,285.7**	**$4,209.3**
International Space Station	**$1,458.2**	**$1,458.2**
Space Transportation	**$1,828.6**	**$1,828.6**
Space and Flight Support (SFS)	**$848.9**	**$772.4**
Space Communications and Navigation	$611.0	$534.6
Space Communications Networks	*$468.1*	*$391.7*
Communications Service Office (CSO)	$76.4	
Space Communications Support	*$142.9*	*$142.9*
Human Space Flight Operations	$99.8	$99.8
Launch Services	$88.6	$88.6
Rocket Propulsion Test	$46.5	$46.5
Communications Services Program	$3.0	$3.0
Commercial LEO Development	**$150.0**	**$150.0**
Science	**$6,393.7**	**$6,393.7**
Earth Science	**$1,779.8**	**$1,779.8**
Planetary Science	**$2,712.1**	**$2,712.1**
Astrophysics	**$844.8**	**$844.8**
Heliophysics	**$704.5**	**$704.5**
Heliophysics Research	$237.0	$237.0
Living with a Star	$107.6	$107.6
Solar Terrestrial Probes	$177.9	$177.9
Heliophysics Explorer Program	$182.0	$182.0
ICON	*$1.4*	
Other Missions and Data Analysis	*$180.6*	*$182.0*
Ionospheric Connection Explorer		$1.4
James Webb Space Telescope	**$352.6**	**$352.6**
Aeronautics	**$666.9**	**$783.9**
Aeronautics	**$666.9**	**$783.9**
Airspace Operations and Safety Program	$121.2	$96.2
Airspace Operations and Safety Program	*$121.2*	*$96.2*
Advanced Air Mobility	$25.0	
Advanced Air Vehicles Program	$188.1	$188.1
Aerosciences Eval. & Test Capab. Program		$117.0
Integrated Aviation Systems Program	$233.2	$258.2
Low Boom Flight Demonstrator	*$103.5*	*$103.5*
Integrated Aviation Systems Program	*$129.7*	*$154.7*
Advanced Air Mobility		$25.0
Transformative Aero Concepts Program	$124.4	$124.4
STEM Engagement	**$0.0**	**$0.0**
Safety, Security, and Mission Services	**$3,084.6**	**$3,044.0**
Center Management and Operations	**$2,065.0**	
Agency Management and Operations	**$1,019.6**	
Agency Management	$390.4	
Safety and Mission Success	$192.0	
Agency IT Services (AITS)	$275.7	

COMPARABILITY ADJUSTMENT TABLES

Strategic Capabilities Asset Program	$161.5	
Strategic Capabilities Assets Program	*$161.5*	
Aerosciences Evaluation and Test Capabil	$117.0	
Mission Services & Capabilities		**$1,814.6**
Information Technology (IT)		$613.2
Information Technology (IT)		*$613.2*
Communications Service Office (CSO)		$76.4
Mission Enabling Services		$519.8
Mission Enabling Services		*$519.8*
Infrastructure & Technical Capabilities		$681.6
Infrastructure & Technical Capabilities		*$681.6*
Engineering, Safety, & Operations		**$1,229.5**
Agency Technical Authority		$192.0
Agency Technical Authority		*$192.0*
Center Engineering, Safety, & Operations		$1,037.5
Center Engineering, Safety, and Operations		*$1,037.5*
Construction & Envrmtl Compl Restoration	**$600.4**	**$600.4**
Inspector General	**$41.7**	**$41.7**
NASA TOTAL	**$22,615.7**	**$22,615.7**

1/ - Reflects FY 2020 President's Budget Request (Amended) funding amounts

NOTE: Chart represents changes in budget structure and does not reflect funding changes.

REBASELINED PROJECTS

In accordance with NPR 7120.5, NASA rebaselined the estimated Life Cycle Costs for the following projects. The original baselines are shown for comparison.

($ in millions)

Webb	Date	Prior	FY16	FY17	FY18	FY19	FY20	FY21	BTC	Total
Original Life Cycle Cost	2009	4,448	92	93	94	94	76	54	12	4,964
Rebaselined Life Cycle Cost	2019	5,991	620	569	534	305	423	415	806	9,663
Actual	n/a	5,991	620	569	534	305				

ICESat-2	Date	Prior	FY16	FY17	FY18	FY19	FY20	FY21	BTC	Total
Original Life Cycle Cost	2013	683	119	27	14	11	6		-	860
Rebaselined Life Cycle Cost	2015	725	141	93	67	14	14	9	-	1,064
Actual	n/a	730	117	87	39	22				

IT STATEMENT OF AFFIRMATION

National Aeronautics and
Space Administration

Headquarters
Washington, DC 20546-0001

JAN 2 3 2020

Reply to Attn of:Office of the Chief Information Officer

TO: NASA Chief Financial Officer, Jeff DeWit

FROM: NASA Chief Information Officer, Renee Wynn

SUBJECT: Fiscal Year 2021 NASA IT Budget Justification Statement of Affirmation

As required by the Office of Management and Budget (OMB) Circular A-11 and the Federal
Information Technology Acquisition Reform Act (FITARA), and based on the information presented from the Offices of the Chief Information Officer, and on insights into the current Information Technology (IT) Portfolio over which the Chief Information Officer (CIO) has direct budget authority, this letter affirms the following:

1. The CIO's common baseline rating for Element D ("CIO reviews and approves major IT Investment portion of budget request") is fully implemented;

2. The Chief Financial Officer (CFO) and the CIO jointly affirm that the CIO had a significant role in reviewing planned IT support for major program obj ectives;

3. Significant increases and decreases in IT resources are reflected in the Agency's current services baseline budget submission for those items over which the CIO has direct budget authority;

4. The CIO has reviewed and approved the use of incremental development for all investments submitted as major investments in the IT Portfolio;

5. The CIO holds the role ofNASA's Senior Agency Official for Privacy (SAOP) and has therefore reviewed the IT Budget submission to ensure that privacy requirements and any associated costs, are explicitly identified and included with respect to any IT resources that will be used to create, collect, use, process, store, maintain, disseminate, disclose, or dispose of personally identifiable information (PID;

IT STATEMENT OF AFFIRMATION

6. Agency budget request funding levels will include expected contributions to the E-GovLineof-Business initiatives;

7. The CIO collaborated with the Information Technology Council (ITC) comprised of

Missions, Centers and Mission Support including the CFO on the IT Budget submission;

8. The IT Portfolio (OMB Circular A-11, Section 55.6 and as described herein) includes appropriate estimates of all IT resources included in the President's Budget; and

9. The CIO has reviewed and had significant input in approving all IT Investments included in the President's Budget.

Jeff DeWit
Chief Financial Officer

Renee P. Wynn
Chief Information Officer

Cost and Schedule Performance Summary

2020 Major Program Annual Report Summary

The 2020 Major Program Annual Report (MPAR) is provided to meet the requirements of section 103 of the NASA Authorization Act of 2005 (P.L. 109-155; 42 U.S.C. 16613). The 2020 MPAR consists of this summary and FY 2021 Congressional Justification pages designated as "Projects in Development," for the projects outlined below, with the exception of the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) project. These project pages constitute each project's annual report, or if this is the first year for which it is in reporting, the baseline report. The MPAR summary also includes the confidence level of achieving the commitments as requested in the Conference Report accompanying the FY 2010 Consolidated Appropriations Act (P.L. 111-117).

Changes in MPAR Composition since the FY 2020 NASA Budget Estimates

There are four new projects with estimated lifecycle costs greater than $250 million that received authority to proceed into the development phase since NASA submitted its 2019 MPAR in the FY 2020 NASA Congressional Justification.

- The Europa Clipper project with a baseline development cost of $2,412.8 million;
- The Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) project with a baseline development cost of $558.0 million;
- The Psyche project with a baseline development cost of $681.9 million; and
- The Solar Electric Propulsion (SEP) project with a baseline development cost of $155.9 million

All four projects have a joint confidence level of 70 percent. The Budget request provides no funding for PACE, as current ocean-monitoring capabilities are sufficient and demonstrating enhanced capabilities is a lower priority compared to other NASA programs.

There are two projects that successfully launched since NASA submitted its 2019 MPAR in the FY 2020 NASA Congressional Justification.

1. Ionospheric Connection Explorer (ICON) successfully launched on October 10, 2019; and
2. Parker Solar Probe (PSP) successfully launched on August 12, 2018.

Changes in Development Cost and Schedule Estimates from the 2019 MPAR

Four projects (Double Asteroid Redirection Test (DART), Low Boom Flight Demonstrator (LBFD), Surface Water and Ocean Topography (SWOT) and James Webb Space Telescope (Webb) had no changes in their development cost or schedule estimates over the last year. Development cost increases were experienced by both the Laser Communications Relay Demonstrator (LCRD) (up 40%) and Mars 2020 (up 18%) projects. The Mars 2020 project is consuming cost, primarily for labor, in order to maintain schedule. Although the LCRD project saw a 14 month schedule slip (driven by delays in the Air Force-managed spacecraft development, which will host the LCRD payload, not development of the LCRD payload itself), the Mars 2020 project had no schedule changes. Another four projects had development cost decreases with no schedule changes: Landsat 9 (down -6%), Lucy (down -1%) NASA ISRO Synthetic Aperature Radar (NISAR) (down -4%) and Sentinel-6 (down -1%) . The Solar Orbiter Collaboration (SOC) project also experienced a development cost decrease (down -84%) while maintaining its current schedule.

The Exploration Ground System (EGS), Orion and Space Launch System (SLS) projects all experienced development cost increases (up 4%, 8% and 10% respectively). However, the schedules for EGS and SLS are both currently under review. Whereas the Orion schedule has increased by 6 months.

Cost and Schedule Performance Summary

MPAR Summary Table

Figure 1 provides cost, schedule, and confidence level information for NASA projects currently in development with lifecycle cost estimates of $250 million or more. NASA records the estimated development cost and a key schedule milestone and then measures changes from them. NASA tracks one of several key milestones, listed below, for reporting purposes:

- Launch Readiness Date (LRD);
- Full Operational Capability (FOC);
- Initial Operating Capability (IOC); or
- Launch Readiness for Artemis I or Artemis II

As a note for clarification, LRD schedule milestones, as reported here, are not typically the launch dates on the NASA launch manifest, but are the desired launch dates as determined by the payload mission and approved by the NASA Flight Planning Board (FPB). A launch manifest is a dynamic schedule that is affected by real world operational activities conducted by NASA and multiple other entities. It reflects the results of a complex process that requires the coordination and cooperation by multiple users for the use of launch range and launch contractor assets. The launch dates shown on the NASA FPB launch manifest are a mixture of confirmed range dates for missions launching within approximately six months and contractual/planning dates for the missions beyond six months from launch. The NASA FPB launch manifest date is typically earlier than the reported schedule dates reported here, thereby allowing for the operationally driven fluctuations to the launch schedule that may be outside of the Project's control. The NASA FPB launch manifest is updated on a periodic basis throughout the year.

Additional explanations for the data in the summary table are provided here:

- Orion, SLS and EGS: The Artemis I and II launch dates are under review pending completion of several assessments. NASA is conducting a Program Status Assessment of the overall Artemis effort, of which Orion, SLS and EGS are key components. This assessment includes review of the schedule and technical approaches as well as systems engineering integration and program management. In parallel, NASA is performing an independent technical and programmatic assessment, including a joint cost and schedule confidence level analysis of the SLS and EGS programs. NASA Leadership will review the results of these assessments before considering potential updates to the Artemis I and II launch planning dates.
- Webb: Cost Estimate includes Construction of Facilities funds.
- SOC: The cost of the two instruments is below the $250M LCC threshold for JCL. Independent cost and schedule estimates completed by Aerospace and GSFC RAO with each instrument had confidence levels for cost and schedule that were 70 percent when NASA approved the start of development (at KCP-C).
- EGS: The 80% JCL is inferred from analysis based on FY14 President's Budget Request (PBR) including FY14 Appropriation changes. JCL analysis was completed prior to the release of the FY15 PBR. The ABC is informed by the 80% JCL and adjusted to reflect the FY15 PBR budget reduction.
- LCRD: The project will fly as a hosted payload on the U.S. Air Force Space Test Program (STPSat-6) mission. The primary spacecraft bus is co-funded by NASA and the U.S. Air Force. The LCRD project has remained within its cost and schedule baseline for payload development and has completed payload integration and testing. The replan incorporating the U.S. Air Force managed spacecraft bus and schedule problems was completed in April 2019. The table below reflects the LCRD proposed rebaselined cost and schedule as provided in the 2019 Congressional notification.

Cost and Schedule Performance Summary

Additional information on the projects shown in the table below can be found in their individual program and project pages, with the exception of PACE which is included here, in the main body of the Congressional Justification.

Figure 1: MPAR Summary and Confidence Levels

Project	Base Year	JCL (%)	Development Cost Estimate ($M)		Cost Change (%)	Key Milestone Event	Key Milestone Date		Schedule Change (months)
			Baseline	FY 2020			Baseline	FY 2020	
DART	2019	70	258.3	258.3	0%	LRD	Feb 2022	Feb 2022	0
EGS*	2015	80	1,843.5	2,329.0	26%	LR for Artemis I	Nov 2018	U/R	N/A
Europa Clipper+	2020	N/A	2,412.8	2,412.8	0%	LRD	Sep 2025	Sep 2025	0
Landsat-9	2018	70	634.2	587.7	-7%	LRD	Nov 2021	Nov 2021	0
LBFD	2019	70	467.7	467.7	0%	First Flight	Jan 2022	Jan 2022	0
LCRD**	2020	70	128.6	128.6	0%	LRD	Jan 2021	Jan 2021	0
Lucy	2019	70	622.2	614.2	-1%	LRD	Nov 2021	Nov 2021	0
Mars 2020	2017	70	1,676.9	2,036.2	21%	LRD	Jul 2020	Jul 2020	0
NISAR	2017	70	661.0	640.4	-3%	LRD	Sep 2022	Sep 2022	0
Orion***	2016	70	6,768.4	7,686.6	14%	LR for Artemis II	Apr 2023	U/R	N/A
PACE	2020	70	558.0	558.0	0%	LRD	Jan 2024	Jan 2024	0
Psyche	2020	70	681.9	681.9	0%	LRD	Aug 2022	Aug 2022	0
Sentinel-6	2017	70	465.9	460.9	-1%	LRD	Nov 2021	Nov 2021	0
SEP*****	2020	70	155.9	155.9	0%	AEPS Life Qual Test Report	Dec 2024	Dec 2024	0
SLS	2015	70	7,021.4	8,750.2	25%	LR for Artemis I	Nov 2018	U/R	N/A
SOC	2014	N/A	376.9	279.8	-26%	LRD	Oct 2018	Feb 2020	16
SWOT	2017	80	571.5	571.5	0%	LRD	Apr 2022	Apr 2022	0
Webb****	2019	N/A	7,002.6	7,002.6	0%	LRD	Mar 2021	Mar 2021	0

** The 80% JCL is inferred from analysis based on FY14 President's Budget Request (PBR) including FY14 Appropriation changes. JCL analysis was completed prior to the release of the FY15 PBR. The ABC is informed by the 80% JCL and adjusted to reflect the FY15 PBR budget reduction.*

*** The table reflects the LCRD proposed rebaselined cost and schedule as provided in the 2019 Congressional notification.*

**** Approximately -2% of this amount reflects a transfer of funding to formulation costs and does not represent a reduction in the life cycle cost estimates.*

***** Based on the Consolidated Apropropriations Act, 2019 the Webb project has a new reporting baseline. Compared to the prior baseline of $6,197.9, the mission has been delayed 29 months and increased by $804.7 million.*

****** Aerojet Electric Propulsion String Qual Test: The test demonstrates continuous long-term operation of the system sufficient to characterize and predict the capability and lifetime of the system. The report tells us what the capability is based on the results of the test.*

+ The Budget proposes to launch the Europa Clipper on a commercial launch vehicle as early as 2024. The launch date in Figure 1 assumes current law, which requires launch on an SLS rocket in 2025. Launching the Europa Clipper on a commercial launch vehicle would save over $1.5 billion compared to using an SLS rocket

Launch Readiness (LR) Launch Readiness Date (LRD) Aerojet Electric Propulsion String (AEPS)

PACE Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2020	558.0	>70%	2019	558.0	0%	LRD	Jan 2024	Jan 2024	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost. The Budget request provides no funding for PACE, as current ocean-monitoring capabilities are sufficient and demonstrating enhanced capabilities is a lower priority compared to other NASA programs.

PACE Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	558.0	558.0	0.0
Aircraft/Spacecraft	103.6	104.1	0.5
Payloads	79.2	82.0	2.7
Systems I&T	18.8	18.8	0.0
Launch Vehicle	105.0	105.0	0.0
Ground Systems	19.3	19.4	0.1
Science/Technology	50.0	50.0	0.0
Other Direct Project Costs	182.1	178.8	-3.3

FY 2021 Proposed Appropriations Language

DEEP SPACE EXPLORATION SYSTEMS

For necessary expenses, not otherwise provided for, in the conduct and support of exploration research and development activities, including research, development, production, and operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $8,761,700,000, to remain available until September 30, 2022. (Science Appropriations Act, 2020.)

EXPLORATION TECHNOLOGY

For necessary expenses, not otherwise provided for, in the conduct and support of space exploration technology activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $1,578,300,000, to remain available until September 30, 2022. (Science Appropriations Act, 2020.)

LEO AND SPACEFLIGHT OPERATIONS

For necessary expenses, not otherwise provided for, in the conduct and support of space operations research and development activities, including research, development, operations, support and services; space flight, spacecraft control and communications activities, including operations, production, and services; maintenance and repair, facility planning and design; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance and operation of mission and administrative aircraft, $4,187,300,000, to remain available until September 30, 2022. (Science Appropriations Act, 2020.)

Science

For necessary expenses, not otherwise provided for, in the conduct and support of science research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $6,306,500,000, to remain available until September 30, 2022. (Science Appropriations Act, 2020.)

FY 2021 PROPOSED APPROPRIATIONS LANGUAGE

AERONAUTICS

For necessary expenses, not otherwise provided for, in the conduct and support of aeronautics research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $819,000,000, to remain available until September 30, 2022. (Science Appropriations Act, 2020.)

SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS ENGAGEMENT

Unobligated balances previously appropriated under this heading shall be available for purposes of the closure of the Office of STEM Engagement, including, but not limited to, ongoing administration, oversight, monitoring, and funding of grants previously awarded by the Office of STEM Engagement. (Science Appropriations Act, 2020.)

SAFETY, SECURITY, AND MISSION SERVICES

For necessary expenses, not otherwise provided for, in the conduct and support of science, aeronautics, space technology, exploration, space operations and education research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; not to exceed $63,000 for official reception and representation expenses; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $3,009,900,000, to remain available until September 30, 2022. (Science Appropriations Act, 2020.)

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

For necessary expenses for construction of facilities including repair, rehabilitation, revitalization, and modification of facilities, construction of new facilities and additions to existing facilities, facility planning and design, and restoration, and acquisition or condemnation of real property, as authorized by law, and environmental compliance and restoration, $539,085,000, to remain available until September 30, 2026: Provided, That proceeds from leases deposited into this account shall be available for a period of 5 years to the extent and in amounts as provided in annual appropriations Acts: Provided further, That such proceeds referred to in the preceding proviso shall be available for obligation for fiscal year 2021 in an amount not to exceed $18,700,000: Provided further, That each annual budget request shall include an annual estimate of gross receipts and collections and proposed use of all funds collected pursuant to section 20145 of title 51, United States Code. (Science Appropriations Act, 2020.)

INSPECTOR GENERAL

For necessary expenses of the Office of Inspector General in carrying out the Inspector General Act of 1978, $44,200,000, to remain available until September 30, 2022. (Science Appropriations Act, 2020.)

FY 2021 PROPOSED APPROPRIATIONS LANGUAGE

ADMINISTRATIVE PROVISIONS

Funds for any announced prize otherwise authorized shall remain available, without fiscal year limitation, until a prize is claimed or the offer is withdrawn.

Not to exceed 5 percent of any appropriation made available for the current fiscal year for the National Aeronautics and Space Administration in this Act may be transferred between such appropriations, but no such appropriation, except as otherwise specifically provided, shall be increased by more than 10 percent by any such transfers. Any funds transferred to "Construction and Environmental Compliance and Restoration" for construction activities shall not increase that appropriation by more than 20 percent. Balances so transferred shall be merged with and available for the same purposes and the same time period as the appropriations to which transferred. Any transfer pursuant to this provision shall be treated as a reprogramming of funds under section 505 of this Act and shall not be available for obligation except in compliance with the procedures set forth in that section.

Not to exceed 5 percent of any appropriation provided for the National Aeronautics and Space Administration under previous appropriations Acts that remains available for obligation or expenditure in fiscal year 2021 may be transferred between such appropriations, but no such appropriation, except as otherwise specially provided, shall be increased by more than 10 percent by any such transfers. Any transfer pursuant to this provision shall retain its original availability and shall be treated as a reprogramming of funds under section 505 of this Act and shall not be available for obligation except in compliance with the procedures set forth in that section.

Notwithstanding the limitations in the preceding two paragraphs, upon the determination of the Administrator that such action is necessary in support of establishment of a United States strategic presence on the Moon, the Administrator may transfer funds between Deep Space Exploration Systems and LEO and Spaceflight Operations appropriations available to the National Aeronautics and Space Administration, including funds appropriated in prior Acts that remain available for obligation or expenditure, to be merged with and to be available for the same purposes as the appropriation to which transferred. Any transfer pursuant to this provision shall be treated as a reprogramming of funds under section 505 of this Act and shall not be available for obligation except in compliance with the procedures set forth in that section.

The spending plan required by this Act shall be provided by NASA at the theme, and program level. The spending plan, as well as any subsequent change of an amount established in that spending plan that meets the notification requirements of section 505 of this Act, shall be treated as a reprogramming under section 505 of this Act and shall not be available for obligation or expenditure except in compliance with the procedures set forth in that section. (Science Appropriations Act, 2020.)

ACRONYMS AND ABBREVIATIONS

AA	Ascent Abort
AAM	Advanced Air Mobility
AATT	Advanced Air Transport Technology
AAVP	Advanced Air Vehicles Program
ABC	Agency Baseline Commitment
ABoVE	Arctic Boreal and Vulnerability Experiment
AC	Advanced Composites
ACCESS	Advancing Collaborative Connections for Earth System Science
ACE	Advanced Composition Explorer (Heliophysics)
ACF	Analytic Center Framework
ACO	Announcement of Collaborative Opportunity
ACP	Advanced Composites Project
ACSC	Advanced Cislunar and Surface Capabilities
ACTIVATE	Aerosol Cloud Meteorology Interactions over the Western Atlantic Experiment
ADAP	Astrophysics Data Analysis Program
ADCAR	Astrophysics Data Curation and Archival Research
AEPS	Advanced Electric Propulsion Systems
AES	Advanced Exploration Systems
AETC	Aeronautics Evaluation & Testing Capability Project
AFRC	Armstrong Flight Research Center
AFRL	Air Force Research Laboratory
AGBRESA	Artificial Gravity Bed Rest with the European Space Agency
AI	Artificial Intelligence
AI&T	Assembly, Integration, and Testing
AIA	Atmospheric Imaging Assembly
AIM	Aeronomy of Ice in the Mesosphere
AIRS	Atmospheric Infrared Sounder
AIST	Advanced Information Systems Technology
AMMOS	Advanced Multi-Mission Operations System
AMO	Agency Management and Operations
AMR	Advanced Microwave Radiometer
AMS	Alpha Magnetic Spectrometer
AO	Announcements of Opportunity
AOSP	Airspace Operations and Safety Program
APL	Applied Physics Laboratory
APMC	Agency Project Management Council
ARC	Ames Research Center
ARES	Astromaterials Research and Exploration Science
ARIEL	Atmospheric Remote-sensing Infrared Exoplanet Large-survey
ARMD	Aeronautics Research Mission Directorate

ACRONYMS AND ABBREVIATIONS

ARRM	Asteroid Redirect Robotic Mission
ARSET	Applied Remote Sensing Training
ARTEMIS	Acceleration, Reconnection, Turbulence and Electrodynamics of the Moon's Interaction with the Sun
ASAP	Aerospace Safety Advisory Panel
ASCAN	Astronaut Candidate
ASMPM	Astrophysics Strategic Mission Program Management
AST	Architecture Study Team
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ASU	Arizona State University
ATA	Agency Technical Authority
ATD	Air Traffic Management Technology Demonstration-1
ATLAS	Advanced Topographic Laser Altimeter System
ATLO	Assembly, Test, and Launch Operations
ATM	Air Traffic Management
AU	Astronomical Units
AURA	Association of Universities for Research in Astronomy
AUVSI	Association of Unmanned Vehicle Systems International
AWE	Atmospheric Waves Experiment
BAA	Broad Agency Announcement
BCDU	Battery Charge/Discharge Unit
BCT	Blue Canyon Technologies
BPS	Biological and Physical Sciences
BTC	Budget to Complete
BWG	Beam Wave Guide
CAC	Common Access Cards
CAL	Cold Atom Laboratory
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation
CAPSTONE	Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment
CAS	Convergent Aeronautics Solutions
CASE	Contribution to ARIEL Spectroscopy of Exoplanets
CASIS	Center for the Advancement of Science in Space
CAST	Commercial Aviation Safety Team
CATALYST	Cargo Transportation and Landing by Soft Touchdown
CATSAT	Cognitive Application Technology Satellite
CCAFS	Cape Canaveral Air Force Station
CCDev	Commercial Crew Development
CCDev2	Commercial Crew Development Round 2
CCF	Converter Compressor Facility
CCiCap	Commercial Crew Integrated Capability

ACRONYMS AND ABBREVIATIONS

CCP	Commercial Crew Program
CCRPP	Civilian Commercialization Readiness Pilot Program
CCSDS	Consultative Committee for Space Data Systems
CCtCap	Commercial Crew Transportation Capability
CDM	Continuous Diagnostic Mitigation
CDR	Critical Design Reviews
CERES	Compact Radiation Belt Explorer
CESAS	Committee on Earth Science and Applications from Space
CESO	Center Engineering, Safety, and Operations
CFD	Computational Fluid Dynamics
CHS	Crew Health and Safety
CIF	Center Innovation Fund
CL	Confidence Level
CLIN	Contract Line Item Number
CLPS	Commercial Lunar Payload Services
CLV	Commercial Launch Vehicles
CM	Crew Module
CMA	Crew Module Adapter
CME	Coronal Mass Ejections
CMO	Center Management and Operations
CNEOS	Center for Near-Earth Object Studies
CNES	Centre National d'Etudes' Spatiales
CNT	Carbon Nontube Composites
COF	Construction of Facilities
COFR	Certification of Flight Readiness
COMSEC	Communications Security
COOP	Continuity of Operations
COR	Cosmic Origins
CoSTEM	Committee on science, technology, engineering, and mathematics
CPIC	Capital Planning and Investment Control
CRP	Commercialization Readiness Program
CRS	Commercial Resupply Services
CSA	Canadian Space Agency
CSDA	Commercial SmallSat Data Acquisition
CSESP	Citizen Science for Earth Systems Program
CSI	Calorimeter Spectrometer Insert
CSIM	Compact Spectral Irradiance Monitor
CSLI	CubeSat Launch Initiative
CSM	Crew and Service Module
CSP	Communications Services Program

ACRONYMS AND ABBREVIATIONS

CSPD	Cyber Security Privacy Division
CST	Commercial Supersonic Transport
CT	Computerized Tomography
CY	Calendar Year
CYGNSS	Cyclone Global Navigation Satellite System
DAA	Detect and Avoid
DAAC	Distributed Active Archive Center
DAEP	DSN Aperture Enhancement Project
DALI	Development and Advancement of Lunar Instrumentation
DARPA	Defense Advanced Research Projects Agency
DART	Double Asteroid Redirection Test
DATA	Digital Accountability and Transparency Act
DC	District of Columbia
DCAA	Defense Contract Audit Agency
DCIS	Defense Criminal Investigative Service
DCOTSS	Dynamics and Chemistry of the Summer Stratosphere
DDAP	Discovery Data Analysis Program
DDR	Detailed Design Review
DDT&E	Design, Development, Test, and Evaluation
DEAP	Deep Space Network Aperture Enhancement Project
DEFEND	Dynamic and Evolving Federal Enterprise Network Defense
DEUCE	Dual-Channel Extreme Ultraviolet Continuum Experiment
DHS	Department of Homeland Security
DI	Decadal Incubation
DLR	German Aerospace Center
DM/CM	Document Management/Case Management
DNA	Deoxyribonucleic Acid
DO	Designated Observable
DOE	Department of Energy
DOIMS	Digital Object Identifier Management System
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
DRACO	Didymos Reconnaissance and Asteroid Camera for OpNav
DRAW	Dynamic Routes for Arrivals in Weather
DRIVE	Diversify, Realize, Integrate, Venture, Educate
DRPS	Dynamic RPS
DSAC	Deep Space Atomic Clock
DSCOVR	Deep Space Observatory
DSE	Data System Evolution
DSI	Deutsches SOFIA Institute
DSN	Deep Space Network

ACRONYMS AND ABBREVIATIONS

DSOC	Deep Space Optical Communication
DSRR	DSN Operations Readiness Review
DSS	Deep Space Station
EAP	Electric Aircraft Propulsion
ECI	Early Career Initiative
ECLSS	Environmental Control and Life Support Systems
ECM	Europa Clipper Magnetometer
ECOSTRESS	Ecosystem Spaceborne Thermal Radiometer Experiment on Space Station
ECR	Environmental Compliance and Restoration
eCryo	Evolvable Cryogenics
ECS	Environmental Control System
EDL	Entry, Descent, and Landing
EEO	Equal Employment Opportunity
EES	Emergency Egress Systems
EGS	Exploration Ground Systems
EIA	Equatorial ionization Anomaly
EIK	Extended Interaction Klystrons
EIS	Europa Imaging System
EM	Exploration Mission
EMIT	Earth Surface Mineral Dust Source Investigation
ENA	Energetic Neutral Atoms
ENSO	El Nino Southern Oscillation
EOS	Earth Observation Systems
EOSDIS	Earth Observing System Data and Information System
EPA	Environmental Protection Agency
EPFD	Electrified Powertrain Flight Demonstration
EPIC	Earth Poly-Chromatic Imaging Camera
EPSCoR	Established Program to Stimulate Competitive Research
ERB	Earth Radiation Budget
ERBS	Earth Radiation Budget Science
ERD	Exploration Research and Development
EROS	Earth Resources Observation and Science
ESA	European Space Agency
ESAero	Empirical Systems Aerospace
ESD	Exploration Systems Development
ESDIS	Earth Science Data and Information System
ESDR	Earth System Data Records
ESDS	Earth Science Data Systems
ESM	European Service Module
ESO	Engineering, Safety, and Operations

ACRONYMS AND ABBREVIATIONS

ESPA	EELV Secondary Payload Adapters
ESSP	Earth System Science Pathfinder
ESSP PO	Earth System Science Pathfinder Program Office
ESTP	Earth Science Technology Program
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EUS	Exploration Upper Stage
EUV	Extreme UV
EVA	Extravehicular Activity
EVC	Earth Venture Continuity
EVI	Earth Venture Instruments
EVM	Earth Venture small Missions
EVS	Earth Venture Suborbital
EXCOM	Executive Committee
EXPORTS	Export Processes in the Ocean from Remote Sensing
FAA	Federal Aviation Administration
FAR	Federal Acquisition Regulation
FBI	Federal Bureau of Investigation
FDC	Flight Demonstrations and Capabilities
FEIF	Flight Electronics Integration Facility
FEMA	Federal Emergency Management Agency
FEWS NET	Famine Early Warning System Network
FIRST	For Inspiration and Recognition of Science and Technology
FISMA	Federal Information Security Modernization Act
FITARA	Federal Information Technology Acquisition Reform Act
FMECA	Failure Modes, Effects, and Criticality Analysis
FO	Follow-On
FOC	Full Operational Capability
FRR	Flight Readiness Review
FSR	Formulation Synchronization Review
FSSE	Flight Software Sustaining Engineering
FY	Fiscal Year
GC	Grand Challenge
GDC	Geospace Dynamics Constellation
GDMS	General Dynamic Mission Systems
GE	General Electric
GEDI	Global Ecosystem Dynamics Investigation Lidar
GEO	Geostationary Earth Orbit
GGAO	Goddard Geophysical and Astronomical Observatory
GIMP	Greenland Ice Mapping Project-3
GISS	Goddard Institute for Space Studies

ACRONYMS AND ABBREVIATIONS

GLIMR	Geosynchronous Littoral Imaging and Monitoring Radiometer
GLM	Geostationary Lightning Mapper
GLOBE	Global Learning and Observations to Benefit the Environment
GLS	Gateway Logistics Services
GMI	GPM Microwave Imager
GNSS	Global Navigation Satellite System
GOES	Geostationary Operational Environmental Satellite
GOLD	Global-scale Observations of the Limb and Disk
GPCP	Global Precipitation Climatology Project
GPM	Global Precipitation Measurement
GPS	Global Positioning System
GPSP	Global Positioning System-Payload
GRACE	Gravity Recovery and Climate Experiment
GRC	Glenn Research Center
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
GSI	Ground Systems Implementation
GSLV	Geosynchronous Satellite Launch Vehicle
GUSTO	Galactic/Extragalactic Ultralong duration balloon Spectroscopic Terahertz Observatory
GV	Ground Validation
HALO	Hydrogen Albedo Lunar Orbiter
HAQAST	Health and Air Quality Applied Sciences Team
HARP	Hyper-Angular Rainbow Polarimeter
HCIT	Human Capital Information Technology
HEASARC	High Energy Astrophysics Science Archive Center
HECC	High End Computing Capability
HEOMD	Human Exploration and Operations Mission Directorate
HERA	Human Exploration Research Analog
HERO	Human Exploration Research Opportunity
H-FORT	Heliophysics Flight Opportunities for Research and Technology
HGEP	Hybrid Gas-Electric Propulsion
HHS	Department of Health and Human Services
HIRMES	High Resolution Mid-Infrared Spectrometer
HIS	Heavy Ion Sensor
HLS	Harmonized Landsat/Sentinel
HMTA	Health and Medical Technical Authority
HOME	Habitats Optimized for Missions of Exploration
HP3	Heat Flow and Physical Properties Package
HPA	High Pressure Air
HPSC	High Performance Spaceflight Computing

ACRONYMS AND ABBREVIATIONS

HQ	Headquarters
HRP	Human Research Program
HSFO	Human Space Flight Operations
HT	Hypersonic Technology
HTV	H-II Transfer Vehicle
HVAC	Heating, Ventilating, and Air Conditioning
I&T	Integration & Test
I&TC	Infrastructure & Technical Capabilities
IADS	Integrated Arrival/Departure/Surface
IASP	Integrated Aviation Systems Program
IBEX	Interstellar Boundary Explorer
ICAM	Identify, Credential, and Access Management
ICAO	International Civil Aviation Organization
ICEMAG	Interior Characterization of Europa Using Magnetometry
ICESat	Ice, Cloud, and Land Elevation Satellite
ICON	Ionospheric Connection Explorer
ICPS	Interim Cryogenic Propulsion Stage
IDA	ISS Docking Adapter
IDIQ	Indefinite-Delivery-Indefinite-Quantity
ILLUMA-T	Integrated LCRD LEO User Modem and Amplifier Terminal
IM	Information Management
IMAP	Interstellar Mapping and Acceleration Probe
IMC	International Mission Contributions
IMERG	The Integrated Multi-satellite Retrievals for GPM
IMPACT	Interagency Implementation and Advance Concepts Team
IMPACTS	Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Storms
INL	Idaho National Lab
InSight	Interior Exploration using Seismic Investigations, Geodesy and Heat Transport
InVEST	In-space Validation of Earth Science Technology
IOAG	Interagency Operations Advisory Group
IPAC	The Infrared Processing and Analysis Center
IR	Infrared
IRB	Independent Review Board
IRIS	Interface Region Imaging Spectrograph
IRT	Independent Review Team
IRTF	Infrared Telescope Facility
ISA	Israel Space Agency
ISAAC	Integrated System for Autonomous and Adaptive Caretaking
ISPF	In Space Propulsion Facility
ISRO	Indian Space Research Organisation

ACRONYMS AND ABBREVIATIONS

ISRS	In-Space Robotic Servicing
ISRU	in-situ resource utilization
ISS	International Space Station
IT	Information Technology
ITL	Integrated Test Lab
IV&V	Independent Verification and Validation
IWTF	Industrial Waste Water Tank Facility
IXPE	Imaging X-Ray Polarimetry Explore
JAXA	Japanese Aerospace Exploration Agency
JCL	Joint Confidence Level
JHU	Johns Hopkins University
JPL	Jet Propulsion Laboratory
JPSS	Joint Polar Satellite System
JSC	Johnson Space Center
JUICE	Jupiter Icy Moons Explorer
KARI	Korea Aerospace Research Institute
KaRIn	Ka-band Radar Interferometer
KDP	Key Decision Point
KOA	Keck Observatory Archive
KORUS-AQ	Korea-United States Air Quality Study
KSC	Kennedy Space Center
KUS	Kenney Uplink Station
LANCE	Land, Atmosphere Near real-time Capability for EOS
LANL	Los Alamos National Laboratory
LARC	Langley Research Center
LAS	Launch Abort System
LASP	Laboratory for Atmospheric and Space Physics
LBFD	Low Boom Flight Demonstrator
LC	Launch Complex
LCAS	Low-Cost Access to Space
LCC	Life Cycle Cost
LCLUC	Land Cover/Land Use Change
LCPSO	Land Cover Project Science Office
LCRD	Laser Communications Relay Demo
LCS	Launch Communications Segment
LDEP	Lunar Discovery and Exploration Program
LEED	Leadership in Energy and Environmental Design
LEO	Low Earth Orbit
LEOS	Legal Enterprise Operating System
LETF	Launch Equipment Test Facility

ACRONYMS AND ABBREVIATIONS

LH2	Liquid Hydrogen
LIDAR	Light Detection and Ranging
LIS	Lightning Imaging Sensor
LISA	Laser Interferometer Space Antenna
LLC	Limited Liability Company
LOFTID	LEO-based Flight Test of Inflatable Decelerator
LOX	Liquid Oxygen
LRA	Laser Retro-reflector Assembly
LRD	Launch Readiness Date
LRO	Lunar Reconnaissance Orbiter
LRR	Launch Readiness Review
LSII	Lunar Surface Innovation Initiative
LSP	Launch Services Program
LST	Land Surface Temperature
L'TES	Thermal Emission Spectrometer
LunIR	Lunar InfraRed imaging
LVSA	Launch Vehicle Stage Adapter
LWS	Living With a Star
MAF	Michoud Assembly Facility
MAIA	Multi-Angle Imager for Aerosols
MARCI	Mars Color Imager
MASPEX	The Mass Spectrometer for Planetary Exploration/Europa
MAST	Mikulski Archive for Space Telescopes
MAVEN	Mars Atmosphere & Volatile Evolution
MCL	Metrology and Calibration Laboratory
MCR	Mission Concept Review
MCS	Mars Climate Sounder
MDR	Mission Design Review
MEaSUREs	Making Earth System data records for Use in Research Environments
MEDA	Mars Environmental Dynamics Analyzer
MEDLI	Mars Entry, Descent, and Landing Instrumentation
MEGANE	Mars-moon Exploration with Gamma rays and Neutrons
MES	Mission Enabling Services
MESSENGER	Mercury Surface, Space Environment, Geochemistry, and Ranging
MEVV	Multi-Element Validation and Verification
MIDEX	Medium-Class Explorers
MISE	Mapping Imaging Spectrometer for Europa
MISR	Multi-angle Imaging SpectroRadiometer
MIT	Massachusetts Institute of Technology
MJO	Madden-Julian Oscillation

ACRONYMS AND ABBREVIATIONS

ML	Mobile Launcher
MMRTG	Multi-mission Radioisotope Thermoelectric Generator
MMS	Magnetospheric Multiscale
MMX	Martian Moons Exploration
MO	Missions of Opportunity
MO&I	Mission Operations and Integration
MODIS	Moderate Resolution Imaging Spectroradiometer
MOMA	Mars Organic Molecule Analyzer
MOMA-MS	Mars Organic Molecule Analyzer Mass Spectrometer
MOPS	Minimum Operational Performance Standards
MOXIE	Mars Oxygen ISRU Experiment
MPAR	Major Program Annual Report
MPPF	Multi-Payload Processing Facility
MRO	Mars Reconnaissance Orbiter
MS	Mass Spectrometer
MSF	Modular Supercomputing Facility
MSFC	Marshall Space Flight Center
MSL	Measurement Systems Laboratory
MSR	Mars Sample Return
MTB	Multirotor Test Bed
MUREP	Minority University Research and Education Program
MUSS	Multi User Systems and Support
MW	Megawatt
NAC	National Agency Check
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASEM	National Academies of Science, Engineering, and Mathematics
NAVO	NASA Astronomical Virtual Observatories
NCRP	National Council on Radiation Protection
NDE	Non-Destructive Evaluation
NEA	Near Earth Asteroid
NEAT	NASA Electric Aircraft Testbed
NED	NASA/IPAC Extragalactic Database
NEN	Near Earth Network
NEO	Near-Earth objects
NEOO	Near-Earth Object Observations
NEOWISE	Near Earth Objects Wide-field Infrared Survey Explorer
NESC	NASA Engineering and Safety Center
NET	No Earlier Than
NextSTEP	Next Space Technologies for Exploration

ACRONYMS AND ABBREVIATIONS

NG	Northrop Grumman
NGAP	NASA Compliant General Application Platform
NGAS	Northrop Grumman Aerospace Systems
NGIS	Northrop Grumman Innovation Systems
NIAC	NASA Innovative Advanced Concepts
NICER	Neutron star Interior Composition Explorer
NID	NASA Interim Directive
NIF	NASA Industry Forum
NIH	National Institutes of Health
NIRCam	Near Infrared Camera
NISAR	NASA-ISRO Synthetic Aperture Radar
NIST	National Institute of Standards and Technology
NISTAR	National Institute of Standards and Technology Advances Radiometer
NLS	NASA Launch Services
NOAA	National Oceanographic and Atmospheric Administration
NOS	New Observing Strategies
NOx	Mono Nitrogen Oxide
NPP	National Polar-orbiting Partnership
NRA	NASA Research Announcement
NRHO	Near Rectilinear Halo Orbit
NRPTA	National Rocket Propulsion Test Alliance
NSC	NASA Safety Center
NSF	National Science Foundation
NSPM-20	National Security Presidential Memorandum-20
NSS	National Security Systems
NSSDCA	National Space Science Data Coordinated Archive
NTRS	NASA Technical Reports Server
NTTS	NASA's Technology Transfer System
NuSTAR	Nuclear Spectroscopic Telescope Array
O&M	Operations and Maintenance
O&TM	Operations and Test Management
O2O	Optical to Orion
OA	Office of Audits
OCE	Office of the Chief Engineer
OCFO	Office of the Chief Financial Officer
OCHCO	Office of Chief Human Capital Officer
OCHMO	Office of Chief Health Medical Officer
OCIO	Office of the Chief Information Officer
OCO	Orbiting Carbon Observatory
OCOMM	Office of Communications

ACRONYMS AND ABBREVIATIONS

OCSD	Optical Communications and Sensor Demonstration
OCT	Office of the Chief Technologist
ODEO	Office of Diversity and Equal Opportunity
OFT	Orbital Flight Test
OGC	Office of General Counsel
OGS	Optical Ground Station
OI	Office of Investigations
OIG	Office of Inspector General
OLI	Operational Land Imager
OLIA	Office of Legislative and Intergovernmental Affairs
OMB	Office of Management and Budget
OMG	Oceans Melting Greenland
OMI	Ozone Monitoring Instrument
OMPS	Ozone Mapping and Profiler Suite
OMS	Orbital Maneuvering System
ONERA	French Office National d'Etudes et Recherches Aérospatiales
OP	Office of Procurement
OPR	Operating Pressure Ratio
OPS	Office of Protective Services
ORR	Operational Readiness Review
OSAM	On-Orbit Servicing, Assembly, and Manufacturing
OSBP	Office of Small Business Programs
OSC	Orbital Sciences Corporation
OSHA	Occupational Safety and Health Administration
OSIRIS-REx	Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer
OSMA	Office of Safety and Mission Assurance
OSMU	Orion Service Module Umbilical
OSST	Ocean Salinity Science Team
OSTM	Ocean Surface Topography Mission
OSTST	Ocean Surface Topography Science Team
OTE	Optical Telescope Element
OTIS	Optical Telescope and Integrated Science Instrument Module
P.L.	Public Law
PAC	Planetary Science Advisory Committee
PB	President's Budget
PBS	Plum Brook Station
PCOS	Physics of the Cosmos
PCSF	Procurement Collusion Strike Force
PD	Position Description
PDCO	Planetary Defense Coordination Office

ACRONYMS AND ABBREVIATIONS

PDR	preliminary design review
PDS	Planetary Data System
PEP	Particle Environment Package
PFAS	Per- and Polyfluoroalkyl Substances
PGN	Pandonia Global Network
PHO	Potentially Hazardous Objects
PHSF	Payload Hazardous Servicing Facility
PI	Principal Investigator
PIMS	Plasma Instrument for Magnetic Sounding
PIR	Program Implementation Review
PIV	Personal Identity Verification
PIXL	Planetary Instrument for X-ray Lithochemistry
PLI	Propellant, Liner, and Insulation
PMPO	Planetary Missions Program Office
PMT	Program Management Team
PNTAB	Positioning, Navigation, and Timing Advisory
POWER	Protecting Our Workers and Ensuring Reemployment
PPE	Power and Propulsion Element
PPF	Payload Processing Facility
PPM	Program Project Management
PQM	Propulsion Qualification Module
PREFIRE	Polar Radiant Energy In The Far Infrared Experiment
PTD	Pathfinder Technology Demonstrator
PTS	Propellant Transfer Subsystem
PU	Plutonium
PUFFER	Pop-Up Flat Folding Explorer Robot
PUNCH	Polarimeter to Unify the Corona and Heliosphere
QueSST	Quiet Supersonic Technology
QuikSCAT	Quick Scatterometer
R&A	Research and Analysis
R&D	Research and Development
R&T	Research and Technology
RAMPT	Rapid Analysis and Manufacturing Propulsion Technology
RAP	Robotics Alliance Project
RapidScat	Rapid Scatterometer
RDAP	Rosetta Data Analysis Program
RDT&E	Research, Development, Test and Evaluation
REASON	Radar for Europa Assessment and Sounding: Ocean to Near-surface
RF	Radio Frequency
RFI	Request for Information

ACRONYMS AND ABBREVIATIONS

RFID	Radio Frequency Identification
RFP	Request for Proposal
RFU	Radio Frequency Unit
RHESSI	Ramaty High Energy Solar Spectroscopic Imager
RHU	Radioisotope Heater Unit
RIME	Radar for Icy Moons Exploration
RO	Radio Occultation
ROSA	Roll Out Solar Array
ROSES	Research Opportunities in Space and Earth Sciences
RPS	Radioisotope Power Systems
RPSF	Rotation, Processing, and Surge Facility
RPT	Rocket Propulsion Testing
RS	Reflected Solar
RTCA	Radio Technical Commission for Aeronautics
RTG	Radioisotope Thermoelectric Generator
RVLT	Revolutionary Vertical Lift Technology
RWT	Robotic Weld Tool
SAGE	Stratospheric Aerosol and Gas Experiment
SAM	Sample Analysis at Mars (Planetary Science)
SAR	Synthetic Aperture Radar
SARI	South/Southeast Asia Regional Initiative
SASS	Small Altitude Simulation System
SAT	Strategic Astrophysics Technology
SBIR	Small Business Innovation Research
SCaN	Space Communications and Navigation
SCE	Spacecraft Element
SCMD	Science Mission Directorate
SCS	Supplemental Calibration System
SDAP	Science Data Analytics Platform
SDN	Software Defined Networking
SDO	Solar Dynamics Observatory
SDPC	Science Data Processing Center
SDR	System Design Review
SE&I	Systems Engineering and Integration
SEC	Space Environments Complex
SEDAC	Socio-economic Data and Applications Center
SEIS	Seismic Experiment for Interior Structure
SEP	solar electric propulsion
SET	Space Environment Testbeds
SFCO	Space Flight Crew Operations

ACRONYMS AND ABBREVIATIONS

SFOF	Space Flight Operations Facility
SFS	Space and Flight Support
SGLT	Space-Ground Link Terminals
SGP	Space Geodesy project
SGSLR	Space Geodesy Satellite Laser Ranging
SGSS	Space Network Ground Segment Sustainment
SHERLOC	Scanning Habitable Environments with Raman & Luminescence for Organics and Chemicals
SIF	Solar Induced Chlorophyll Fluorescence
SIO	Systems Integration and Operationalization
SIPS	Science Investigator-led Processing Systems
SIR	System Integration Review
SIRIUS	Scientific International Research in Unique Terrestrial Station
SISTINE	Suborbital Imaging Spectrograph for Transition region Irradiance from Nearby Exoplanet
SLI	Sustainable Land Imaging
SLPSRA	Space Life and Physical Sciences Research and Applications
SLS	Space Launch System
SM	Service Module
SMA	Safety and Mission Assurance
SMAP	Soil Moisture Active/Passive
SMART-VG	Shape Memory Alloy Reconfigurable Technology-Vortex Generator
SMBH	Super Massive Black Holes
SMD	Science Mission Directorate
SMEX	Small Explorers
S-MODE	Sub-Mesoscale Ocean Dynamics and Vertical Transport
SMS	Safety and Mission Success
SN	Space Network
SNC	Sierra Nevada Corporation
SNWG	Satellite Needs Working Group
SOC	Solar Orbiter Collaboration
SOFIA	Stratospheric Observatory for Infrared Astronomy
SOHO	Solar and Heliospheric Observatory
SoloHI	Solar Orbiter Heliospheric Imager
SOST	Subcommittee on Ocean Science and Technology
SpaceX	Space Exploration Technologies Inc.
SPD	Space Policy Directive
SPHERES	Synchronized Position Hold, Engage, Reorient, and Experimental Satellites
SPHEREx	Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ices Explorer
SPIDER	Space Infrastructure Dexterous Robot
SPLICE	Safe and Precise Landing-Integrated Capabilities Evolution

ACRONYMS AND ABBREVIATIONS

SR&T	Strategic Research and Technology
SRB	Standing Review Board
SRC	Sample Return Capsule
SRR	Systems Requirement Review
SSC	Stennis Space Center
SSFL	Santa Susana Field Laboratory
SSI	Solar Spectral Irradiance
SSL	Space Systems Loral
SSMS	Safety, Security, and Mission Services
STAR	Strategic Technology Architecture Round-table
STDT	Science and Technology Definition Team
STEM	Science, Technology, Education, and Mathematics
STEREO	Solar Terrestrial Relations Observatory
STEVE	Strong Thermal Emission Velocity Enhancement
STI	Scientific and Technical Information
STMD	Space Technology Mission Directorate
STP	Solar Terrestrial Probes
STRG	Space Technology Research Grants
STScI	Space Telescope Science Institute
STTR	Small Business Technology Transfer
SUDA	Surface Dust Mass Analyzer
SWOT	Surface Water Ocean Topography
SWP	Strategic Workforce Plan
SWRI	Southwest Research Institute
SWS	System-Wide Safety
TACP	Transformative Aeronautics Concepts Program
TAG	Touch-And-Go
TALOS	Thruster Advancement for Low-Temperature Operations in Space
TBCC	Turbine-Based Combined Cycle
TBD	To Be Determined
TBIRD	Terabyte Infrared Delivery
TBM	Technology Business Management
TC	Tropical Cyclone
TCL	Technical Capability Level
TDE	Tidal Disruption Event
TDRS	Tracking and Data Relay Satellite
TEMPO	Tropospheric Emissions: Monitoring of Pollution
TESS	Transiting Exoplanet Survey Satellite
TGO	Trace Gas Orbiter
THEMIS	Time History of Events and Macroscale Interactions during Substorms

ACRONYMS AND ABBREVIATIONS

TI	Technology Investments
TIMED	Thermosphere Ionosphere Mesosphere Energetics and Dynamics
TIRS	Thermal Infrared Sensor
TLI	Trans-Lunar Injection
TOPEX	Topography Experiment
TP	Tipping Point
TPS	Thermal Protection System
TRACERS	Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites
TREAT	To Research, Evaluate, Assess, and Treat
TRIDENT	The Regolith and Ice Drill for Exploring New Terrain
TRISH	Translational Research Institute for Space Health
TRL	Technology Readiness Level
TRMM	Tropical Rainfall Measurement Mission
TRN	Terrain Relative Navigation
TROPICS	Time-Resolved Observations of Precipitation Structure and Storm Intensity with a Constellation of SmallSats
TSI	Total Solar Irradiance
TSIS	Total and Spectral Solar Irradiance Sensor
TTBW	Transonic Truss-Braced Wing
TTT	Transformational Tools and Technologies
TUI	Tethers Unlimited Inc.
TWINS	Two Wide-angle Imaging Neutral-atom Spectrometers
U.S.	United States
UAG	Users' Advisory Group
UAM	Urban Air Mobility
UARC	University Affiliated Research Center
UAS	Unmanned Aircraft Systems
UCLA	University of California Los Angeles
UFE	Unallocated Future Expenses
UI	University Innovation
UKSA	United Kingdom Space Agency
ULA	United Launch Alliance
ULDB	Ultra-Long Duration Balloon
ULI	University Leadership Initiative
ULS	United Launch Services
UPS	Uninterruptable Power System
UQ	Uncertainty Quantification
URT	Underway Recovery Test
USAF	U.S. Air Force
USAID	U.S. Agency for International Development

ACRONYMS AND ABBREVIATIONS

US-COMP	Ultra-Strong Composites by Computational Design
USDA	U.S. Department of Agriculture
USG	U.S. Government
USGCRP	U.S. Global Change Research Program
USGS	U.S. Geological Survey
USOS	U.S. Operating Segment of ISS
USRA	Universities Space Research Association
UTM	UAS Traffic Management
UV	Ultraviolet
UVS	Ultraviolet Spectrograph
UWMS	Universal Waste Management System
V&V	Verification and Validation
VAB	Vehicle Assembly Building
VAFB	Vandenberg Air Force Base
VCLS	Venture Class Launch Services
VGOS	VLBI Global Observing System
VIIRS	Visible Infrared Imaging Radiometer
VIPER	Volatiles Investigating Polar Exploration Rover
VLBI	Very Long Baseline Interferometry
VMS	Virtual Motion Simulator
VO	Virtual Observatory
VOIP	Voice over Internet Protocols
VPP	Voluntary Protection Program
VTOL	Vertical Take Off and Landing
WAN	Wide Area Networks
Webb	James Webb Space Telescope
WFF	Wallops Flight Facility
WFIRST	Wide-Field Infrared Survey Telescope
WISE	Wide-field Infrared Survey Explorer
WIT	Water Impact Testing
WIYN	Wisconsin, Indiana, Yale, and NOAO Telescope
WMKO	W.M. Keck Observatory
WRC	World Radiocommunications Conferences
WSC	White Sands Complex
WSTF	White Sands Test Facility
WWAO	Western Water Applications Office
XMM	X-Ray Multi-Mirror Mission
XRISM	X-Ray Imagining and Spectroscopy
XVS	External Vision System