National Aeronautics and Space Administration

FY 2020

EXPLORE

BUDGET ESTIMATES

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FY 2020 PRESIDENT'S BUDGET REQUEST SUMMARY

Budget Authority ($ in millions)	Operating Plan 2018	Enacted 2019	PBR 2020	Fiscal Year 2021	2022	2023	2024
NASA Total	20,736.1	21,500.0	21,019.0	21,229.2	21,441.5	21,655.9	21,872.5
Deep Space Exploration Systems	4,790.0	5,050.8	5,021.7	5,295.5	5,481.4	6,639.0	7,042.3
Exploration Systems Development	4,395.0	4,092.8	3,441.7	3,441.0	3,468.4	3,788.5	3,654.7
Exploration Research & Development	395.0	958.0	1,580.0	1,854.5	2,013.0	2,850.4	3,387.6
Exploration Technology	760.0	926.9	1,014.3	976.1	995.4	964.4	943.1
LEO and Spaceflight Operations	4,749.2	4,639.1	4,285.7	4,369.5	4,369.5	4,235.5	4,182.3
International Space Station	1,493.0	--	1,458.2	1,448.5	1,449.4	1,352.6	1,315.7
Space Transportation	2,345.8	--	1,828.6	1,854.1	1,814.5	1,746.2	1,727.2
Space and Flight Support (SFS)	910.3	--	848.9	891.9	905.7	911.8	914.5
Commercial LEO Development	--	--	150.0	175.0	200.0	225.0	225.0
Science	6,211.5	6,905.7	6,303.7	6,319.0	6,319.0	5,846.5	5,815.0
Earth Science	1,921.0	--	1,779.8	1,785.6	1,779.7	1,666.5	1,674.6
Planetary Science	2,217.9	--	2,622.1	2,577.3	2,629.4	2,402.4	2,350.9
Astrophysics	850.4	--	844.8	902.4	965.2	913.5	907.7
James Webb Space Telescope	533.7	375.1	352.6	415.1	175.4	172.0	172.0
Heliophysics	688.5	--	704.5	638.6	769.3	692.0	709.8
Aeronautics	690.0	725.0	666.9	673.6	680.3	587.1	587.0
STEM Engagement	100.0	110.0	--	--	--	--	--
Safety, Security, and Mission Services	2,826.9	2,755.0	3,084.6	3,084.6	3,084.6	2,871.6	2,871.6
Center Management and Operations	1,983.4	--	2,065.0	2,058.4	2,052.9	1,906.0	1,905.8
Agency Management and Operations	843.5	--	1,019.6	1,026.2	1,031.7	965.6	965.8
Construction and Environmental Compliance and Restoration	569.5	348.2	600.4	468.8	468.8	468.8	387.8
Construction of Facilities	483.1	--	517.5	385.9	385.9	385.9	304.9
Environmental Compliance and Restoration	86.4	--	82.9	82.9	82.9	82.9	82.9
Inspector General	39.0	39.3	41.7	42.1	42.5	43.0	43.4
NASA Total	20,736.1	21,500.0	21,019.0	21,229.2	21,441.5	21,655.9	21,872.5

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

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	Fiscal Year						
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NASA Total	**20,736.1**	**21,500.0**	**21,019.0**	**21,229.2**	**21,441.5**	**21,655.9**	**21,872.5**
Deep Space Exploration Systems	**4,790.0**	**5,050.8**	**5,021.7**	**5,295.5**	**5,481.4**	**6,639.0**	**7,042.3**
Exploration Systems Development	**4,395.0**	**4,092.8**	**3,441.7**	**3,441.0**	**3,468.4**	**3,788.5**	**3,654.7**
Orion Program	**1,350.0**	**1,350.0**	**1,266.2**	**1,245.7**	**1,146.7**	**1,119.3**	**1,000.0**
Crew Vehicle Development	**1,339.5**	**1,339.5**	**1,255.7**	**1,235.2**	**1,136.2**	**1,107.2**	**990.0**
Orion Program Integration and Support	**10.5**	**--**	**10.5**	**10.5**	**10.5**	**12.1**	**10.0**
Space Launch System	**2,150.0**	**2,150.0**	**1,775.4**	**1,837.5**	**1,933.0**	**2,221.2**	**2,253.3**
Launch Vehicle Development	**2,093.9**	**2,099.1**	**1,715.3**	**1,772.8**	**1,871.7**	**2,160.0**	**2,197.3**
SLS Program Integration and Support	**56.1**	**--**	**60.1**	**64.7**	**61.3**	**61.1**	**56.0**
Exploration Ground Systems	**895.0**	**592.8**	**400.1**	**357.8**	**388.7**	**448.1**	**401.3**
Exploration Ground Systems Development	**878.2**	**587.8**	**396.5**	**350.1**	**385.1**	**444.5**	**401.3**
EGS Program Integration and Support	**16.8**	**--**	**3.6**	**7.7**	**3.6**	**3.6**	**--**
Exploration Research & Development	**395.0**	**958.0**	**1,580.0**	**1,854.5**	**2,013.0**	**2,850.4**	**3,387.6**
Advanced Exploration Systems	**237.8**	**--**	**255.6**	**239.8**	**188.3**	**146.7**	**130.1**
Advanced Cislunar and Surface Capabilities	**--**	**--**	**363.0**	**647.0**	**967.7**	**1,775.9**	**2,360.0**
Gateway	**17.2**	**--**	**821.4**	**827.7**	**717.0**	**787.8**	**757.5**
Human Research Program	**140.0**	**--**	**140.0**	**140.0**	**140.0**	**140.0**	**140.0**
Exploration Technology	**760.0**	**926.9**	**1,014.3**	**976.1**	**995.4**	**964.4**	**943.1**
Early Stage Innovation and Partnerships	**91.9**	**--**	**123.4**	**118.0**	**123.0**	**118.0**	**123.0**
Technology Maturation	**151.5**	**--**	**282.5**	**227.2**	**250.3**	**246.7**	**328.0**
Technology Demonstration	**321.7**	**--**	**397.5**	**411.8**	**391.4**	**362.3**	**231.2**
Laser Comm Relay Demo (LCRD)	**21.5**	**17.2**	**--**	**--**	**--**	**--**	**--**
Solar Electric Propulsion (SEP)	**34.2**	**--**	**43.4**	**20.9**	**4.0**	**2.6**	**--**
Restore/In-Space Robotic Servicing (ISRS)	**130.0**	**180.0**	**45.3**	**45.3**	**45.3**	**--**	**--**
Small Spacecraft, Flight Opportunities & Other Tech Demonstration	**136.0**	**--**	**308.8**	**345.6**	**342.1**	**359.6**	**231.2**
SBIR and STTR	**194.8**	**--**	**210.8**	**219.1**	**230.8**	**237.5**	**261.0**
LEO and Spaceflight Operations	**4,749.2**	**4,639.1**	**4,285.7**	**4,369.5**	**4,369.5**	**4,235.5**	**4,182.3**
International Space Station	**1,493.0**	**--**	**1,458.2**	**1,448.5**	**1,449.4**	**1,352.6**	**1,315.7**
International Space Station Program	**1,493.0**	**--**	**1,458.2**	**1,448.5**	**1,449.4**	**1,352.6**	**1,315.7**
ISS Systems Operations and Maintenance	**1,117.6**	**--**	**1,105.5**	**1,079.8**	**1,088.7**	**1,007.5**	**983.1**
ISS Research	**375.4**	**--**	**352.7**	**368.7**	**360.7**	**345.1**	**332.6**
Space Transportation	**2,345.8**	**--**	**1,828.6**	**1,854.1**	**1,814.5**	**1,746.2**	**1,727.2**
Crew and Cargo Program	**1,613.9**	**--**	**1,726.6**	**1,789.6**	**1,751.2**	**1,683.0**	**1,662.6**
Commercial Crew Program	**731.9**	**--**	**102.0**	**64.5**	**63.2**	**63.2**	**64.6**
Space and Flight Support (SFS)	**910.3**	**--**	**848.9**	**891.9**	**905.7**	**911.8**	**914.5**
Space Communications and Navigation	**638.8**	**--**	**611.0**	**632.4**	**593.0**	**562.9**	**557.0**
Space Communications Networks	**560.2**	**--**	**468.1**	**483.4**	**457.5**	**448.3**	**448.6**
Space Communications Support	**78.7**	**--**	**142.9**	**149.0**	**135.5**	**114.6**	**108.5**

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Budget Authority ($ in millions)	Operating Plan 2018	Enacted 2019	PBR 2020	2021	2022	2023	2024
			Fiscal Year				
Human Space Flight Operations	124.4	--	99.8	99.9	109.5	111.4	112.4
Launch Services	86.8	--	88.6	88.6	88.6	88.6	88.6
Rocket Propulsion Test	46.0	--	46.5	47.6	47.6	47.6	47.6
Communications Services Program	--	--	3.0	23.4	67.0	101.2	108.9
21st Century Space Launch Complex	14.3	--	--	--	--	--	--
Commercial LEO Development	--	--	150.0	175.0	200.0	225.0	225.0
Science	6,211.5	6,905.7	6,303.7	6,319.0	6,319.0	5,846.5	5,815.0
Earth Science	1,921.0	--	1,779.8	1,785.6	1,779.7	1,666.5	1,674.6
Earth Science Research	461.6	--	447.9	466.9	484.1	508.1	532.4
Earth Science Research and Analysis	344.3	--	296.2	314.2	320.0	322.3	325.7
Computing and Management	117.4	--	151.7	152.7	164.2	185.9	206.7
Earth Systematic Missions	899.4	--	719.2	701.5	664.1	501.5	481.3
Surface Water and Ocean Topography Mission (SWOT)	105.9	109.1	82.2	63.9	32.8	11.5	9.5
NASA-ISRO Synthetic Aperature Radar (NISAR)	67.1	146.0	114.0	68.2	81.0	32.4	22.8
Landsat 9	175.8	162.3	108.9	94.2	10.8	2.9	3.0
Sentinel-6	53.4	70.4	64.5	20.4	14.9	35.3	52.9
Other Missions and Data Analysis	497.2	--	349.7	454.8	524.7	419.4	393.2
Earth System Science Pathfinder	242.0	--	275.4	255.1	253.0	265.2	248.3
Venture Class Missions	179.2	--	199.2	183.2	188.1	197.5	183.4
Other Missions and Data Analysis	62.8	--	76.1	71.9	64.9	67.7	64.9
Earth Science Data Systems	204.4	--	214.4	229.0	239.3	250.1	267.7
Earth Science Technology	60.4	--	69.6	79.2	82.8	84.6	86.4
Applied Sciences	53.2	--	53.3	53.9	56.3	57.0	58.5
Planetary Science	2,217.9	--	2,622.1	2,577.3	2,629.4	2,402.4	2,350.9
Planetary Science Research	279.5	--	266.2	272.6	268.6	270.2	301.9
Planetary Science Research and Analysis	197.9	--	183.8	188.0	181.9	180.9	204.7
Other Missions and Data Analysis	81.6	--	82.4	84.7	86.7	89.3	97.2
Planetary Defense	76.0	--	150.0	150.0	150.0	99.5	100.0
DART	41.0	98.0	72.4	66.4	9.1	4.5	--
Other Missions and Data Analysis	35.0	--	77.6	83.6	140.9	95.0	100.0
Lunar Discovery and Exploration	22.0	--	210.0	327.0	417.0	441.0	458.0
Discovery	258.3	--	502.7	393.4	364.4	371.6	371.6
Lucy	81.4	170.5	218.5	153.4	56.0	16.5	18.6
Psyche	42.0	--	213.2	181.9	156.4	33.7	24.0
Other Missions and Data Analysis	134.9	--	71.0	58.1	152.0	321.4	329.0
New Frontiers	88.1	--	190.4	261.2	341.9	387.3	291.7
Mars Exploration	678.0	--	546.5	472.2	481.7	506.1	590.1
Mars Rover 2020	505.8	305.6	278.0	145.0	110.0	60.0	60.0
Other Missions and Data Analysis	172.2	--	268.5	327.2	371.7	446.1	530.1
Outer Planets and Ocean Worlds	676.2	--	608.4	549.6	463.7	224.2	68.8
Jupiter Europa	595.0	740.0	592.6	530.8	445.1	207.3	54.6
Other Missions and Data Analysis	81.2	--	15.8	18.8	18.6	16.9	14.2
Radioisotope Power	139.8	--	147.9	151.3	142.1	102.5	168.8
Astrophysics	850.4	--	844.8	902.4	965.2	913.5	907.7
Astrophysics Research	203.1	--	250.7	309.3	302.5	299.1	298.8

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			Fiscal Year				
Astrophysics Research and Analysis	74.1	--	86.6	90.2	92.2	94.2	94.2
Balloon Project	36.6	--	44.8	44.8	44.8	44.8	44.8
Science Activation	44.0	--	45.6	45.6	45.6	45.6	45.6
Other Missions and Data Analysis	48.5	--	73.7	128.7	119.9	114.5	114.2
Cosmic Origins	211.2	--	185.3	173.9	181.7	121.7	121.7
Hubble Space Telescope Operations	98.3	--	83.3	93.3	98.3	98.3	98.3
Stratospheric Observatory for Infrared Astronomy (SOFIA)	85.2	--	73.0	60.0	60.0	--	--
Other Missions and Data Analysis	27.7	--	29.0	20.6	23.4	23.4	23.4
Physics of the Cosmos	118.0	--	148.4	128.5	123.3	117.8	117.4
Exoplanet Exploration	200.8	--	46.4	44.3	45.6	46.1	48.5
Astrophysics Explorer	117.4	--	214.1	246.4	312.0	328.8	321.4
James Webb Space Telescope	533.7	375.1	352.6	415.1	175.4	172.0	172.0
Heliophysics	688.5	--	704.5	638.6	769.3	692.0	709.8
Heliophysics Research	206.3	--	237.0	223.6	214.7	219.3	222.0
Heliophysics Research and Analysis	54.5	--	66.6	58.6	58.6	58.6	58.6
Sounding Rockets	59.0	--	63.1	68.1	60.1	65.1	65.1
Research Range	24.8	--	28.7	27.0	26.0	26.4	26.4
Other Missions and Data Analysis	68.1	--	78.6	69.9	69.9	69.2	71.8
Living with a Star	376.1	--	107.6	83.6	108.7	121.9	118.3
Solar Orbiter Collaboration	59.2	62.3	4.1	4.2	4.2	4.3	4.3
Other Missions and Data Analysis	316.9	--	103.5	79.4	104.4	117.6	114.0
Solar Terrestrial Probes	45.2	--	177.9	220.4	210.9	192.7	152.0
Heliophysics Explorer Program	60.9	--	182.0	111.1	235.0	158.1	217.5
ICON	19.0	4.7	1.4	--	--	--	--
Other Missions and Data Analysis	41.9	--	180.6	111.1	235.0	158.1	217.5
Aeronautics	690.0	725.0	666.9	673.6	680.3	587.1	587.0
Aeronautics	690.0	725.0	666.9	673.6	680.3	587.1	587.0
Airspace Operations and Safety Program	118.7	--	121.2	130.6	133.5	136.2	138.9
Advanced Air Vehicles Program	237.7	--	188.1	203.3	212.2	219.3	224.2
Integrated Aviation Systems Program	221.5	--	233.2	209.4	202.2	97.1	87.2
Low Boom Flight Demonstrator	127.2	105.9	103.5	79.1	75.5	13.8	3.8
Integrated Aviation Systems Program	94.3	--	129.7	130.3	126.7	83.3	83.4
Transformative Aero Concepts Program	112.2	--	124.4	130.3	132.3	134.6	136.7
STEM Engagement	100.0	110.0	--	--	--	--	--
Aerospace Research and Career Development	58.0	65.0	--	--	--	--	--
National Space Grant College and Fellowship Project	40.0	44.0	--	--	--	--	--
Experimental Project To Stimulate Competitive Research (EPSCoR)	18.0	21.0	--	--	--	--	--
STEM Education and Accountability	42.0	--	--	--	--	--	--
Minority University Research Education Project	32.0	--	--	--	--	--	--
STEM Education and Accountability Projects	10.0	--	--	--	--	--	--

National Aeronautics and Space Administration

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Safety, Security, and Mission Services	2,826.9	2,755.0	3,084.6	3,084.6	3,084.6	2,871.6	2,871.6
Center Management and Operations	1,983.4	--	2,065.0	2,058.4	2,052.9	1,906.0	1,905.8
Center Institutional Capabilities	1,536.8	--	1,641.2	1,627.6	1,613.4	1,459.2	1,454.2
Center Programmatic Capabilities	446.6	--	423.8	430.8	439.5	446.8	451.6
Agency Management and Operations	843.5	--	1,019.6	1,026.2	1,031.7	965.6	965.8
Agency Management	363.7	--	390.4	397.0	402.3	336.9	343.0
Safety and Mission Success	175.7	--	192.0	192.0	194.2	186.2	186.2
Safety and Mission Assurance	49.2	--	57.0	57.0	59.0	51.0	51.0
Chief Engineer	83.0	--	91.5	91.5	91.5	91.5	91.5
Chief Health and Medical Officer	4.4	--	4.4	4.4	4.6	4.6	4.6
Independent Verification and Validation	39.1	--	39.1	39.1	39.1	39.1	39.1
Agency IT Services (AITS)	277.3	--	275.7	275.7	263.9	271.1	260.1
IT Management	29.4	--	18.3	18.3	19.2	20.6	19.1
Enterprise IT	247.9	--	257.4	257.4	244.7	250.5	241.0
Strategic Capabilities Asset Program	26.8	--	161.5	161.5	171.3	171.4	176.5
Construction and Environmental Compliance and Restoration	569.5	348.2	600.4	468.8	468.8	468.8	387.8
Construction of Facilities	483.1	--	517.5	385.9	385.9	385.9	304.9
Institutional CoF	348.3	--	430.6	385.9	385.9	385.9	304.9
Exploration CoF	95.9	--	52.1	--	--	--	--
Space Operations CoF	23.9	--	19.5	--	--	--	--
Science CoF	15.0	--	15.3	--	--	--	--
Environmental Compliance and Restoration	86.4	--	82.9	82.9	82.9	82.9	82.9
Inspector General	39.0	39.3	41.7	42.1	42.5	43.0	43.4
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MESSAGE FROM THE ADMINISTRATOR

As the international leader in space for 60 years, NASA has achieved inspiring feats of exploration, discovery, science and technology. We have changed the way the world flies, communicates, navigates, predicts weather, and so much more.
President Trump's Fiscal Year 2020 NASA budget is one of the strongest on record for our storied agency. In keeping with Space Policy Directive-1, it provides for the foundation of a national exploration campaign that will use the experience of the NASA workforce, coupled with the agility and innovation of our commercial and international partners, to create an exploration architecture that is open, sustainable and agile. This unified effort will inspire generations and change the course of history as we realize the next great scientific, economic and technical achievements in space.

The 2020 NASA budget supports a sustainable campaign of exploration, returning humans to lunar orbit and then the surface of the Moon, and eventually embarking on human missions to Mars and other destinations.

In low-Earth orbit, our Commercial Crew program remains strong and will soon be delivering American astronauts, on American rockets, from American soil to the International Space Station for the first time since 2011. The successes of our commercial and international partnerships on the International Space Station are now serving as the foundation for moving deeper into space.

For the first time in a decade, NASA has a budget for pursuing activities on the lunar surface. We have called on American companies to help design and develop human lunar landers and reusable systems for surface activities. The Space Launch System and Orion, critical components of our exploration architecture, will reach important milestones in construction and testing this year, and our new lunar command module, the Gateway, will see international and commercial partnerships solidified and construction begin.

With this budget we will initiate the first round trip mission to the Red Planet with a Mars sample return mission, and many of the technological advancements we achieve moving forward to the Moon will provide critical data and capabilities for future robotic and crewed Mars missions. NASA is positioned to provide American leadership across each of these key destinations, empowering industry and the international community to move off the Earth in a unified, collaborative way.

As this Administration places a priority on human exploration, the whole of NASA benefits with robust budgets and synergy across our mission directorates. We will continue to pursue transformative aeronautics technology as we develop the next generation of aircraft and make air travel safer and more efficient. We will increase our understanding of our home planet and move out on ambitious programs to study the far reaches of our solar system and beyond. Through the leadership and investment of this Administration, the world will participate together in civilization-changing discoveries and achievements. The fiscal year 2020 NASA budget is strong. We will explore, discover and inspire, and all of humanity will benefit from our efforts. We are NASA.

MESSAGE FROM THE ADMINISTRATOR

We will increase our understanding of our home planet and move out on ambitious programs to study the far reaches of our solar system and beyond.

Through the leadership and investment of this Administration, the world will participate together in civilization-changing discoveries and achievements.

The fiscal year 2020 NASA budget is strong. We will explore, discover and inspire, and all of humanity will benefit from our efforts.

We are NASA, Ad astra

James F. Bridenstine
Administrator

NOTES ON THE BUDGET

The President's strong support and vision for NASA are reflected in the FY 2020 President's Budget, which will drive new exploration. NASA's historic and enduring purpose is captured in four major strategic thrusts: Discover, Explore, Develop, 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.

NASA conducts its missions in support of and aligned to six National strategic themes:

Making New Discoveries, Expanding Human Knowledge and Pushing Human Presence Deeper into Space

NASA's discoveries re-write science textbooks and transform our knowledge of ourselves, our planet, solar system, and universe. Through its missions and sponsored research, NASA provides access to the farthest reaches of space, time, and essential information about our home planet. We seek 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 relationship with our quality of life and our economy. From scientific discovery, expanding human presence in space, to helping the nation in other ways, are all built upon developing new technologies that fuel this exploration.

One of NASA's core missions is to expand scientific knowledge through exploration. Currently, we do this by tackling some of the world's greatest questions: Are we alone? How does our planet work? What can the Moon teach us about the history of the Earth, and the development of life in our solar system? Addressing these and other questions yields insights into the human condition and advances humanity's scientific knowledge.

Strengthening Global Engagement and Diplomacy

Since its establishment in 1958, international cooperation has been a significant component of NASA's missions, playing a unique role in U.S. global engagement and diplomacy. This role extends from data sharing agreements to joint science and technology payloads, all the way up to major diplomatic initiatives. For example, NASA recently opened a regional data center in the increasingly strategic area of West Africa that will help capacity building and development efforts in this region. Over two-thirds of our science missions have foreign partners who enhance missions in ways we could not achieve on our own. The International Space Station (ISS), a complex partnership of 15 nations, relies upon partner contributions for essential elements, from launching astronauts to on-orbit operations.

Expanding Commercial Partnerships

NASA is pursuing a Lunar Exploration Campaign to establish U.S. preeminence to, around, and on the Moon through commercial and international partnerships, and using new procurement approaches. NASA plans to end direct U.S. financial support for the International Space Station as reliance on commercial partners for low Earth orbit research and technology demonstration requirements becomes commonplace. NASA intends to pursue commercial partnerships related to its new lunar robotic exploration program and Earth science data buys.

NOTES ON THE BUDGET

Providing Leadership and Inspiration

From big firsts to dramatic discoveries, to sharing its information and programs globally, NASA is a platform for U.S. leadership and inspiration. Our plans to return to the Moon first before we move on to Mars and other destinations will provide significant opportunities for participation by both industry and our international partners. We are most successful when we lead through example and practice, attracting partners who realize the benefits of shared values. Such principles include a shared understanding of the responsible use of space, free and open data policies, and the broad benefits of fundamental public R&D.

Additionally, leadership in space is due in part to our ability to inspire and create access to challenges. NASA plans to partner with industry to land robotic missions on the surface of the Moon, paving the way for a return of our astronauts—this time not just to visit, but to lay the foundation for further journeys of exploration and the expansion of our economy into space. The Budget supports a space exploration program that Americans can be proud of – one that reflects American ingenuity, ambition, and leadership.

Even as over 80 percent of NASA funds go out externally to industry and academia, the Agency continues to retain and serve as a unique national resource of systems engineers, scientists, business and international specialists, and technologists. From this foundation and the facilities that support them, NASA provides the nation a tool for leadership and inspiration.

Driving Economic Development and Growth

NASA has always been a driver of national economic development and growth. As nations vie for advantage on the global stage, economic growth and productivity are the engines that drive national power. Such power is measured in a variety of ways, but one important way is through competitiveness, or the ability of a nation's firms to perform in the global marketplace. Drawing upon a highly diffuse and technical supply chain and workforce, firms at the leading edge of exploration and aircraft development represent a benchmark of national capability across a wide spectrum of activities.

With the growth of technologies and innovations outside of the Agency, NASA will utilize a partnership acquisition strategy, in part focusing on leveraging and collaborating with the private sector and academia to harness their innovations for our missions. NASA recognizes that American companies are on the cutting edge of space technology and are developing ground-breaking new technologies that will unleash new opportunities and economic growth.

In this Budget, NASA plans to pursue commercial partnerships related to its communications networks, its new lunar robotic exploration program, and further afield commercial launch services.

With this budget, NASA continues transitioning Low Earth Orbit (LEO) activities to the commercial sector, while the core of NASA's future work re-focuses on exploration, new lunar missions, and keeps an eye towards Mars.

Addressing National Challenges

NASA strives to maintain its importance, utility, and relevance to the U.S. public by tackling significant national challenges and providing invaluable benefits to citizens.

NOTES ON THE BUDGET

EXTENDING HUMAN PRESENCE INTO THE SOLAR SYSTEM

NASA's primary goal is opening the space frontier with the objective of extending human presence deeper into the solar system starting with returning humans to the Moon through a sustainable human and robotic spaceflight program. The Agency has initiated a strategic, pioneering approach to expand the distance and duration of human space exploration, building off the research happening today on the International Space Station. NASA is pushing human presence deeper into space while making new discoveries, and strengthening the Nation's diplomatic posture.

The FY 2020 budget request includes $10.7 billion to pursue the exploration campaign, focusing on transitioning LEO operations to commercial providers and returning humans to the Moon & cislunar space, with eventual missions to Mars and beyond. NASA will evolve its core capabilities through continued technical advancements, and new approaches and 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 lunar landers and progressing to human activity in cislunar space, the lunar surface, then eventually to Mars and beyond. The campaign will be enabled by pursuing near-term milestones for lunar exploration, such as the commercial launch of the power propulsion element, a key element of the Lunar Gateway. The Lunar Discovery and Exploration program is supporting innovative approaches to achieve human and science exploration goals by funding contracts for commercial transportation services and the development of instruments and rover capabilities to meet lunar science and exploration needs.

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

TECHNOLOGY LEADERSHIP

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.

New technology is critically needed to enable these goals, Exploration Technology rapidly develops, demonstrates, and infuses revolutionary, high-payoff technologies through transparent, collaborative partnerships, expanding the boundaries and increasing the capability and affordability of NASA's exploration capability. These transformative technologies enable NASA's lunar and deep space exploration missions to meet human space exploration needs, as well as foster commercial expansion in low Earth orbit, cislunar space and beyond.

For example, NASA will begin testing a multicore processor to enable advanced precision landing and autonomous operations, and advanced cryogenic fluid management capabilities, through Tipping Point partnerships with industry and NASA-led activities. Under the new *Lunar Surface Innovation Initiative*, Exploration Technology will develop and integrate systems used for in situ resource utilization, including oxygen, water, and hydrogen, reducing mission mass, cost, and risk. NASA's Kilopower technology will transition into a demonstration mission - building on the 2018 demonstration of a small, lightweight nuclear fission power system that would permit long-duration crewed missions on the surface of the Moon. The Initiative 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.

Exploration Technology contributes to growing the U.S. industrial and academic base to continue the Nation's economic leadership and strengthen our national security. Exploration Technology 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, Exploration Technology 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.

LIVING AND WORKING IN SPACE

NASA capabilities create pathways for discovery and human exploration of space, making discoveries, creating economic and commercial markets and applications, while addressing societal challenges.

These capabilities include research on, or operation of, crew and cargo transportation to ISS; rocket propulsion testing; safe, reliable, and affordable access to space for NASA science missions and communications satellites, as well as other civil sector missions such as weather satellites for NOAA; and secure, dependable communications with crewed and robotic missions across the solar system and beyond.

ISS is an unparalled global project that exhibts National leadership and engages the public and students. It offers a unique platform for NASA and its international partners to learn how to live and work in space. Research, technology demonstrations, tests, and experiments on ISS continue to advance the capabilities required for future long-duration missions. 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. The ISS National Lab, managed by the non-profit Center for the Advancement of Science in Space (CASIS), is making great strides in getting new users to the ISS, including private industry and other U.S. government agencies. These entities are using the ISS for research into pharmaceuticals, biotechnology, and in-space manufacturing, among others, as well as being able to iterate on technology design before moving to operational production.

NASA and the U.S. space transportation industry are well on the way to developing an affordable capability to carry crew to ISS by the end of 2019, bolstering American leadership while eliminating reliance on the Russian Soyuz to transport American astronauts. This competitive commercial approach, distinct from a traditional NASA-owned and operated system, allows the Agency to reduce costs, improve affordability and sustainability, and stimulate the private sector space industry. With U.S. commercial industry providing cargo resupply services to ISS, NASA is funding development activities for commercial crew systems. The Agency will purchase commercial crew transportation services using the same model used for cargo services.

NASA is working to implement a step-wise transition of ISS from the current regime of NASA sponsorship and direct NASA funding, to a regime where NASA is one of many customers purchasing services from a LEO non-governmental human space flight enterprise. NASA will gradually transition from current ISS operations to this new regime to ensure that the United States always has access to a crewed space station in LEO. As part of this transition, NASA plans to purchase needed LEO services from a commercial operator of ISS and/or new commercial LEO destinations. The rationale for this transition is threefold: to encourage and facilitate the development of a robust LEO ecosystem that will lead to economic growth; to turn over LEO operations to the private sector so NASA can focus on the challenges of exploration beyond LEO; and reducing costs for meeting NASA needs in LEO that will help support a sustainable approach for human exploration of the Moon and eventually Mars.

SCIENCE IS ANSWERING ENDURING QUESTIONS IN, FROM, AND ABOUT SPACE

NASA's Science program 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 National leadership in space, and expand human knowlege.

This budget continues the work of the Lunar Discovery and Exploration program that partners with industry to go to the Moon and advance science and exploration objectives. It provides funding for a Mars Sample Return mission launching from Earth in 2028, later returning the first sample of another planet. It also proposes to launch the Europa Clipper mission, which will conduct flybys of Jupiter's icy moon, in 2023 on a commercially procured launch vehicle, saving over $700 million that can be used on other missions.

NASA missions continue to enhance our understanding of the Earth. The Sustainable Land Imaging program will provide U.S. users with high-quality, global, land imaging measurements that are compatible with the existing 45-year Landsat record. This budget supports launch of Landsat 9 as early as FY 2021. The request fully funds Surface Water and Ocean Topography (SWOT); NASA-ISRO Strategic Aperture Radar (NISAR); and many other future Earth Science missions.

The request fully funds major missions to advance our understanding of the Sun and its impact on the Earth, including Solar Orbiter Collaboration (SOC). The request also funds the Ionospheric Connection Explorer (ICON) mission. ICON's goal is to understand the tug-of-war between Earth's atmosphere and the space environment, in the "no man's land" of the ionosphere. The request also supports interagency efforts to improve space weather predictive capabilities. The James Webb Space Telescope, a successor to the Hubble Space Telescope, will launch in 2021.

The budget also supports initiatives that use smaller, less expensive satellites and/or public-private partnerships to advance science. A Science-wide CubeSat/SmallSat initiative is implementing the recommendations from a recent study of the National Academies that concluded that, with ongoing technological progress in both private sector and through federal investments, these small satellites are on a path to address specific high-priority science goals. A targeted investment strategy focuses technology development on CubeSats/SmallSats in all four SMD science themes to exploit this value, and will provide novel partnership opportunities between commercial partners and NASA.

AERONAUTICS RESEARCH TO ADDRESS AVIATION'S CHALLENGES

The air transportation system of today is a vital part of the U.S. and global economies. It enhances our national security and the industrial base and provides a key catalyst to the nation's economic development and growth. Aviation is the primary mechanism for connecting major population centers in the U.S. and countries across the world for people and cargo. NASA conducts aeronautics research to bring transformational advances in the safety, capacity, and efficiency of the air transportation system and to enable breakthroughs in the speed and efficiency of transport aircraft that are the backbone of today's aviation system as well as innovative new aircraft concepts and technologies that will enable new aviation markets.

The FY 2020 budget request for NASA Aeronautics supports development of a supersonic X-plane, the X-59 QueSST, scheduled for first flight in 2022. The X-59 will demonstrate quiet overland supersonic flight which will enable U.S. industry to open a new market. The request supports cutting edge research to demonstrate and validate new aircraft configurations and propulsion systems. NASA will advance new electric propulsion technologies with a focus on developing 1 megawatt electric propulsion systems for flight.

The request supports a robust investment in air traffic management improvements that will safely increase air traffic capacity and reduce flight delays. In cooperation with FAA, NASA will complete a series of flight tests to demonstrate new concepts and technologies that will increase the rate of airport arrivals and departures. NASA Aeronautics will complete demonstrations of key technologies that will integrate unmanned aircraft systems (UAS) operations in the National Air Space, as well as realize safe, low-altitude operations of small UAS. NASA will accelerate urban air mobility (UAM) research to support industry readiness to perform advanced safety and operations testing for this emerging global UAM market.

MANAGING NASA'S PEOPLE AND CAPABILITIES TO SAFELY ACCOMPLISH OUR MISSION

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 2020, NASA will strengthen cybersecurity capabilities, safeguarding critical systems and data.

NOTES ON THE BUDGET

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, implementing efficiency and high performance upgrades, and prioritizing repairs to achieve the greatest return on investment. In FY 2020, 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. NASA will decommission and continue preparations to dispose of property and equipment no longer needed for 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 past NASA activities.

NASA's WORKFORCE

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 2020 Budget support NASA's scientists, engineers, researchers, managers, technicians, and business professionals workforce. It 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.

NASA will continue to explore opportunities across the Agency to find efficiencies in workforce productivity, especially in mission support functional areas. The Agency will apply the valued civil service workforce to priority mission work, adjusting the mix of skills where appropriate. Centers will explore cross-mission opportunities for employees whenever possible, use the range of tools available to reshape the workforce, and continue to identify, recruit, and retain a multi-generational workforce of employees who possess skills critical to the Agency.

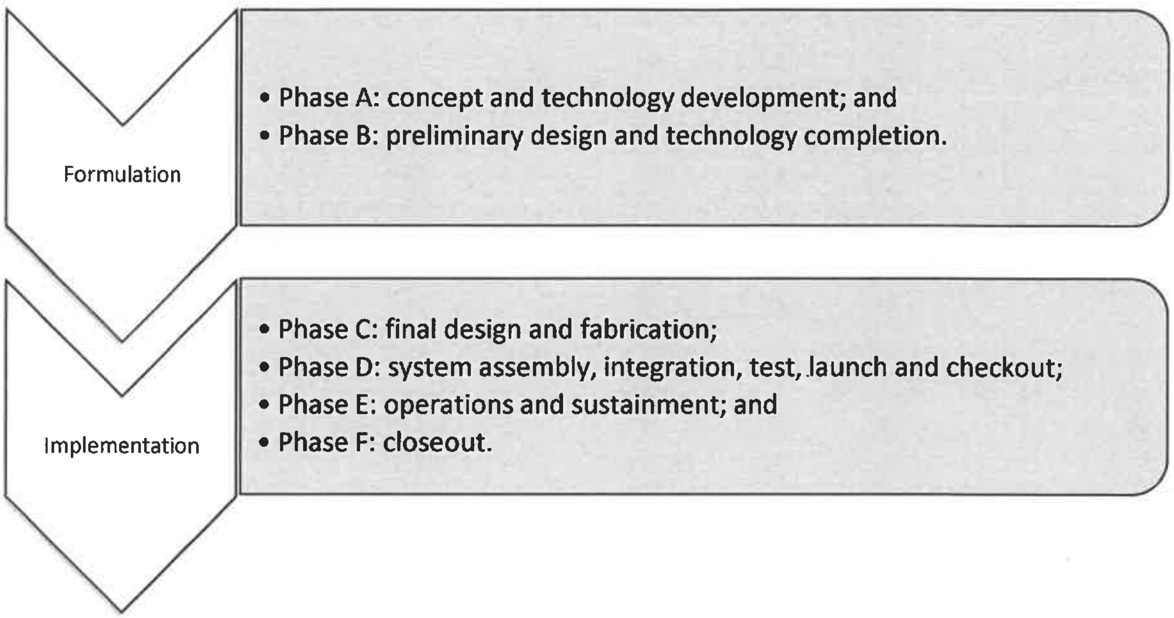
EXPLANATION OF BUDGET TABLES AND SCHEDULES

The FY 2019 Enacted column in budget tables displays appropriations enacted in the Full Year Appropriations Law for 2019 (P.L. 116–06). The amounts included for FY 2018 reflect actual funding as set forth in NASA's final FY 2018 operating plan. As of budget release, an initial FY 2019 operating plan has not been developed and submitted to the Congress. As a result, budget tables show only account-level appropriations for FY 2019. Tables also show tentatively planned FY 2019 funding for projects in development (subject to change pending finalization of the FY 2019 initial operating plan). Budget structures and figures are adjusted for comparability to the FY 2020 budget structure.

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.

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.

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.

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.

EXPLORATION CAMPAIGN

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	IOP FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Exploration Campaign TOTAL	**$10,449.0**	**$10,927.6**	**$10,712.3**	**$11,147.1**	**$11,542.3**	**$12,637.9**	**$13,068.0**
Deep Space Exploration Systems	$4,790.0	$5,050.8	$5,021.7	$5,295.5	$5,481.4	$6,639.0	$7,042.3
Exploration Technology	$760.0	$926.9	$1,014.3	$976.1	$995.4	$964.4	$943.1
LEO & Spaceflight Operations	$4,749.2	$4,639.1	$4,285.7	$4,369.5	$4,369.5	$4,235.5	$4,182.3
Exploration Campaign COF	$119.8	$42.8	$71.6	$0.0	$0.0	$0.0	$0.0
Elements of Science+	$30.0	$268.0	$319.0	$506.0	$696.0	$799.0	$900.3
Change from FY 2019 PBR			**$-215.3**				
Percentage change from FY 2019			**-2.0%**				

+Elements of Science: Lunar Discovery & Exploration Program and Mars Sample Return

Space Policy Directive 1 calls for 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. Based on this objective the *National Space Exploration Campaign Report*, submitted to Congress in September 2018, laid out five strategic goals for NASA's near-term exploration:

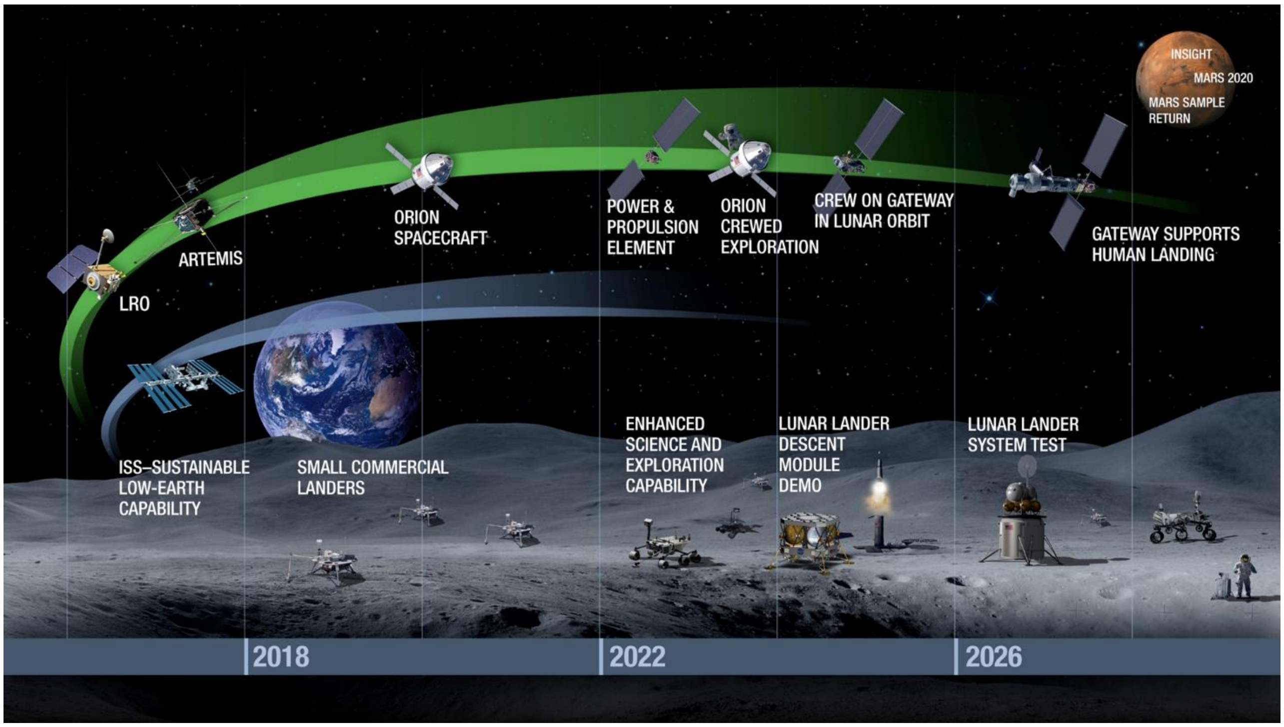
1. Transition U.S. human spaceflight in LEO to commercial operations that support NASA and the needs of an emerging commercial economy;
2. Lead the emplacement of capabilities that support lunar surface operations and facilitate missions beyond cislunar space;
3. Foster scientific discovery and characterization of lunar resources through a series of robotic missions;
4. Return U.S. astronauts to the surface of the Moon for a sustained campaign of exploration and utilization; and
5. Demonstrate on the Moon the capabilities required for human missions to Mars and other destinations.

Additionally, NASA will continue to engage with partners, and expand purchase of competitive commercial services and international cooperative agreements to carry out the Exploration Campaign.

The FY 2020 President's Budget prioritizes human exploration and lunar related activities, and proposes significant funding increases in support of these objectives. With the funding requested in FY 2020 and outyears, by 2028, NASA seeks:

- Provide opportunities for at least 13 deep space CubeSat missions, including 7 to the Moon (on EM-1)
- Complete 6-7 Exploration Missions with SLS and Orion, strengthening American capabilities to launch astronauts and spacecraft
- Fund the deployment of at least one commercial space station in Low Earth Orbit and begin conducting science, technology development, and human research on this new platform
- Fly up to 10 Commercial Lunar Payload Services (CLPS) missions, enabling new science and demonstrating new technologies supporting human return to the lunar surface;

- Complete assembly, and begun supplying, the Lunar Gateway using competitively procured commercial launch vehicles - establishing the initial exploration infrastructure orbiting the Moon
- Demonstrate, for the first time, industry-led lunar descent vehicles and a reusable lunar ascent vehicle
- Use, for the first time on the Moon, key exploration technologies including precision landing, cryogenic fluid management, in-situ resource utilization, and surface nuclear power, and invested in technologies for long-term utilization
- Launch a Mars Sample Return mission as early as 2026, later returning the first sample of another planet back to Earth
- Return humans to the lunar surface



Over the last year, NASA took specific steps to continue implementation of the program of space exploration laid out above, with goals of looking at more innovative procurement models and increasing sustainability of the program.

- In November 2018, NASA selected nine companies as part of the Commercial Lunar Payload Services (CLPS) procurement, making them eligible to provide transportation services to the lunar surface for science, technology, and exploration payloads.
- In February 2019, NASA selected twelve NASA-provided payloads that could be flown on the early CLPS missions.
- In Q2 of calendar year 2019, additional payloads will be selected from the Lunar Surface Instrument and Technology Payloads NASA Research Announcement (NRA) which includes the broader U.S. scientific community, as well as technology and exploration payloads.

- The Commercial Crew Program (CCP) is expecting crewed test flights during Summer of 2019 for both commercial providers, with flights to ISS by the end of calendar year 2019;
- For the Lunar Gateway system, the contract for the Power & Propulsion Element (PPE) is planned for award in Q2/Q3 of calendar year 2019;
- Also for Gateway, NASA issued RFP's for the habitation & logistics modules;
- NASA issued a Broad Agency Announcement (BAA) seeking partners to study and develop a human-rated lunar lander system;
- NASA commissioned twelve studies from industry to describe how a future commercial economy in LEO would be structured and financed to inform the first Commercial LEO Development solicitation; and
- NASA is maturing technologies and systems in preparation for deep space missions to the Lunar Gateway, and is developing advanced power and propulsion capability.

The FY 2020 Budget Request maintains the existing budget structure for the Exploration Campaign, as it will continue to be a cross-functional effort at Headquarters and across the Centers. NASA continues to assess the proper organizational structure to manage the Exploration Campaign and intends to notify the Congress in FY 2019 if any reorganization is necessary.

Deep Space Exploration Systems

NASA continues to develop the Lunar Gateway, which will reside in cislunar space, including a power and propulsion element by 2022, with a habitation module, and the required logistics capabilities following soon after. NASA will use this infrastructure as part of a broader strategy to explore and utilize the Moon and its surface.

Advanced Cislunar and Surface Capabilities funding supports lunar exploration efforts by developing a reusable human lunar landing architecture utilizing innovative public-private partnerships.

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 consolidate the technology research and development programmatic content previously funded by Space Technology Mission Directorate and Advanced Exploration Systems, integrating and refocusing these activities toward lunar and deep space exploration. This will enable NASA's workforce, in concert with industry and academia, to focus on 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 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. NASA is implementing this Initiative by embracing competition and external partnerships with industry, universities, and other government agencies.

EXPLORATION CAMPAIGN

LEO & Spaceflight Operations

The Low Earth Orbit (LEO) and Spaceflight Operations account funds NASA's efforts to expand government and commercial access to space and lays the foundation to support future commercial operations in LEO. These activities support existing and future space operations, commercialization, and space and flight support capabilities for all NASA and non-NASA missions.

NASA's industry partners have proven themselves capable of successfully launching and returning cargo to and from Earth, and NASA is building upon that partnership with commercial crew launches to and from the ISS expected by the end of 2019.

NASA will continue its mission in low earth orbit (LEO) with the International Space Station (ISS) to enable exploration with humans to the Moon and on to Mars, continuing to perform research that benefits humanity, supporting National Lab research by private industry and other organizations, and working towards reducing operations and maintenance costs. The Commercial LEO Development effort is providing resources for NASA to assist industry in developing a commercial low Earth orbit presence, with and without crews. Once these new commercial capabilities have been deployed in orbit, NASA will begin transitioning LEO operations to private industry. Together, NASA's ISS and Commercial LEO Development efforts will lay the foundation for the emergence of an environment in LEO where NASA is one of many customers of a non-governmental human space flight enterprise.

Scientific Exploration

The final element of exploration comes from NASA's Science Mission Directorate (SMD), which will continue its efforts to explore and enhance scientific discovery. This account line is made up of the Lunar Development & Exploration Program (LDEP), and the Mars Sample Return mission.

NASA is developing a series of instruments, experiments, and other payloads for robotic lunar missions to the surface of the Moon. 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.

Amid the ongoing lunar exploration work, SMD will also continue to study and explore other bodies in our Solar System including a Mars Sample Return mission launching from Earth as early as 2026.

Through these activities, NASA's budget will realize exploration opportunities in the near-term and set the stage for America space leadership decades to come. NASA's FY 2020 budget proposal lays out an aggressive exploration program of work for NASA, and includes more than $10.7 billion in funding to achieve those objectives. This funding will empower American global leadership, spur innovation and economic growth, and return the United States to the forefront of space exploration.

DEEP SPACE EXPLORATION SYSTEMS

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Exploration Systems Development	4395.0	4092.8	**3441.7**	3441.0	3468.4	3788.5	3654.7
Exploration Research & Development	395.0	958.0	**1580.0**	1854.5	2013.0	2850.4	3387.6
Total Budget	**4790.0**	**5050.8**	**5021.7**	**5295.5**	**5481.4**	**6639.0**	**7042.3**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

DEEP SPACE EXPLORATION SYSTEMS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Exploration Systems Development	4395.0	4092.8	**3441.7**	3441.0	3468.4	3788.5	3654.7
Exploration Research & Development	395.0	958.0	**1580.0**	1854.5	2013.0	2850.4	3387.6
Total Budget	**4790.0**	**5050.8**	**5021.7**	**5295.5**	**5481.4**	**6639.0**	**7042.3**
Change from FY 2019			**-29.1**				
Percentage change from FY 2019			**-0.6%**				

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

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NASA has been charged with leading an innovative and sustainable exploration program. Beginning with missions beyond low-Earth orbit (LEO), the United States will lead the return of humans to the Moon and lunar surface for long-term exploration and utilization, followed by human missions to Mars and other destinations. This direction means NASA must more effectively organize government, commercial, and international efforts to generate new scientific and economic markets and opportunities, and more efficiently procure government systems.

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.

ESD consists of the Orion crew capsule, the Space Launch System (SLS) rocket, and the Exploration Ground Systems (EGS) that support integration and launch. This space transportation system is a key component of NASA's strategy for exploration in cislunar space and will have a first un-crewed test flight and crewed test flight in the near future; launch dates are currently under review. NASA’s Orion spacecraft and Space Launch Systems are a backbone for deep space exploration, from which private companies could one day provide an equivalent commercial capability, thus perpetuating the relationship of government and commercial capabilities that started in low-Earth orbit.

ERD is comprised of four areas: Advanced Cislunar and Surface Capabilities (ACSC), Lunar Gateway, Advanced Exploration Systems (AES) and the Human Research Program (HRP). The overarching goal of ERD is to infuse technologies and research, and develop high-priority capabilities and missions to enable the return of humans to the Moon and lunar surface 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 2020 President's Budget, there are three major initiatives:

(1) Gateway funding focuses on developing a small way station that will orbit the Moon and enable lunar landers and surface activities, to include a Power and Propulsion Element by 2022, and the habitation,

airlock, and logistics elements thereafter; (2) ACSC funding focuses on design analysis, technology maturation, system development and integration, and spaceflight demonstrations for a human lunar landing system. ACSC is developing human lunar landing, lunar robotic, and surface capabilities through commercial and international partnerships as well as in coordination with other NASA programs. This includes leveraging the SMD development of smaller landers for capabilities such as navigation and precision landing and investments through exploration technology and the lunar surface initiative; (3) AES funding includes next generation risk reduction and habitation capabilities. AES ground test habitation prototypes are being developed by private-public-partnerships to evaluate human factors for different habitat configurations, assess how the various systems interact together and with other capabilities like propulsion modules and airlocks, and provide platforms to test and ensure that the standards and common interfaces being considered are well designed. Additional risk reduction activities include advanced subsystems development such as avionics and Environmental Control and Life Support Systems (ECLSS). AES will continue to work on identifying and addressing knowledge gaps existing outside of the astronaut habitats. Major areas of work include space communication, near earth object monitoring, robotic precursor small satellites, and potential improvements on how spacecraft are powered.

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, and providing appetizing food and optimal nutrition, HRP scientists and engineers work to predict, assess, and solve the problems that humans encounter in space. Planned future 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 programmatic information, go to: http://www.nasa.gov/directorates/heo/home/index.html.

EXPLORATION SYSTEMS DEVELOPMENT

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Orion Program	1350.0	1350.0	**1266.2**	1245.7	1146.7	1119.3	1000.0
Crew Vehicle Development	1339.5	1339.5	**1255.7**	1235.2	1136.2	1107.2	990.0
Orion Program Integration and Support	10.5	--	**10.5**	10.5	10.5	12.1	10.0
Space Launch System	2150.0	2150.0	**1775.4**	1837.5	1933.0	2221.2	2253.3
Launch Vehicle Development	2093.9	2099.1	**1715.3**	1772.8	1871.7	2160.0	2197.3
SLS Program Integration and Support	56.1	--	**60.1**	64.7	61.3	61.1	56.0
Exploration Ground Systems	895.0	592.8	**400.1**	357.8	388.7	448.1	401.3
Exploration Ground Systems Development	878.2	587.8	**396.5**	350.1	385.1	444.5	401.3
EGS Program Integration and Support	16.8	--	**3.6**	7.7	3.6	3.6	0.0
Construction & Envrmtl Compl Restoration	95.9	25.9	**52.1**	0.0	0.0	0.0	0.0
Exploration CoF	95.9	25.9	**52.1**	0.0	0.0	0.0	0.0
Total Budget	**4490.9**	**4118.7**	**3493.8**	**3441.0**	**3468.4**	**3788.5**	**3654.7**
Change from FY 2019			**-624.9**				
Percentage change from FY 2019			**-15.2%**				

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

At night, on November 1, 2018, a test version of the Orion capsule is pulled into the well deck of the USS John P. Murtha during Underway Recovery Test-7 (URT) in the Pacific Ocean. URT-7 is one in a series of tests conducted by the Exploration Ground Systems Recovery Team to verify and validate procedures and hardware that will be used to recover the Orion spacecraft and its crew after it splashes down in the Pacific Ocean following deep space exploration missions.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

NASA's Exploration Systems Development programs are working together to build the space transportation system made up of the Orion crew vehicle, Space Launch System (SLS) rocket, and the Exploration Ground Systems. This system will enable the Agency's mission to extend human presence into the solar system, by first transporting a crew to the Gateway, who will then return to the Moon's surface for long-term exploration. These program objectives support National Space Policy Directive-1, and Agency Strategic Goal two 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 is designed to meet the evolving needs of our nation's deep space exploration program for decades to come. Its versatile design will be able to not only carry crew to space, but provide emergency abort capability, sustain crew during space travel, and provide safe reentry at deep space return velocities. With modifications and the addition of new modules, most of the Orion capsule systems could be capable of operating in deep space for periods of time up to 1,000 days. 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 super 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. SLS has the potential to launch a variety of missions to ensure NASA is able to expand human knowledge through new scientific discoveries. With the capability to evolve to the highest-ever payload mass and volume capability and energy to send missions into space, SLS is designed to be flexible and evolvable, to meet a variety of crew and cargo mission needs to enable exploration across the solar system.

The objective of the Exploration Ground Systems is to prepare Kennedy Space Center (KSC) to process and launch next-generation vehicles and spacecraft, like Orion and SLS. 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 in order 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.

As NASA works towards building a sustainable Exploration Campaign, the Agency is focused on looking at ways to reduce production and operations costs. Through reduction in costs, the Agency can focus on capabilities needed for future deep space systems and successful exploration missions.

ORION PROGRAM

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Crew Vehicle Development	1339.5	1339.5	**1255.7**	1235.2	1136.2	1107.2	990.0
Orion Program Integration and Support	10.5	--	**10.5**	10.5	10.5	12.1	10.0
Total Budget	**1350.0**	**1350.0**	**1266.2**	**1245.7**	**1146.7**	**1119.3**	**1000.0**
Change from FY 2019			**-83.8**				
Percentage change from FY 2019			**-6.2%**				

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

The Orion spacecraft will play an integral part of NASA deep space exploration objectives. The Orion Program is continuing 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, provide emergency abort capability, sustain crew during space travel, 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 orbit and to the Moon.

Orion design, development, and testing (including the flight tests) will have the spacecraft ready to carry crew on Exploration Mission (EM-2); but the launch date is under review pending the completion of an independent assessment of the integrated mission schedule, to be completed spring 2019. Given ongoing challenges, meaningful delays are anticipated. These challenges are unrelated to available budget, and the proposed FY2020 President's Budget level is sufficient to support a launch at the earliest technically feasible date. Future flights of the Space Launch System (SLS) and the Orion spacecraft into cislunar space will extend our capability

For further programmatic 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 SLS and Exploration Ground System (EGS). This effort is critical to ensuring Orion’s performance meets technical and safety specifications, and 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 three programs enables the Agency to avoid potential design overlaps, schedule disconnects, and cost issues.

CREW VEHICLE DEVELOPMENT

See the Crew Vehicle Development section.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

FY 2020 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	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	3011.1	1308.4	1182.3	**845.8**	567.0	213.8	18.8	0.0	0.0	7147.2
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2019 MPAR LCC Estimate	**7521.5**	**1308.4**	**1182.3**	**845.8**	**567.0**	**213.8**	**18.8**	**0.0**	**0.0**	**11657.6**
Total Budget	**7530.4**	**1339.5**	**1339.5**	**1255.7**	**1235.2**	**1136.2**	**1107.2**	**990.0**	**0.0**	**15933.7**
Change from FY 2019				**-83.8**						
Percentage change from FY 2019				**-6.3%**						

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

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The difference between the total budget and the MPAR LCC estimate is the total budget includes content outside of EM-2 and excludes CoF; LCC only includes EM-2 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.

On November 6, 2018, the European-Built Service Module that will propel, power, and cool during Orion's flight to the Moon on EM-1 arrived from Bremen, Germany to KSC to begin final outfitting, integration and testing with the crew module and other Orion elements.

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 further programmatic information, go to http://www.nasa.gov/orion.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2020

NASA has realized the six months of risk in the previous plan, and therefore the Exploration Mission – 1 (EM-1) LRD is currently NET June 2020. NASA believes there is continuing risk involving SLS end item completion (e.g. Engine Section), functional test and integration of the Core Stage for delivery to Stennis Space Center, and completion of Green Run test that precedes delivery to Kennedy Space Center (KSC). Given these challenges, further delays beyond June 2020 are anticipated.

In October 2018, the SLS program began an assessment of core stage production. The assessment included representatives with experience in aerospace manufacturing and covered production schedule risks, risk mitigation approaches in work, and recommendations for additional schedule risk mitigations and corrective action and was presented to HEO in February 2019. On March 4, 2019, HEO chartered an assessment of other activities planned to achieve a launch in 2020. Specifically, this assessment will evaluate alternate approaches for hardware processing and facilities utilization for key components. The goal of this activity is to maintain an early as possible launch date. This activity, scheduled to conclude April 15, 2019, could result in a proposed new plan to include update to the EM-2 planning LRD based on identified schedule constraints between EM-1 and EM-2; but EM-2 should still be within the ABC of April 2023.

After completion of the HEO assessment, an independent schedule risk review led by the NASA Office of the Chief Financial Officer, set to begin mid-April 2019, will assess the proposed new plan to include: the integrated, detailed schedule and associated risk factors ahead of EM-1; considering technical complexity, as well as delays caused by the government furlough. The OCFO assessment report will include evaluation of schedule risks to critical milestone dates to include: SLS Core Stage delivery to SSC for Green Run Test, SLS Core Stage and Orion Crew Service Module deliveries to KSC, and is expected to be completed late spring. NASA leadership will review the results of these assessments in late spring 2019 at an Agency Program Management Council, before considering potential updates to the EM-1 and EM-2 launch planning dates.

Project Parameters

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 three components are the Crew Module (CM), European Service Module (ESM), and Launch Abort System (LAS). The Service Module (SM), comprises of a Crew Module Adapter (CMA) and the ESM, is designed and developed by European Service Agency (ESA). The SM provides in-space power, propulsion, and other life support systems. The CM, the pressure vessel, will be mounted to the SM to become the Crew and Service Module (CSM). Atop the CSM will sit the LAS, which in the event of an emergency during launch or climb to orbit, will activate within milliseconds to propel the CM away from the launch vehicle to safety. 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 jet the LAS. The vehicle will travel 280,000 miles from Earth and thousands of miles beyond the Moon. 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 from

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

reentry during a high-speed return from the lunar vicinity – heating that will exceed that experienced by any human spacecraft in over four decades.

ACHIEVEMENTS IN FY 2018

Completed production and installation in August of EM-1 major hardware including the heat shield to protect the vehicle upon its 5,000 degree return to Earth; and critical components for the ESM such as the Pressure Control Assembly Valves, the propellant tanks and Orbital Maneuvering System Engine, the CMA and the CM in September. These components will be delivered to KSC for assembling and testing, not just for EM-1, but also for subsequent exploration missions.

Completed a series of tests on the ESM Structural Test Article (STA) in June at Lockheed Martin (LM) facility near Denver, CO such as acoustics, modal, and static loads to ensure the space-bound article is ready to withstand the pressure and loads it will endure during launch, flight, and landing. Modified testing for sound and vibration evaluations has confirmed Orion can withstand the intense noise and shaking that launch on the SLS rocket will produce.

In September, the program successfully released EM-1 final software that enable the command and control of the Orion during nominal and emergency operations such as ascent aborts, safe mode, fault detection, isolation and recovery, optical navigation, maneuver plan management, and propulsion failure detection. These tests are essential for identifying software problems and validating proper functionality and performance of the spacecraft.

In September, the program Flight Operations Directorate flight control team successfully sent commands to the Orion CM for the first time via Near Earth Network at KSC and via the Tracking and Data Relay Satellite System (TDRSS) from Mission Control Center (MCC) in Houston. The Space Communication and Navigation Office also executed file downlink from Orion through TDRSS

In August, the program completed the CM primary structure welding of the EM-2 and delivered to KSC to begin final assembly for Orion's first crewed flight. The pressure vessel is the primary structure that holds the pressurized atmosphere that astronauts will breathe and work in while in the vacuum of deep space.

Completed the final test to qualify Orion's parachute system for flights with astronauts in September, checking off an important milestone on the path to send humans on missions to the Moon and beyond. The parachute system is the only system that must assemble itself in mid-air and must be able to keep the crew safe in several failure scenarios.

Completed a series of recovery operations scenarios with the United States Navy in January to evaluate recovery of the CM in different sea conditions, time of day, and equipment scenarios. The tests are structured to improve the processes and ground support hardware to recover astronauts and the Orion capsule once they splash down in the Pacific Ocean just off the coast of California.

Completed the Ascent Abort (AA-2) CM initial power-on test in June to ensure the vehicle is healthy, can work in an integrated fashion and provides correct test data to the ground.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Delivered the AA-2 CM and completed the acoustic testing at GRC's Plum Brook Station in Ohio in August. The testing successfully characterized how the structure will respond to the abort environment during flight.

Delivered the AA-2 CM and Separation Ring to JSC in September for integration of avionics, onboard computers and software. They were then shipped and mated together at KSC in the same month.

WORK IN PROGRESS IN FY 2019

Completed the first Propulsion Qualification Module (PQM) 5-second firing and a successful 20-second firing of the PQM with active control of the pressurization system in October. It was one of the prerequisites for ESA to ship the ESM to the United States for integration. Other PQM testing will continue throughout FY 2019 in order to qualify the ESM.

Airbus delivered the first ESM from its aerospace site in Bremen, Germany on November 6, 2018 by Antonov cargo aircraft to NASA's KSC. Function checkouts were completed to ensure all elements are working properly before integration. Following the functional tests, the ESM was mated with the CMA to complete the SM assembly. The completed SM will be subsequently joined to the CM, resulting in the combined CSM in the spring 2019. This will mark the first time all three major elements will be integrated.

The program will ship the integrated EM-1 CSM to Plum Brook Station later in the fiscal year for thermal vacuum, acoustics, and electromagnetic interference testing which is a crucial step towards launch readiness. Once completed, the mated CSM will be returned to KSC for final launch processing.

Continuing the manufacturing efforts for EM-2, the program will complete CM secondary structure and component assembly such as the heatshield to lower backshell pre-fit and begin Clean Room Operations for Environment Control and Life Support System (ECLSS) welding. Once complete, the EM-2 CM will be ready to mate with the SM.

ESM-2 preparations have begun with the integration of the second SM in its clean room. Long-lead activities, such as welding of high- pressure valves and engine manufacturing are underway.

The program has delivered the AA-2 test article to KSC and will complete the final assembly and stacking operations in support of the test flight in June 2019, which will demonstrate the ability to safely separate the CM from the SLS during an ascent abort scenario. This will be the test campaign to demonstrate the LAS function.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

The Integrated Test Lab (ITL) will conclude its testing on the EM-1 software and will begin its testing of the EM-2 software. This lab will simulate flight environment and test the flight software functions such as ascent aborts, safe mods, fault detections, isolation and recovery optical navigation, maneuver plan management and propulsion failure detection for both EM-1 and EM-2. These tests are essential for identifying software problems and validating proper functionality and performance of the spacecraft.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

NASA will complete the EM-1 STA configuration test in Denver and ship it to LaRC for subsequent water impact testing. This is the last action in the series of test that will complete the test campaign on the full scale replica of the EM-1. jThese test are conducted to ensure the space bound article is ready to withstand the pressure and loads it will endure during launch, flight and landing.

NASA will begin stacking and integrating the CSM in the LAS Facility and mate the LAS to the CSM for EM-1. After the mating, it will be delivered to Exploration Ground Operations at KSC for final preparation and stacking in the Vertical Assembly Building (VAB). The uncrewed mission will take the spacecraft beyond the Moon in order to demonstrate its capabilities. After the 21-days launch, Orion program will conduct the EM-1 Mission and Post Flight Analysis along with recovery and offloading for component reuse for future flights.

In preparations for an EM-2, the first crewed mission. Orion will complete outfitting the CM Pressure Vessel at KSC's Operation and Checkout (O&C) building. During FY 2020, the Orion program will install ECLSS for the crew to live and work, the core avionics for the navigation and control and the heatshield to protect the vehicle and crew from extreme temperatures. Once 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 crew members.

The production of the EM-2 CMA will be completed, which serves as the interface between the ESM-2 and the CM. To prepare for mating to the ESM-2, the CMA will undergo perform proof pressure and leak tests followed by subsystem installations, harness testing, and Developmental Flight Instrumentation (DFI) testing.

Orion will complete manufacturing of ESM-2 and delivery of to KSC's O&C which will provide power, propulsion and air support. Once the ESM-2 is delivered and functional tests are performed, it will be mated to the CMA. After mating, the EM-2 SM will undergo clean room operations for ECLSS welding, followed by proof pressure and leak tests in preparation for integrating with the CM-2 in 2021.

The development of the rendezvous and docking capability will be underway to enable rendezvous, proximity operations, docking and undocking (RPODU) for integrated Orion/Gateway activity and lunar surface.

Long-lead material purchases for EM-3 will arrive and Orion will start vehicle production. The EM-3 will be the first crewed mission to utilize the docking capability for RPODU in order to begin the construction of the Gateway.

The program will initiate long lead material purchases for EM-4 and EM-5, which will enable the program to meet an annual flight rate to support lunar exploration. These missions represent United States commitment and 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.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2020 PB Request
System Design Review (SDR)		Aug 2007
PDR		Aug 2009
Key Decision Point (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
Abort Ascent (AA)-2 Flight Test	FY 2020	FY 2019
EM-1 Launch Readiness	FY 2018	Under review
EM-2 Launch Readiness*	FY 2023	Under review

** The program is currently reviewing cost and schedule impacts based on the change to the EM-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 (mths)
2015	6,768.4	70	2019	7,147.2	+5.6%	EM-2	Apr 2023	*June 2022	-10

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 reflects the planning for the EM-2 mission based on a June 2022 launch date. The EM-1 and EM-2 launch dates are under review pending completion of independent assessments of SLS core stage production and the integrated mission schedule. NASA leadership will review the results of these assessments in spring 2019 before considering potential updates to the EM-1 and EM-2 launch planning dates.*

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**	**7,147.2**	**+378.8**
Mission Operations	281.6	273.8	-7.8
Program Management	671.5	665.3	-6.2
Safety and Mission Assurance	191.4	180.8	-10.6
Spacecraft and Payload	3,205.1	4,490.3	+1,285.2
Systems Engineering and Integration	539.3	684.4	+145.1
Test and Verification	460.6	544.6	+84.0
Other Direct Project Costs	1,418.9	308.0	-1,110.9

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

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

The Current Year Development Cost Estimate and Milestone data reflects the planning for the EM-2 mission based on a June 2022 launch date. The EM-1 and EM-2 launch dates are under review pending completion of independent assessments of SLS core stage production and the integrated mission schedule. NASA leadership will review the results of these assessments in spring 2019 before considering potential updates to the EM-1 and EM-2 launch planning dates.

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 serves as the docking port for crew transfers.	Provider: JSC Lead Center: JSC Performing Center(s): Ames Research Center (ARC), GRC, JSC, and Langley Research Center (LaRC) Cost Share Partner(s): N/A	None
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	None
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	None

Project Risks

Risk Statement	Mitigation
If: Re-use of EM-1 core Avionics hardware on EM-2 Then: There is a possibility that the EM-2 launch will be delayed due to the turnaround time associated with refurbishment of Avionics boxes from EM-1	At the MPCV (Multi-Purpose Crew Vehicle) Program Control Board (MPCB) in December 2018, NASA approved to build and test the eleven core Avionics components in support of EM-2.

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 EM-2 flight readiness date. The Orion Program released a Request for Proposal from Lockheed Martin for the Production & Operations (P&O) effort in January 2018. The Orion Program issued a Justification for Other than Open Competition for Production and Operations (P&O) beginning with EM-3 and expects the sole-source contract with Lockheed Martin to be in place in the spring of 2019. NASA signed an Implementing Arrangement with ESA to provide service modules for the Orion spacecraft for EM-1 and EM-2. 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. Orion is discussing with ESA about their contribution for EM-3 and subsequent missions.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Orion Design and Development	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
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
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

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
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 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
CDR	SRB	Oct 2015	To evaluate the integrity of the program integrated design. This includes 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. This includes 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

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next 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 AI&T with acceptable risk, and within cost and schedule constraints.	Program cleared to proceed to next phase.	N/A
EM-2 CDR	IA/IRT	Dec 2018	To evaluate the integrity of the program integrated design. This includes 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
ESD EM-1 Independent Schedule Assessment	Schedule assessors from OCFO	Begins April 2019	Programmatic assessment and analysis of EM-1 schedules across all ESD programs with an emphasis on program performance and risks	After NASA leadership review in late Spring 2019, update EM-1 launch date	N/A

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
System Acceptance Review/Design (SAR) Certification Review	IA/IRT	TBD	The purpose of this review is to evaluate whether a specific end item is sufficiently mature for shipment from the supplier to its designated operational facility or launch site.	N/A	N/A
System Integration Review (SIR)	IA/IRT	TBD	To assess risks and plans for starting integration of all hardware into the structure to build up the flight vehicle	N/A	N/A
Operation Readiness Review (ORR)/Flight Readiness Review (FRR)	IA/IRT	TBD	The purpose of this review is to evaluate whether a specific end item is sufficiently mature for shipment from the supplier to its designated operational facility or launch site.	N/A	N/A
Launch Readiness Date (LRD)/Industrial Operations Capabilities (IOC)	IA/IRT	TBD	The purpose of this review is to evaluate whether a specific end item is sufficiently mature for shipment from the supplier to its designated operational facility or launch site.	N//A	N/A

SPACE LAUNCH SYSTEM

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Launch Vehicle Development	2093.9	2099.1	**1715.3**	1772.8	1871.7	2160.0	2197.3
SLS Program Integration and Support	56.1	--	**60.1**	64.7	61.3	61.1	56.0
Total Budget	**2150.0**	**2150.0**	**1775.4**	**1837.5**	**1933.0**	**2221.2**	**2253.3**
Change from FY 2019			**-374.6**				
Percentage change from FY 2019			**-17.4%**				

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

The EM-1 intertank structural test article in the test jig at Marshall Space Flight Center ready to undergo testing that will ensure structural integrity of the core stage.

NASA seeks to expand the boundaries of human space exploration, Space Launch System (SLS) is looking to lead the way by preparing to carry humans, infrastructure, supporting equipment, and science missions farther into deep space than ever before.

SLS will play an instrumental role in carrying out the Exploration Campaign objectives, as a critical component for delivering crew to the Lunar Gateway. The Agency will continue to identify and implement affordability strategies to ensure SLS can be a sustainable exploration capability for decades to come.

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

Program Elements

SLS PROGRAM INTEGRATION AND SUPPORT

SLS program integration and support activities manage the Orion and Exploration Ground Systems (EGS) 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 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 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 2020 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	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	5967.1	1168.3	618.4	**296.2**	0.0	0.0	0.0	0.0	0.0	8050.0
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2019 MPAR LCC Estimate	**8641.1**	**1168.3**	**618.4**	**296.2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**10724.0**
Total Budget	**10021.9**	**2093.9**	**2099.1**	**1715.3**	**1772.8**	**1871.7**	**2160.0**	**2197.3**	**0.0**	**23932.0**
Change from FY 2019				**-383.8**						
Percentage change from FY 2019				**-18.3%**						

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

The difference between the total budget and the MPAR LCC estimate is the total budget includes content outside of EM-1 and excludes CoF; LCC only includes EM-1 content, including CoF.

The Current Year Development Cost Estimate and Milestone data does not accurately reflect current planning and are based on prior planning for an EM-1 launch date in June 2020. The EM-1 and EM-2 launch dates are under review pending completion of independent assessments of SLS core stage production and the integrated mission schedule. NASA leadership will review the results of these assessments in spring 2019 before considering potential updates to the EM-1 and EM-2 launch planning dates.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

EM-1 flight Intertank shown at the completion of welding and assembly work on October 14, 2018, at the Michaud Assembly Facility in New Orleans.

PROJECT PURPOSE

In support of the agency's strategic goal to extend and sustain human activities across the solar system, 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 be able to explore space beyond low Earth orbit (LEO) and return astronauts to the Moon, a charge toward reinvigorating America's human exploration.

EXPLANATION OF MAJOR CHANGES IN FY 2020

The FY 2020 President's Budget proposes funding to support launches at the earliest technically feasible dates. However, due to ongoing performance challenges NASA has realized the six months of risk in the previous year's launch readiness plan, and therefore the Exploration Mission – 1 (EM-1) LRD is currently NET June 2020. NASA believes there is continuing risk involving SLS end item completion (eg. Engine Section), functional test and integration of the Core Stage for delivery to Stennis Space Center, and completion of Green Run test that precedes delivery to Kennedy Space Center (KSC). Given these challenges, further delays beyond June 2020 are anticipated.

In October 2018, the SLS program began an assessment of core stage production. The assessment included representatives with experience in aerospace manufacturing and covered production schedule risks, risk mitigation approaches in work, and recommendations for additional schedule risk mitigations and corrective action and was presented to HEO in February 2019. On March 4, 2019, HEO chartered an assessment of other activities planned to achieve a launch in 2020. Specifically, this assessment will evaluate alternate approaches for hardware processing and facilities utilization for key components. The goal of this activity is to maintain an early as possible launch date. This activity, scheduled to conclude April 15, 2019, could result in a proposed new plan to include update to the EM-2 planning LRD, but EM-2 should still be within the ABC schedule of April 2023.

After completion of the HEO assessment, an independent schedule risk review led by the NASA Office of the Chief Financial Officer, set to begin mid-April 2019, will assess the proposed new plan to include: the integrated, detailed schedule and associated risk factors ahead of EM-1; considering technical complexity. The OCFO assessment report will include evaluation of schedule risks to critical milestone dates to include: SLS Core Stage delivery to SSC for Green Run Test, SLS Core Stage and Orion Crew Service Module deliveries to KSC, and is expected to be completed late spring. NASA leadership will review the results of these assessments in late spring 2019 at an Agency Program Management Council, before considering potential updates to the EM-1 and EM-2 launch planning dates.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

While the SLS Block 1B configuration with the Exploration Upper Stage (EUS) remains an important future capability, there have been significant delays and cost overruns in EM-1 SLS core stage manufacturing and design updates related to the Exploration Upper Stage (EUS) requirements. These delays and performance issues require that NASA concentrate in the near term on the successful completion of EM-1 and EM-2 and supporting a reliable annual flight cadence. As a result, SLS Block 1B final design efforts are deferred. This approach is intended to speed up the timeline for lunar surface exploration and increase the sustainability of the exploration program. .

PROJECT PARAMETERS

SLS is an integral part of the Exploration Campaign and will launch Orion to the Moon. Launch Vehicle Development leverages hardware designed for previous programs, including using adapted and refurbished Space Shuttle main engines, five-segment Shuttle-derived solid rocket boosters, and an interim cryogenic propulsion stage (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. The SLS rocket will be the most powerful rocket ever built with a total thrust greater than that of the Saturn V.

In an effort to achieve schedule and cost efficiencies, future SLS development will include block evolution, in which future upgrades share the same core stage while adding capability to accommodate more challenging missions. Initially, SLS will exceed its required 70 metric ton lift capability to LEO, and will use its Trans-Lunar Injection (TLI) performance to send nearly 25-30 metric tons to cislunar space, which will be used to launch the Orion crew capsule. Current estimates of lift capability to LEO are at 85 metric tons. Future block upgrades will add a more powerful upper stage, and improve vehicle lift performance to more than 105 metric tons to LEO and more than 40 metric tons to cislunar space, launching the Orion crew capsule and co-manifested payloads. Ultimately, after addressing obsolescence issues with the old Shuttle-era boosters and replacing depleted hardware using today's standard of practice, SLS is expected to be capable of carrying over 130 metric tons to LEO or more than 45 metric tons to cislunar space. SLS enables an increasing capability to demonstrate deep space technologies and hardware needed for future missions independent of Earth.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

ACHIEVEMENTS IN FY 2018

SLS program content continues to progress for EM-1, while simultaneously the future EM-2 elements core stage, solid rocket sections, and related structures were rapidly taking shape for both future flights. The Engine Section presented particularly challenging manufacturing difficulties, which were largely resolved. EM-1 critical issues include first-time production issues for the SLS core stage, such as the engine section, and early production issues are not unprecedented for an activity of this scope and ambition.

The Orion Stage Adaptor was finalized and shipped to KSC. The Launch Vehicle Stage Adapter, which finished welding in FY 2017, was finalized for flight and prepared for shipment in FY 2019. SLS continued conducting multiple development engine tests on the A-1 Test Stand at Stennis Space Center (SSC). The combined lab testing, and hot-fire testing on the A-1 test stand advanced the flight certification of the Engine Controller Units (ECU), which completed in early FY 2018.

Structural test stands for new core stage test articles at MSFC were completed and testing of the Engine Section successfully completed. The Engine Section was stressed and twisted to extremes beyond what will be experienced during flight and passed successfully. The large LH2 and LOX structural test stands were completed and readied for testing in FY 2019.

During launch and flight, the all-important flight software and associated avionics will fly the rocket. SLS completed significant activities for this effort, including release of flight software build 14 and associated avionics.

WORK IN PROGRESS IN FY 2019

During FY 2019, SLS continues to progress towards EM-1 while concurrently building hardware for EM-2, and development of the Block 1B/EUS, consistent with appropriations direction. EM-1 launch vehicle stage adapter will complete assembly and check out and will ship to KSC in preparation for integration. The completed EM-1 RS-25 flight engines are in storage at Michoud Assembly Facility (MAF) and are ready for integration into the core stage. The core stage sections continue outfitting with avionics, testing, and joining into the full flight core stage.

In addition to making considerable progress towards EM-1 fabrication, qualification, and assembly of flight elements, SLS is making strides towards EM-2 flight components including core stage-2, casting solid rocket booster segments, ICPS-2, and other elements.

Additionally, work continued on developing the new RS-25 engines for future missions. The RS-25 engines are based on the Space Shuttle Program heritage and will achieve a 33 percent cost reduction with innovative and advanced manufacturing methods. The full scale core stage mock up, a Pathfinder for major core stage handling maneuvers, completed in FY 2018 will deliver to SSC for B2 test stand confirmation planned during FY 2019.

Flight software and related avionic components will continue testing in the software integration laboratory at MSFC. All of the EM-1 booster components including, aft skirt assemblies, and forward assemblies will be completed and (along with the already completed segments and nozzle assemblies) and

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

delivered to KSC. The EM-1 core stage components including RS-25 engines, the engine section, hydrogen tank, inter-tank, and oxygen tank will complete joining. Shipment date from MAF to SSC for hot fire green run testing is under review. 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.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

The EM-1 flight is preceded by hot fire green run testing scheduled for FY 2020. Planning dates for green run testing are under review. Green run testing will test fire the flight core stage with a full load of fuel and liquid oxygen in test stand B2 at SSC. Upon the successful green run test, the core stage will ship to KSC and complete vehicle certification with the conclusion of the Design Certification Review Board in preparation for the EM-1 Flight Readiness Review.

With all EM-1 SLS hardware at KSC, SLS will effectively hand off all the launch components to Exploration Ground Systems (EGS). EGS will integrate the rocket with the Orion capsule in the Vehicle Assembly Building (VAB) using a co-developed Design Center concept. SLS will provide subject matter expertise as needed to support vehicle build-up and Integrated Test and Checkout, but will have limited VAB floor presence to minimize potential obstructions to integration flow operations. SLS and EGS will conduct daily meetings to communicate and coordinate integration operations.

With delivery of EM-1 hardware, the SLS program focus shifts to EM-2 and future flights. Fabrication and testing of elements of EM-2 will continue, to include Core Stage, solid rocket booster components, and additional flight elements. Additionally SLS will continue efforts to restart RS-25 engine manufacturing to support EM-4+ missions.

Schedule Commitments/Key Milestones

Milestone	Confirmation Baseline Date	FY 2020 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
CDR Board	Jul 2015	Jul 2015
Design Certification Review	Sep 2017	Date under review

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Milestone	Confirmation Baseline Date	FY 2020 PB Request
EM-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 (mths)
2015	7,021.4	70	2020	8,050.0	+14.6%	EM-1 Launch Readiness	Nov 2018	*June 2020	+19

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 Current Year Development Cost Estimate and Milestone data does not accurately reflect current planning and is based on prior planning for an EM-1 launch date in June 2020. The EM-1 and EM-2 launch dates are under review pending completion of independent assessments of SLS core stage production and the integrated mission schedule. NASA leadership will review the results of these assessments in spring 2019 before considering potential updates to the EM-1 and EM-2 launch planning dates.

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**	**8,050.0**	**+1,028.6**
Stages Element	3,138.6	4,455.5	+1,316.9
Liquid Engines Office*	1,198.3	495.5	-702.8
Booster Element	1,090.3	981.8	-108.5
SPIE	447.1	564.2	+117.1

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
Other	1,147.1	1,553.0	+405.9

The Agency Baseline Commitment previously included fixed and shared costs with the RS-25 production restart activity (in the Liquid Engines Office) which supports EM-1 and later missions. SLS removed those costs from the estimate and significantly lowered the EM-1 Liquid Engines Office and Current Year Development Cost Estimate.

The Current Year Development Cost Estimate and Milestone data does not accurately reflect current planning and is based on prior planning for an EM-1 launch date in June 2020. The EM-1 and EM-2 launch dates are under review pending completion of independent assessments of SLS core stage production and the integrated mission schedule. NASA leadership will review the results of these assessments in spring 2019 before considering potential updates to the EM-1 and EM-2 launch planning dates.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

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: 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 and SSC Cost Share Partner(s): N/A	N/A
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, and 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

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Project Risks

Risk Statement (Ranked in Sequential order)	Mitigation
Given new Propellant, Liner, and Insulation (PLI) materials requirements levied for SLS, and new design and stress state information identified during the QM-1 Aft Segment Investigation, there is the risk that structural & fracture concerns may prevent development of acceptable flight rationale.	New PLI materials have properties that are very different from historical materials. The recent QM-1 Aft Segment Investigation resulted in a PLI system design change to the barrier coating, and found that the cure process may result in insulation mechanical & fracture properties where acceptable EM-1 flight rationale cannot be developed. HEOMD accepted a SLS proposal to remove the barrier coating on future flight segments, complete analysis of the no-barrier design for review at the SLS Design Certification Review (DCR), and continue work on flight rationale for completed segments with the barrier.
Given multiple schedule-related challenges (timeliness of component deliveries, rate of infrastructure development progress, testing impacts, quality structural article testing and hot fire Green Run, and barge availability), one or more of these challenges will result in a schedule delay and associated cost overruns.	Stages process for schedule risk identification, assessment, tracking, and reporting of all top level schedule critical path drivers (with days of negative or positive slack) are reported monthly. Updated mitigation actions are employed as necessary preserving and improving schedule margin. Actions include reallocating budget, increasing activity to parallel paths (schedule resequencing), multi-shifting, later installation, etc. for in-house activities as well as prime contract based efficiencies. Early FY 2018 analysis shows improving trends. Threats and opportunities are addressed on a daily basis.
Given that the SLS program is employing a dynamic test philosophy and methodology different from heritage programs using an integrated dynamic test of the vehicle stack, there is a possibility that prior to EM-1 flight, element or vehicle analyses or tests reveal that math models are insufficient. This characterization model uncertainty may result in the need to repeat virtual modeling analysis and lead to a potential launch delay.	Mitigation is through a building block testing including static & modal tests of Stages, ICPS & MPCV. These individual elements are then integrated into vehicle modal tests including Partial Stack Modal Test (PSMT), Integrated Modal Test (IMT), and Dynamic Rollout Test (DRT). In addition, planning is under way for a full-scale Mobile Launcher only modal test. Results of this test will correlate and update the dynamic flex models to assess impact, if any, on design of the integrated vehicle loads and control systems of the vehicle. If negative impacts arise, they will be assessed as part of flight dynamics risk assessment and mitigated accordingly.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

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	NGIS (formerly Orbital ATK)	Magna, UT
Core Stage Engine	Aerojet Rocketdyne	Desoto Park, CA and SSC
ICPS	United Launch Alliance under contract to Boeing Aerospace	Huntsville, AL
Stages	Boeing Aerospace	New Orleans, LA
Upper Stage Engines	Aerojet Rocketdyne	West Palm Beach, FL

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

INDEPENDENT REVIEWS

NASA established an SRB to perform the independent reviews of the Space Launch Vehicle project as required by 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

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
DCR	SLS Independent Review Team	Under review	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
	HEOMD Independent Review Team (IRT)	NET Oct 2020	To evaluate the integrity of the Block 1B design and its ability to meet mission requirements with appropriate margins and acceptable risk. To determine if the design is appropriately mature to continue with the final design and fabrication phase.	The IRT will evaluate Block 1B content to assess if the program has achieved sufficient maturity to progress to major manufacturing, assembly and integration.	N/A

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Core Stage Independent Assessment	Independent Review Team	March 2019	Independent assessment of the ongoing Stages production effort. Includes assessment of production schedule risks, risk mitigation approaches in work, and recommendations for additional schedule risk mitigations and corrective actions. Focus areas include parts, supplies and material flows; work instructions; schedule; drawings; people; production management; and risk management and lessons learned.	Prepare recommendations for NASA Leadership review by April 15, 2019	N/A
ESD EM-1 Independent Schedule Assessment	Schedule assessors from the OCFO	April 2019	Programmatic assessment and analysis of EM-1 schedules across all ESD programs with an emphasis on program performance and risks	After NASA leadership review in late Spring 2019, update EM-1 launch date	N/A

EXPLORATION GROUND SYSTEMS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**895.0**	**592.8**	**400.1**	**357.8**	**388.7**	**448.1**	**401.3**
Change from FY 2019			**-192.7**				
Percentage change from FY 2019			**-32.5%**				

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

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. EGS is also modernizing communication and control systems to support these activities. Upon completion, the KSC launch site will be able to 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's mission is to transform the center from a historically Government-only launch complex focusing on a single type of launch vehicle, such as Saturn V or space shuttle, to a spaceport that can handle multiple varieties of spacecraft and rockets—both government and commercial.

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

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 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

EXPLORATION GROUND SYSTEMS DEVELOPMENT

See the Exploration Ground Systems Development.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

FY 2020 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	BTC	Total
Formulation	965.8	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	965.8
Development/Implementation	1385.3	323.4	360.7	**175.5**	0.0	0.0	0.0	0.0	0.0	2244.9
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2019 MPAR LCC Estimate	**2351.1**	**323.4**	**360.7**	**175.5**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**3210.7**
Total Budget	**2133.4**	**878.2**	**587.8**	**396.5**	**350.1**	**385.1**	**444.5**	**401.3**	**0.0**	**5577.0**
Change from FY 2019				**-191.3**						
Percentage change from FY 2019				**-32.5%**						

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

The difference between the total budget and the MPAR LCC estimate is the total budget includes content outside of EM-1 and excludes CoF; LCC only includes EM-1 content, including CoF.

The Current Year Development Cost Estimate and Milestone data does not accurately reflect current planning and are based on prior planning for an EM-1 launch date in June 2020. The EM-1 and EM-2 launch dates are under review pending completion of independent assessments of SLS core stage production and the integrated mission schedule. NASA leadership will review the results of these assessments in spring 2019 before considering potential updates to the EM-1 and EM-2 launch planning dates.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

PROJECT PURPOSE

The Mobile Launcher atop crawler-transporter 2 traveling 4.4 miles to Launch Complex 39B to undergo a fit check, followed by several days of systems testing.

Exploration Ground Systems (EGS) is preparing to launch the Space Launch System (SLS) and Orion space transportation systems in support of lunar exploration. 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 Pad 39B, the Vehicle Assembly Building (VAB), the mobile launcher and other smaller facilities to move from Space Shuttle focused to support exploration missions. The modernization efforts maintains flexibility on Pad 39B and in the VAB in order to accommodate other potential users and commercial partners. Additionally, following the EM-1 launch of SLS and Orion, the mobile launcher, VAB, and Pad will undergo modifications to accommodate crewed flight.

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

EXPLANATION OF MAJOR CHANGES IN FY 2020

The EM-1 and EM-2 launch dates are expected to be further delayed. Launch dates are under review pending completion of independent assessments of core stage production and the EM-1 integrated mission schedule. In addition, an independent schedule review lead by the NASA Office of the Chief Financial Officer is assessing the integrated, detailed schedule and associated risk factors ahead of EM-1, taking into account technical complexity and delays caused by the government furlough. The assessment report will include an evaluation of schedule risks to critical milestone dates to include SLS Core Stage and Orion Crew Service Module deliveries to Kennedy Space Center (KSC). NASA leadership will review the results of these assessments in spring 2019 before considering potential updates to the EM-1 and EM-2 launch planning dates.

The FY 2020 President's Budget proposes funding is sufficient to support launches at the earliest technically feasible date.

Consistent with provisions in the FY 2018 Consolidated Appropriations Act (P.L. 115-141), as well as the NASA Administrative Provision in P.L. 115-141 pertaining to the Agency's Operating Plan, NASA is proceeding with a contract award in 2019 to start building the second mobile launcher platform.

Although NASA began design and construction on the second mobile launcher platform, additional funding to complete the project is being deferred. NASA does not have plans to utilize the second mobile launcher in the near term and a final Block 1B design has not been set. NASA is deferring these activities

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

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.

PROJECT PARAMETERS

EGS is modernizing and upgrading KSC's ground systems and facilities required to enable integration of SLS and Orion, move the integrated vehicle to the launch pad, and launch it successfully into space. For the Exploration Missions (EMs), like EM-1 and EM-2, 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 mobile launcher and crawler-transporters; preparing Launch Complex (LC)-39B at KSC, modernizing computers, software, tracking systems, and other network communication.

ACHIEVEMENTS IN FY 2018

Underway Recovery Test (URT)-6 occurred off the coast of San Diego in January 2018 aboard a Landing Platform Dock class ship. This was the first URT to attempt night operations. The test allowed NASA and the United States Navy to continue to demonstrate and evaluate the recovery processes, procedures, and hardware before committing to conducting actual recovery operations of the Orion spacecraft.

Spacecraft offline processing began in April 2018. During this process, the program validated all systems hardware and software in order to determine the system readiness for a safe and successful launch.

The System Integration Review was completed in June, which evaluated readiness of multi-element V&V. Validation and Verification (V&V) in the Multi-Payload Processing Facility was completed in June 2018. The program began the operations and integration phase in preparation for multi-element V&V for the Mobile launcher, Pad, and VAB.

The mobile launcher made the 4.4-mile journey atop crawler-transporter-2 to Launch Pad 39B to undergo a fit check, followed by several days of systems testing in August. The 380-foot-tall mobile launcher is equipped with the crew access arm and several umbilicals that provides power, environmental control, pneumatics, communication and electrical connections to SLS and Orion spacecraft.

The mobile launcher departed Launch Pad 39B and returned to VAB High Bay 3 to start multi-element V&V testing with the platforms. This was the first time that the modified mobile launcher made the trip to the pad and the VAB. The mobile launcher will spend seven months in the VAB undergoing testing. The program is preparing the ground systems necessary to launch SLS and Orion on EM-1.

The umbilical lines and accessories that connect from the mobile launcher to the SLS and Orion were tested at the Launch Equipment Test Facility (LETF). A total of 21 umbilicals and launch accessories were tested on various simulators at the LETF before being transferred to the mobile launcher for installation.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

The program completed construction on updates to the flame deflector/flame trench at Launch Pad 39B. The flame deflector will safely deflect the plume exhaust from the SLS rocket during launch. It will divert the rocket's exhaust, pressure and intense heat away from SLS and Orion at liftoff.

The program conducted studies on the requirements to support SLS upgrades for EM-2 on communication systems, the mobile launcher, VAB and requirements for additional liquid hydrogen capacity at the pad. In accordance to the FY 2018 Consolidated Appropriations Act (P.L. 115-141) the program was provided $280M to support a second mobile launcher platform. The program began the solicitation process for a second mobile launcher platform in May with plans to award the construction contract in FY 2019.

WORK IN PROGRESS IN FY 2019

The program performed two successful water flow tests on the Ignition Overpressure Protection and Sound Suppression (IOP/SS) water deluge system at Launch Pad 39B in October. At peak flow, the water reached about 100 feet in the air above the pad surface. During the launch of EM-1 and subsequent missions, this water deluge system will release approximately 450,000 gallons of water across the mobile launcher and Flame Deflector to reduce the extreme heat and energy generated by the rocket.

The first high speed retraction test on the Orion Service Module Umbilical (OSMU) on the mobile launcher was completed in October 2018. 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 for the environmental controls to the Orion service module and Launch Abort System.

Exploration Ground Systems engineers conducted 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. 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 United States Navy ship, or be pulled out immediately and put on the "front porch" until taken by small boat back to the ship. 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. Orion will have 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. The service module will undergo a host of tests and integration work ahead of EM-1. Engineers will complete functional checkouts to ensure all elements are working properly before connecting to the Orion crew module. Teams will weld together fluid lines to route gases and fuel and make electrical wiring connections. The service module and crew module will be mated, and the combined spacecraft will be sent to NASA’s Glenn Research Center’s Plum Brook Station in Ohio early next year where it will undergo 60 days of continuous testing in the world’s largest thermal vacuum chamber to ensure Orion can withstand the harsh environment of deep space. Once that testing is complete, it will return to KSC for integration with the SLS rocket in preparation for launch. The ESM will propel, power and cool Orion during EM-1

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

EGS will continue ground systems development efforts including efforts for mobile launcher structural modifications, installation of GSE, VAB HB3/HB4 platforms and completion of Environmental Control System. Upon design completions, construction activities for the new VAB platforms, mobile launcher, and LC-39B's new liquid hydrogen storage tank will begin, as well as fabrications of the new umbilicals necessary to support the new SLS vehicle configuration.

Consistent with provisions in the FY 2018 Consolidated Appropriations Act (P.L. 115-141), as well as the NASA Administrative Provision in P.L. 115-141 pertaining to the Agency's Operating Plan, NASA is proceeding with a contract award in 2019 to start building the second mobile launcher platform.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

The program will complete software development efforts and MEVV of the ground systems to support EM-1. Spacecraft processing operations for Orion will take place at the MPPF, followed by SLS flight hardware assembly, SLS/Orion integration, and integrated testing at the VAB to support an EM-1. The program will complete URT 8 and 9 to ensure safe recovery of the Orion crew module post the EM-1 mission. Completion of all ground processing operations in support of an EM-1 integrated launch. Following the completion of EM-1, the landing and recovery operations to recover the Orion Crew Module will be completed and the CM will be returned to KSC.

In addition, EGS will continue ground systems development efforts in support of future mission requirements including the first crewed flight on EM-2. This includes modifications to the pad and VAB Environmental Control System (ECS), upgrades to the Converter Compressor Facility (CCF), modifications to the mobile launcher to support crew missions, as well as continuation of Liquid Hydrogen Sphere Construction activities at launch pad 39B

Although NASA began, work on the second mobile launcher platform and will award a contract to begin design and construction, additional funding to complete the project is being deferred. NASA does not have plans to utilize the second mobile launcher in the near term and a final Block 1B design has not been set. 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.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Schedule Commitments/Key Milestones

Milestone	Confirmation Baseline Date	FY 2020 PB Request
KDP-A	Feb 2012	Feb 2012
Formulation Authorization	Apr 2012	Apr 2012
SRR/SDR	Aug 2012	Aug 2012
KDP-B APMC	Nov 2012	Nov 2012
PDR Board	Mar 2014	Mar 2014
KDP-C APMC	May 2014	May 2014
CDR Board	Dec 2015	Dec 2015
SIR	June 2018	Under Review
EM-1 Launch Readiness	December 2018	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 (mths)
2015	1,843.5	80	2018	2,245.0	21.8%	EM-1 Readiness	Nov 2018	*June 2020	19

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 Current Year Development Cost Estimate and Milestone data does not accurately reflect current planning and are based on prior planning for an EM-1 launch date in June 2020. The EM-1 and EM-2 launch dates are under review pending completion of independent assessments of SLS core stage production and the integrated mission schedule. NASA leadership will review the results of these assessments in spring 2019 before considering potential updates to the EM-1 and EM-2 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**	**2,245.0**	**401.5**
Mobile Launcher	213.1	471.4	258.3
LC-39B Pad	77.5	45.4	(32.1)
VAB	92.7	34.5	(58.2)
Command, Control, and Communications	198.0	424.6	226.6
Offline Processing and Infrastructure	110.2	81.3	(28.9)
Other	1152.0	1,187.9	35.9

**Other includes Crawler Transporter, Launch Equipment Test Facility, Integrated Operations, Program Management, Logistics, S&MA, and SE&I.*

The Agency Baseline Commitment for LC-39B, VAB, and Offline Processing and Infrastructure previously integrated Operations cost which support EM-1 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 $27M 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 Current Year Development Cost Estimate and Milestone data does not accurately reflect current planning and are based on prior planning for an EM-1 launch date in June 2020. The EM-1 and EM-2 launch dates are under review pending completion of independent assessments of SLS core stage production and the integrated mission schedule. NASA leadership will review the results of these assessments in spring 2019 before considering potential updates to the EM-1 and EM-2 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): ARC 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): NA 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 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 tr ack and manage progress throughout V&V
If: The mobile launcher 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 has a significant impact to the Mobile Launcher operational readiness date to support launch.	Acceleration Schedule is under review by mobile launcher team and contractors.
If: The Ground Flight Application Software Team (GFAST) internal/external dependencies on GSE subsystems, SCCS, Models and Emulators, SLS, Orion and ICPS to provide requirements, data products and hardware are not within the currently defined GFAST schedule, Then: There is the possibility GFAST will not be ready to perform integrated processing with flight hardware and GSE in the VAB/Pad and MPPF in time to meet Cross-Program objective and schedules while remaining within allocated budgets.	The program approved additional funding for Firing Room assets, which will lower the risk when hardware is installed and available for GFAST use.

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, since they are subject to any losses incurred. In addition, it imposes a minimal administrative burden upon 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)
Mobile Launcher Structural and Facility Support Modification Contract	J.P. Donovan Construction, Inc.	KSC
VAB High Bay Platform Construction	Hensel Phelps Construction, Inc.	KSC
Mobile Launcher -2 Design Build	TBD	KSC

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
All	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; 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

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
SIR	KSC Independent Review Team (IRT)	Mar 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
Block 1B Delta CDR	HEOMD Independent Review Team (IRT)	NET May 2019	To evaluate the integrity of the Block 1B design and its ability to meet mission requirements with appropriate margins and acceptable risk. To determine if the design is appropriately mature to continue with the final design and fabrication phase.	The IRT will evaluate Block 1B content to assess if the program has achieved sufficient maturity to progress to major manufacturing, assembly and integration.	N/A
ESD EM-1 Independent Schedule Assessment	Schedule assessors from OCFO	Begins February 2019	Programmatic assessment and analysis of EM-1 schedules across all ESD programs with an emphasis on program performance and risks	After NASA leadership review in late Spring 2019, update EM-1 launch date	N/A

EXPLORATION RESEARCH & DEVELOPMENT

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Advanced Exploration Systems	237.8	--	**255.6**	239.8	188.3	146.7	130.1
Advanced Cislunar and Surface Capabilities	0.0	--	**363.0**	647.0	967.7	1775.9	2360.0
Gateway	17.2	--	**821.4**	827.7	717.0	787.8	757.5
Human Research Program	140.0	--	**140.0**	140.0	140.0	140.0	140.0
Total Budget	**395.0**	**958.0**	**1580.0**	**1854.5**	**2013.0**	**2850.4**	**3387.6**
Change from FY 2019			**622.0**				
Percentage change from FY 2019			**64.9%**				

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

NASA performed tests at the agency's Johnson Space Center in Houston to help engineers refine NASA's requirements for the design of a deep space habitat.

The Exploration Research and Development (ERD) theme is comprised of four areas: Advanced Cislunar Surface Capabilities (ACSC), Lunar Gateway, Advanced Exploration Systems (AES) and the Human Research Program. The overarching goal of ERD is to infuse technologies and research, and develop high-priority capabilities and missions using a combination of unique in-house activities, public-private partnerships and international partnerships. ERD is developing and testing prototype systems and planning and developing flight missions to lunar orbit and the Moon that will form the basis for future human spaceflight missions throughout the Exploration Campaign.

The ultimate goal of the ACSC program is to establish a sustainable U.S. human presence on the Moon. Working in parallel with scientific lunar exploration, and space technology exploration, NASA is planning to develop a series of progressively more capable missions to the surface of the Moon. ACSC will utilize public-private partnerships and international participation to promote innovative approaches to lunar robotics, a cislunar presence, and lunar landing capabilities to enhance U.S. leadership. ACSC is in close collaboration and partnership with other HEOMD programs, the Science Mission Directorate, and the Exploration Technology Account. ACSC will solicit, engage, and nurture growing capabilities and progress to the ultimate goal of landing a crew of astronauts and land on the lunar surface by 2028. Through development of sustaining operations and in-situ resource utilization (ISRU) with refueling options, reusable vehicles will be able to transport astronauts back and forth between Gateway and the surface of the Moon. ACSC has accelerated development of a human lunar landing architecture that will include uncrewed demonstration missions in 2024 and 2026, leading to the crewed demonstration mission in 2028 to return humans to the lunar surface. Each mission/element launch builds upon the previous, growing the capabilities for the 2028 crewed mission with reusable elements.

As a key part of the Exploration Campaign, ERD will lead development of the Lunar Gateway, a small way station that will orbit the Moon, to serve as an outpost for human and robotic missions to the surface of the Moon. The Gateway will be a temporary home for astronauts and a way station supporting sustainable human lunar surface exploration missions, including by supporting reusable human lunar landers.

AES will invest in development and demonstration of exploration capabilities to reduce risk, lower life cycle cost and validate operational concepts for future human missions. Ground habitation prototypes developed through public-private partnerships will be tested to evaluate human factors for different habitat configurations; assess how the various systems interact together and with other capabilities like propulsion modules and airlocks; and provide platforms to test and ensure that standards and common interfaces being considered are well designed. AES will continue to mature and test capabilities in Habitation Systems, Habitation Capabilities and other risk reduction activities.

Gateway and ACSC programs will be utilizing a variety of agreements and contracts that enable NASA and private industry as well as academia and international partnerships to share in the risk and gain of Government investments. These shared risks and gains include incentivizing technical performance, building future commercial markets and a shared financial interest in developing capabilities. Those programs, as well as the Advanced Exploration Systems effort, are also utilizing the unique skills of the NASA workforce to perform risk reduction, develop life support systems, and build some elements for the Gateway and ACSC programs.

In order to enable NASA's Exploration Campaign, ERD will invest in development and demonstration of exploration capabilities to reduce risk, lower life cycle cost and validate operational concepts for future human missions. The technology capabilities and processes pioneered by ERD will enable the first intrepid crews of the new space age to cross countless frontiers, stay safe and healthy, deliver scientific discoveries, and sustain new homes away from home, for the benefit of all humankind.

EXPLANATION OF MAJOR CHANGES IN FY 2020

None.

ADVANCED EXPLORATION SYSTEMS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	237.8	--	255.6	239.8	188.3	146.7	130.1

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

Universal Waste Management System toilet stall enclosures on ISS

The Advanced Exploration Systems (AES) activities infuse technologies and develop high-priority capabilities using a combination of unique in-house activities and public-private partnerships to develop and test prototype systems that will form the basis for future human spaceflight missions. With a focus on design, development, and demonstration of exploration technologies to reduce risk, lower life cycle cost and validate operational concepts needed for future deep space elements; AES leads development of new approaches to project and engineering management.

In order to enable NASA's Exploration Campaign, 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 the 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 technologies include development and testing of ground habitation prototypes developed through public-private partnerships to evaluate human factors for different habitat configurations and assess how the various systems interact together. AES will continue to work on identifying and addressing knowledge gaps existing outside of the astronaut habitats and deliver fundamental capabilities to provide astronauts a place to live and work with integrated life support systems, radiation protection, fire safety, avionics and software, logistics management, and systems to manage waste.

Other major areas of development include spacecraft fire safety experiments, avionics and software, and potential improvements on how space crafts are powered. AES will also deliver CubeSat payloads for Exploration Mission -1 (EM-1) that will study space communication, near earth object monitoring and robotic lunar prospecting,

ADVANCED EXPLORATION SYSTEMS

AES provides the critical technologies to enable human crewed missions to cislunar space including capabilities that enable 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.

EXPLANATION OF MAJOR CHANGES IN FY 2020

None.

ACHIEVEMENTS IN FY 2018

In FY 2018, AES continued a crucial set of activities to leverage past achievements from development work performed from FY 2012 – FY 2017. Key activities included gaining a fundamental understanding of novel habitation structures, integrated advanced life support systems, logistics reduction, fire safety, and radiation protection as well as avionics and software for increased autonomy. AES continued work on additional technologies including synthetic biology applications, in-space manufacturing, robotic precursor missions, and vehicle systems including modular power systems, advanced propulsion, and lander technologies. Together, these technologies will close critical capability gaps necessary for deep space missions, including the Exploration Systems Development (ESD) Programs, and future human crewed missions to cislunar space such as the Gateway.

The Bigelow Expandable Activity Module (BEAM) successfully completed its two-year original contract. NASA signed a new agreement to support utilization as an International Space Station (ISS) stowage module with a life extension through the end of ISS life. Expandable habitats are designed to be packaged into a smaller volume for launch, but provide greater volume for living and working in space once deployed. BEAM is berthed to the ISS and has demonstrated that inflatable habitats have the integrity to withstand the harsh environment of space.

AES began assembly of Saffire-IV, V, and VI, the final three in a series of six spacecraft fire safety flight experiments on a Cygnus vehicle. The Saffire payloads help us understand how large-scale fires spread in microgravity and test 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. Reliable systems with increased autonomy are essential for missions beyond low Earth orbit in the context of both crew time and limited communications back to Earth.

AES continued the Next Space Technologies for Exploration Partnerships (NextSTEP) with commercial industry to prototype habitats, life support systems, and other habitation technologies ready to feed forward and conduct integrated ground and ISS based testing to reduce risk for deep space missions.

Work continued on development of Habitation Capabilities that will improve life support and environmental monitoring technologies and increase resource recovery, effectively reducing dependence on resupply from Earth. New capabilities from this work to be demonstrated on the ISS include an airborne particulate monitor, a spacecraft atmospheric monitor (SAM), a brine processor assembly (BPA), a Universal Waste Management System (UWMS), and a Plasma Pyrolysis Assembly (PPA). The airborne particulate monitor is based on an ISS demonstration model flown in 2018 and will detect small airborne particles that cause allergies and irritate crew members' eyes and noses. The SAM will monitor atmosphere composition and also detect hazardous contaminants in the ISS air. For future missions, additional water must be reclaimed due to the significant resupply challenge for missions beyond low Earth orbit. NASA matured the BPA to potentially recover 98% of the water in urine. The UWMS will provide a more efficient commode for the Orion and other future crewed vehicles. The PPA will recover hydrogen from methane to potentially increase overall oxygen recovery on ISS from 50% to 75%. Other technologies also continued development in 2018, including advanced trace contaminant control, particulate filtration, carbon dioxide removal, high pressure oxygen replenishment for EVA and medical use, trash processing, and water and microbial monitors.

Through Habitation Systems, flight demonstrations of these new Habitation Capabilities, as well as improvements to the current ISS life support, environmental monitoring, fire safety, and crew health systems are progressing. In addition to efforts described above, improvements for better reliability and performance of the ISS oxygen generation assembly, ISS Urine Processor Assembly, ISS Water Processor Assembly and Temperature and Humidity Control condensing heat exchangers continued in 2018, as well as development of improved technologies for carbon dioxide removal. Ground development of smaller, more efficient exercise devices is also continuing for upcoming ISS flight demonstrations.

In FY 2018, a series of Synchronized Position Hold, Engage, Reorient, Experimental Satellites (SPHERES) runs were performed aboard the ISS. SPHERES are bowling ball-sized spherical satellites that are used inside ISS to test a set of autonomous rendezvous and docking maneuvers, which will free up crew to perform other work and research on ISS.

The first generation Autonomous Power Control platform was delivered to the Integrated Power, Avionics, and Software laboratory in 2018, furthering the modular power system architecture goals for minimized maintenance operations, improving power system availability, and reducing the volume of unique spare parts necessary to enable sustained future exploration missions.

AES maintained investments in efforts that reduce logistics requirements, including in-space manufacturing technology development and demonstration on ISS. A BAA was released and three companies selected to deliver prototypes for a multi-material fabrication laboratory which is a small-scale workshop offering advanced in-space fabrication.

To prove the capabilities of the Disruption Tolerant Network (DTN), AES team members completed a data transfer from the National Science Foundation- McMurdo Station in Antarctica to the ISS. The demonstration served as a precursor to how DTN can be infused into NASA's space communication network.

WORK IN PROGRESS IN FY 2019

As NASA works to extend human space exploration beyond low Earth orbit, AES will continue to develop reliable life support systems, deep space habitats, and overall capabilities to reduce logistics requirements to support future human spaceflight missions.

The NextSTEP Phase 2 habitation prototype development will be completed in early FY 2019 when the industry partners provide NASA the functional habitat ground prototype units for ground testing. The ground prototypes will allow 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, 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.

Space radiation environments must be measured to determine astronaut exposures. In FY 2019, the Hybrid Electronic Radiation Assessor will be deployed on ISS to refine radiation data analysis and serve as an opportunity to evaluate the hardware prior to the EM-1 flight.

In 2019, AES will begin ISS flight demonstrations of life support and environmental monitoring subsystems including the Spacecraft Atmosphere Monitor, the Universal Waste Management System (UWMS), and one of three planned advanced carbon dioxide removal systems. In addition, a UWMS will be delivered to Orion for its EM-2 mission. Development and production work continues in all other life support, logistics reduction, environmental monitoring, and crew health improvements toward ISS flight demonstrations in 2020 and beyond. Additionally, AES will embark on a ground-based test campaign to conduct testing 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.

AES will continue to support development of Orion by leading integration of the Ascent Abort-2 (AA-2) flight test article. The AA-2 flight test will demonstrate the ability of the launch abort system to function as the spacecraft breaks through the speed of sound. The avionics and core flight software developed by AES will be used on the AA-2 test flight and is planned to be utilized on other systems for future capabilities.

The Ka-Band Objects Observation and Monitoring activity will transform into a radar facility, the Ka-Band Array Radar for Near Earth Object Accurate Characterization. The transition to a permanent facility will greatly increase the capability for accurate characterization of object surface porosity, composition and rate of rotation.

AES is developing four small satellites for launch on EM-1 in 2020: 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 effect of space radiation on biological systems, but will also develop capabilities for deep space CubeSats enabling future missions for academia and industry.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

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.

The CubeSat payloads will be integrated and ready for launch on EM-1. BioSentinel will study the effects of the deep space radiation environment on yeast 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 habitation technologies 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 beginning in 2019, 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, a brine processor to recover water from urine, and improvements to the ISS urine and water processors. Work will continue on all other advanced habitation systems toward ISS flight demonstration 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

Five strategic technology development element areas drive NASA's Advanced Exploration Systems division, each focusing on a specific capability required for future human space exploration.

HABITATION

Habitation capabilities and systems deliver the fundamental capability to provide integrated life support systems, 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 deep space for missions lasting up to one thousand days.

Activities include the expandable habitat BEAM, NextSTEP deep space habitation prototype development efforts, life support systems, logistics reduction, 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 transition to the capabilities to define, design, and develop future habitation capabilities and systems for use in exploration missions

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 the Exploration Technology Account, ISS, Orion, SLS, the Human Research Program and the Space Communications and Navigation program.

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

VEHICLE SYSTEMS

In the area of Vehicle Systems, AES develops technologies to enhance the transport of people and payloads across the solar system. Technologies include modular power systems, and the Ascent Abort-2 flight test article.

FOUNDATIONAL SYSTEMS

AES is making investments today to shape the building blocks needed for the missions of tomorrow. Foundational systems enable exploration by providing efficient mission and ground operations that reduce dependence on Earth's resources. AES work in this area fosters autonomous mission operations, avionics and software, in-space manufacturing, as well as communication and networking technologies.

ROBOTIC PRECURSOR ACTIVITIES

Robotic Precursor Activities acquire strategic knowledge about potential destinations for human exploration. These efforts inform systems development through activities such as prospecting for lunar ice, instrument development, and research and analysis.

STRATEGIC OPERATIONS, INTEGRATION, AND STUDIES

AES conducts studies and analysis to translate strategy into developmental (technology and capability) priorities and operational efficiencies. Activities include the CubeSat Launch Initiative, the development of SPHERES and the Astrobee free flyer for ISS, and the NASA Agency Video, Audio and Imagery Library.

Program Schedule

Date	Significant Event
March, 2019	Deliver Spacecraft Atmosphere Monitor (SAM) Flight Demonstration Unit
March, 2019	Demonstrate Refabricator operations on ISS
April, 2019	Issue RFP for NextSTEP Habitation Phase 3
May, 2019	Conduct Ascent Abort(AA)-2 flight test
June, 2019	Deliver RFID Enabled Autonomous Logistics Management(REALM)-2 mobile reader for launch
August, 2019	Deliver Saffire-IV flight hardware for launch on NG-12
August, 2019	Complete ground testing of prototype habitats
September, 2019	Deliver Brine Processor Assembly (BPS) Flight Demonstration Unit
September, 2019	Demonstrate baseline Astrobee functionality on ISS

Program Management & Commitments

HEOMD executes AES activities, and the Directorate's Associate Administrator has 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: HQ Performing Center(s): JSC, MSFC, ARC, GRC, KSC and 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, GSFC, and JPL Cost Share Partner(s): None
Foundational Systems	Provider: NASA Centers Lead Center: HQ Performing Center(s): ARC, JSC, MSFC Cost Share Partner(s): None

Program Element	Provider
Vehicle Systems	Provider: NASA Centers Lead Center: HQ Performing Center(s): GRC, JSC Cost Share Partner(s): None
Strategic Operations	Provider: NASA Centers Lead Center: HQ Performing Center(s): ARC Cost Share Partner(s): None
Robotic Precursors	Provider: NASA Centers Lead Center: HQ Performing Center(s): MSFC, JPL, ARC Cost Share Partner(s): None

Acquisition Strategy

AES selected initial activities through an internal competition in which NASA centers submitted proposals specifically to address the highest priority capabilities for human exploration beyond low Earth orbit. Each year, AES evaluates how the portfolio aligns with human exploration priorities and technology gaps, and either terminates activities that do not demonstrate adequate progress or realigns them, and/or 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 and Advanced Cislunar Surface Capabilities (ACSC). Teams are provided limited procurement funding to purchase materials, equipment, access and coverage of NASA test facilities. AES strives to maximize specialized skills within the civil service workforce, but 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.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Habitat Systems: Universal Waste Management System	United Technologies Aerospace Systems	JSC
Habitat Systems: Inflatable Module	Bigelow Aerospace	North Las Vegas, JSC
Habitation Systems: Brine Water Processor	Paragon	Tucson Arizona, MSFC
NextSTEP BAA 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 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**0.0**	**--**	**363.0**	**647.0**	**967.7**	**1775.9**	**2360.0**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

Through the Advanced Cislunar and Surface Capabilities Program, NASA will return humans to the Lunar Surface.

NASA is continuing to advance its lunar campaign through the Advanced Cislunar and Surface Capabilities (ACSC) program to establish United States preeminence to, around, and on the Moon. NASA is developing a series of lunar missions that build in capability to return humans to the surface in the late 2020s. Utilizing commercial and international partners as appropriate to enhance United States leadership and ensure affordability, ACSC will use new approaches to accelerate human-class lander capability development.

ACSC has accelerated development of a human lunar landing architecture that will include uncrewed demonstration missions in 2024 and a crewed demonstration mission to return humans to the lunar surface.

The ACSC program is an integral part of NASA's Exploration Campaign, working in parallel with exploration technology, scientific lunar exploration, Orion, Gateway, and SLS and commercial launch capabilities. Agency partnerships through the Exploration Campaign will continue with the Science Mission Directorate (SMD) Lunar Discovery and Exploration Program (LDEP) and Exploration Technology account. The partnership with SMD includes coordinating and identifying NASA payloads to fly on commercial lunar transportation services missions, and identifying long-term exploration needs. Exploration Technology's Tipping Point program includes six awards that are related to lunar landers. ACSC will work with the Exploration Technology account to ensure that the technologies developed are relevant and have high potential to on-ramp to the lunar missions.

ACSC will solicit, engage, and nurture growing capabilities and progress to the ultimate goal of landing a crew of astronauts on the lunar surface by 2028. Through development of sustaining operations and in-situ resource utilization (ISRU) with refueling options, reusable vehicles will be able to transport astronauts back and forth between Gateway and the surface of the Moon.

ADVANCED CISLUNAR AND SURFACE CAPABILITIES

EXPLANATION OF MAJOR CHANGES IN FY 2019

ACSC has accelerated development of a human lunar landing architecture that will include uncrewed demonstration missions in 2024 and 2026, and a crewed demonstration mission in 2028 to return humans to the lunar surface. The program will focus on working with industry to create an affordable and sustainable capability.

ACHIEVEMENTS IN FY 2018

In FY 2018, Human Exploration and Operations/Lander Technologies released a Request for Information (RFI) soliciting emerging commercial capabilities, short and long term mission plans, information on what commercial sector opportunities there are that would be enabled through regular access to the lunar surface, and innovative public-private partnership acquisition approaches.

WORK IN PROGRESS IN FY 2019

The responses from the RFI released in 2018 and were used to develop a 2019 solicitation released in February to support joint risk reduction activities. Using a new appendix under the Next Space Technologies for Exploration Partnerships (NextSTEP) Phase 2 Broad Agency Announcement (BAA), NASA is soliciting lander risk reduction activities and concepts from industry leading to sending humans to the surface of the Moon and bringing them home safely as part of a sustainable campaign of exploration.

These activities will be closely coordinated with SMD and the LDEP so that NASA ensures continued options to on-ramp new commercial robotic / cargo landing capabilities as those services become available and economically sustainable.

FY 2018 accomplishments from the Advanced Exploration Systems (AES) Lunar Cargo Transportation and Landing by Soft Touchdown (Lunar CATALYST) partnerships continue to be assessed to evaluate efforts that are directly applicable to ACSC. The CATALYST partnerships encourage development of robotic lunar landers that can be integrated with United States commercial launch capabilities to deliver payloads to the lunar surface.

Through a partnership with the Korea Aerospace Research Institute, ACSC will deliver the ShadowCam flight instrument for the Korea Pathfinder Lunar Orbiter. NASA will provide Deep Space Network lunar navigation and trajectory assistance in return for instrument space on their orbiter. The ShadowCam will image the shadowed regions on the Moon's poles.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

In 2020 ACSC will primarily be focused on partnering with industry to develop the FY 2024 human-class lunar lander (descent element) which will be sized for the largest commercial launch vehicle available at that time. Operational analysis will begin in order to study how to integrate future landers with a lunar surface payloads at the Gateway, allowing for the largest possible payload and increased extensibility for the human lander.

ADVANCED CISLUNAR AND SURFACE CAPABILITIES

ACSC will release studies, develop architecture designs, and perform risk reduction activities for the FY 2026 reusable transfer vehicle which will serve as a means of transport between Gateway and Low Lunar Orbit (LLO), as well as begin development of a reusable human ascent element to return astronauts to the Gateway after landing on the lunar surface. ACSC will continue risk reduction activities on Extravehicular Activity (EVA) suits for astronauts on the lunar surface. Studies and risk reduction activities will begin on a refueling element that will refuel the reusable elements near the Gateway to allow a sustainable cadence of missions to the lunar surface and prepare for missions beyond the Moon

ACSC will also continue to partner with the Science Mission Directorate and the Exploration Technology account for related lander and surface systems.

PROGRAM ELEMENTS

LUNAR LANDER MISSIONS

2024 DESCENT ELEMENT DEMONSTRATION

The first demonstration mission will focus on the descent element of the human landing system. The 2024 mission is intended to demonstrate extended cryogenic fluid management operations that are needed to establish a high performance, reusable propulsion system for sustainable human-class landing systems on later missions. Development of the descent element is intended to be achieved through industry-led design and development using a fixed-price/milestone based contract approach for this demonstration and follow-on missions. NASA is currently targeting a lunar pole for the first landing site because of its potential to collect and utilize lunar polar resources including water. HEO/ACSC and SMD/LDEP will continue to assess existing lunar data sets and information from planned lunar missions, including Commercial Lunar Payload Services (CLPS) missions, to further identify and characterize specific candidate sites for the 2024 mission and beyond.

FUTURE LANDER MISSIONS

ACSC is also planning a demonstration mission in 2026 and a human crewed mission to the surface in 2028. The 2026 lander mission will be an end-to-end test flight of an uncrewed human-class lunar landing system. The 2026 mission will demonstrate the full lunar surface access architecture including the Transfer Vehicle from Gateway to Low Lunar Orbit (LLO), the full human-class Descent Element from LLO to the lunar surface and the full human-class Ascent Element return to Gateway from the lunar surface. Both the Transfer Vehicle and the Ascent Element will be tested for reusability for future missions to demonstrate landing sustainability.

In 2028, the third ACSC lander mission will land a crew of astronauts on the Moon and return them safely to Gateway. For this mission, ACSC will demonstrate EVA space suits on the lunar surface, as well as utilize the reusable Transfer Vehicle and Ascent Element to carry astronauts from Gateway to LLO and to the lunar surface and back, respectively. ACSC will continue the assessment of fueling / refueling capability near Gateway for the lowest amortized cost and sustainability for the human landing system and deep space missions. To support lunar exploration missions after the 2028 human landing, ACSC plans to develop lunar surface capabilities, including ISRU systems that harvest lunar resources such as oxygen and hydrogen as well as produce propellant for the Descent Element so that it can be reused between the lunar surface and Gateway. Development of these ISRU system capabilities will build on technologies matured by the ET account.

ACSC will also continue conducting studies to determine the scope of future lander missions and evolvability to Mars landings.

ACSC LANDER TECHNOLOGY

Activities like Lunar CATALYST will continue to develop necessary technologies, such as propellant liquefaction, and next generation propellant tank health monitoring to enable lunar surface missions. ACSC will continue to focus on lander capabilities, completed designs, and overall risk reduction and access to the lunar surface.

ACSC CORE

In the Core area, ACSC will focus on non-landing capabilities tied to lunar exploration. Activities include lunar mapping and participation in international partnerships for lunar orbiters.

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 2019, NASA will make significant progress on establishing milestones, program implementation assignments, and acquisition strategy beyond the initial engagements.

Date	Significant Event
February 2019	Issued NextSTEP BAA Appendix for initial risk reduction capabilities
May 2019	Select awardees from NextSTEP BAA for Phase A
July 2019	Award Phase A contracts of NextSTEP BAA
September 2019	Deliver ShadowCam instrument to KARI

ADVANCED CISLUNAR AND SURFACE CAPABILITIES

Program Management & Commitments

HEOMD will execute the ACSC activities.

Program Element	Provider
Lunar Lander Missions	Provider: TBD Lead Center: Performing Center(s): MSFC, LaRC, GRC, GSFC, JSC, JPL KSC, ARC, AFRC Cost Share Partner(s): TBD
ACSC Lander Technology	Provider: TBD Lead Center: TBD Performing Center(s): MSFC, LaRC, GRC, GSFC, JSC, KSC, ARC Cost Share Partner(s): TBD
ACSC Core	Provider: TBD Lead Center: TBD Performing Center(s): JSC, JPL, KSC, ARC Cost Share Partner(s): TBD

Acquisition Strategy

Acquisition plans for all functions/elements of ACSC will be determined over the course of FY 2019 and FY 2020 as required and will utilize full and open competition, public-private partnerships, and international partnerships.

MAJOR CONTRACTS/AWARDS

Future awards for the ascent and transfer vehicle elements will also be occurring in the late FY 2020 and early FY 2021 timeframe.

INDEPENDENT REVIEWS

An independent review board will be established in 2019 to participate in the major reviews for the Human Landing System.

GATEWAY

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**17.2**	**--**	**821.4**	**827.7**	**717.0**	**787.8**	**757.5**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

As a key part of the Exploration Campaign, NASA will establish the Lunar Gateway, a way station that will orbit the Moon and enable human and robotic missions to the lunar surface. The Lunar Gateway will support exploration on and around the Moon, and sustainable human lunar surface exploration missions by supporting reusable human lunar landers. It will be a temporary home for astronauts and will foster growing domestic and international economic opportunities for commercial logistics and refueling services, as well as provide robust communications with spacecraft in cislunar space and on the lunar surface. The Lunar Gateway will allow for a continuously expanding knowledge base in the area of deep space maneuvering and solar electric propulsion (SEP). Through the development of Lunar Gateway, the U.S. will maintain its leadership in space exploration and discovery as it pioneers a new era of space travel, research, logistics, and economic development.

The Lunar Gateway will be assembled in orbit around the Moon where it will be used immediately as a staging point for missions to the lunar surface. It can evolve depending on mission needs, and although there are various concepts for its configuration that continue to be evaluated, current analysis suggests that the functionality will support lunar landers and include four main functions: A Power and Propulsion Element (PPE), habitation, an airlock to enable Extra-Vehicular Activities (EVA), and a logistics capability for cargo delivery. These functions will provide critical abilities for the Lunar Gateway to support human-class reusable landers, landing a crew of up to four astronauts on the lunar surface by 2028 and ultimately developing sustaining lunar operations on the Moon. Additional capabilities could enable science utilization, exploration technology demonstrations, and potential commercial utilization.

The PPE is the first element of the Lunar Gateway which will be launched on a commercial rocket in 2022 and placed in orbit around the Moon. Working in partnership with Exploration Technology, PPE will demonstrate advanced high-power SEP bus systems that will support both future NASA and commercial applications. It is being acquired as a public-private partnership and following a spaceflight demonstration period of up to one year, when NASA will then likely take over operations of PPE from the industry partner. The PPE will supply power and propulsion for elements and systems on the Lunar Gateway as well as accommodations for research payloads, and communication to and from Earth, space-to-space, and space-to-lunar. The Lunar Gateway is intended to be capable of supporting human-class lander deployments and operations using multiple docking ports. Once the PPE and habitation capabilities have been delivered to cislunar space, a crew of four - launched on Orion - will visit the Lunar Gateway on missions lasting up to 30 days.

The focus of the Lunar Gateway is on enabling sustainable lunar surface capability as soon as possible. It will support a reusable human lunar landing system, in addition to supporting other science and human

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exploration objectives on and around the Moon. Delivery of Lunar Gateway and lunar lander elements, including refueling of these elements, will create a reusable hub for sustainable lunar activity and feed forward to Mars.

EXPLANATION OF MAJOR CHANGES IN FY 2020

In the FY 2020 budget request, refinements made to the Lunar Gateway implementation strategy continued, focusing on maintaining a lean approach to the final configuration. Adjustments include re-phasing the PPE budget to align with updated planning. In order to enable deep space crew operations on the first mission to Lunar Gateway, NASA has included planning for a Utilization Module and ESPRIT to allow for an early initial crew visit thereby increasing overall utilization potential. Additional rephasing to the habitation budget will allow for more time to evaluate a final design incorporating what international and industry partners should contribute.

This budget also integrates the NASA Docking System (NDS) into the modules of the Lunar Gateway. Implementing the NDS for Lunar Gateway missions as the common docking standard reduces the development cost by only having to develop one docking system that allows NASA, international and commercial partners to easily dock with Lunar Gateway to support lunar landers (including reusable human), the Lunar Gateway itself and science objectives.

ACHIEVEMENTS IN FY 2018

The Agency conducted an Acquisition Strategy Meeting (ASM) in August of 2018, leading to the Lunar Gateway Formulation Sync Review kickoff, which is the equivalent of a program-level System Requirements Review (SRR). The SRR is a preliminary look at functional and performance requirements defined for the system to ensure that the requirements and the selected concept will satisfy the Agency priorities and goals and was recently successfully completed.

Lunar Gateway released several requests for information (RFI) regarding utilization of Lunar Gateway science, technology, and commercial entities, as well as emerging commercial surface capabilities to enable regular access to the lunar surface. In February, NASA hosted a Lunar Gateway science workshop to gather information that is being used to inform utilization opportunities. A few of the science possibilities resulting from these efforts include opportunities for Earth, Heliophysics, Astrophysics and fundamental physics investigations; additional transportation infrastructure (low lunar orbit) tug/pallet, surface access, sample return capability that can enable additional lunar science; and external sample collections that will provide science about cometary material, solar composition, interstellar particles, and near-Earth objects. Additional opportunities include important tests of the effects of radiation on biological organisms.

Using the Next Space Technologies for Exploration Partnerships (NextSTEP) Broad Agency Announcement (BAA), NASA solicited inputs from U.S. industry on their current capabilities and plans that could be leveraged to provide an advanced SEP-based spacecraft bus for the Lunar Gateway. The request identified 23 topic areas including potential commercial synergies to support development of a PPE. These studies will provide data on U.S. commercial capabilities for PPE while NASA continues to define objectives and requirements as well as how to reduce risk for a new powerful and efficient SEP technology in deep space that will be used on future exploration missions.

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PPE selected five proposals for further industry study from the inputs received in FY 2017. These industry studies provided data on U.S. commercial capabilities for PPE and were successfully completed in March 2018. Other progress included developing PPE requirements and planning for acquisition and partnership approaches including interactions with industry through release of a draft solicitation and holding an industry day. A final BAA for a public-private partnership for spaceflight demonstration of PPE was released on September 6, 2018.

WORK IN PROGRESS IN FY 2019

As a decision from the Lunar Gateway Acquistion Strategy Meeting (ASM) in August 2018, the Lunar Gateway program leadership will transition in 2019 from NASA Headquarters-led formulation to Center-led execution as the program matures through the life cycle.

Lunar Gateway PPE will award one or more contracts for the spacecraft development in FY 2019 and mature plans with industry to baseline the preliminary design. Critical to the approach is realization of a deep space operational power and propulsion capability that is directly applicable to a wide range of commercial, robotic, and human spaceflight missions. This will also allow NASA to leverage existing commercial space communication capabilities.

NASA is formulating the Lunar Gateway by defining system requirements, developing design and interoperability standards, establishing program and system-level control boards, developing strategy and execution mechanisms to acquire Lunar Gateway modules, and developing an integrated ground test plan for prototype habitats. The NextSTEP Phase 2 Habitation contracts, funded in Advanced Exploration Systems (AES), are developing prototype deep space Lunar Gateway habitats that are allowing NASA and the NextSTEP habitation partners to: 1) evaluate configurations and habitability attributes of the habitat, 2) assess how the various systems interact together and with other capabilities such as propulsion modules and airlocks, 3) provide platforms to test and validate standards and common interfaces, and 4) reduce the risk of Lunar Gateway development and assembly.

At the end of NextSTEP Phase 2 study contracts, industry partners will provide the functional habitat ground prototype units to NASA for testing. Ground testing beginning in 2019 will further enable Lunar 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 test of full-size ground prototypes.

While the NextSTEP Habitation activities are identifying potential U.S. industry implementation approaches and partnerships for the Lunar Gateway, concurrent assessments are underway by the International Space Station (ISS) partners to evaluate alternative/complementary approaches for implementation that focuses on international capabilities and contributions for the Lunar Gateway buildup in cislunar space.

During FY 2019, NASA will further relationships with both its commercial and international partners to solidify acquisition and partnership plans.

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The ISS approach to international partnerships will serve as a model that has proven to be flexible and adaptable with international entities. It has presented opportunities for NASA to provide a global leadership role, while advancing exploration goals and objectives.

With the growing number of commercial activities in space, partnerships with the private sector offer increasingly beneficial opportunities to help NASA achieve its mission objectives. Public-private partnerships with domestic entities may also present opportunities for NASA to advance exploration goals and objectives in a cost- and/or time-efficient manner. For these reasons, Lunar Gateway shall seek both international and domestic collaborations with industry and academia to strengthen the overall endeavor. A RFI for Lunar Gateway Logistics was released in October to help NASA understand service options to transport cargo, equipment and other goods, like food, to and from the orbiting outpost. Responses were due in November and results are being incorporated into a future solicitation planned for later in 2019.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

NASA will continue working with the newly-selected PPE industry partner(s) to enable successful delivery of their development schedule. The expected milestones will include requirements and design reviews, and component procurements. PPE will work with NASA internal partners to codify deliverables and ensure NASA's confirmation baseline is established.

As Lunar Gateway formulation continues, NASA anticipates making selections for the U.S. habitation module development in 2020. Agreements for internationally provided contributions will be finalized including international partner provided European System Providing Refueling, Infrastructure, and Telecommunications (ESPRIT).

Building upon the current NextSTEP commercial engagement contracts, the Lunar Gateway will continue to advance commercial habitation, avionics, flight software, life support, in-space refueling capabilities, and other commercial space industries that may be incorporated into the Lunar Gateway modules.

Program Elements

The Lunar Gateway functionality and capabilities evolve over the course of each stage of the assembly sequence. The Lunar Gateway will be launched on competitively procured commercial launch vehicles.

PROGRAM INTEGRATION AND MANAGEMENT

The Program Integration and Management Element is responsible for cross-element and cross-program integration to the Systems Engineering and Integration (SE&I) and the Programmatic, Planning, and Control (PP&C) office. The Lunar Gateway program office is responsible for the overall systems engineering and integration of the Lunar Gateway. The PP&C office provides programmatic guidance, executes oversight and insight, and provides assessments (technical, cost, schedule, acquisition, legislative) of Lunar Gateway development health.

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POWER AND PROPULSION ELEMENT (PPE)

The first element of the Lunar Gateway is the PPE. It is a robotic spacecraft that will provide electrical power and propulsion, orbital station keeping, orbital translation, and communication for the Lunar 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 capability and align with anticipated industry needs. It will provide transportation for the Lunar Gateway between cislunar orbits as well as perform needed orbital maintenance. It will provide altitude control for the Lunar 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 NDS for docking and provide refueling capabilities for other Lunar Gateway elements. At the end of the Lunar Gateway operational life, PPE will move the integrated Lunar Gateway stack to a disposal orbit.

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

HABITATION ELEMENT

The Habitation Element is where the astronauts will live and work. With the intention of using the Lunar Gateway as a technology demonstration activity to enable future, more ambitious missions, the Habitation Element provides a relatively austere living space when compared to similar ISS modules or the envisioned exploration modules for future long duration missions.

The Lunar Gateway Habitation Element 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 habitat also provides attach points for external robotics, external payloads or rendezvous sensors; thermal radiators provide heat rejection and micro-meteoroid protection; and additional habitat systems provide accommodations for crew exercise, science/utilization and stowage. Some functions may be outfitted via future logistics flights.

The internationally provided ESPRIT will deliver the fuel tanks and pumps, advanced lunar communications and redundant Earth communications, docking interfaces, and habitable and stowage volumes.

LOGISTICS ELEMENT

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

NASA is currently assessing specific configurations and strategy for pressurized and unpressurized logistics delivery, refueling, commercial launch vehicle, and the Orion pressurized logistics. All potential concepts deliver cargo to the Lunar Gateway to enable extended crew mission durations, science utilization, exploration technology demonstrations, potential commercial utilization, and other supplies.

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The first Logistics Module flight is planned to deliver the international Robotic Arm. The Robotic Arm is envisioned to be a symmetric seven-Degree-Of-Freedom (DOF) manipulator, with the ability to self-deploy and translate to multiple locations on the Lunar Gateway using Low Profile Grapple Fixtures (LPGF). The Robotic Arm includes multiple cameras to provide situational awareness and inspection capability, the capacity to support maintenance using both robotic and EVA based repairs, and Worksite Interface (WIF) sockets and translation aids to assist in EVA. To support cislunar and beyond operations, the Robotic Arm includes some automation such as automated alignment with LPGF and the ability to change base locations.

NASA envisions Logistics Modules having their own power, propulsion, and navigation systems to rendezvous with the Lunar Gateway in cislunar orbit, and docking at a radial port. The Logistics Modules could provide consumable resupply, outfitting equipment, and cargo delivery including utilization and spares. They could also be capable of providing additional stowage volume while attached to Lunar Gateway, and trash disposal upon departure.

AIRLOCK ELEMENT

A key mission objective for the Lunar Gateway is demonstrating that humans can live and work in a deep-space environment. While the Gateway will be designed to minimize a need for extra vehicular activity (EVA), experience has shown that complex spacecraft and long-term missions may eventually require the utility of EVAs. The airlock element provides the Lunar Gateway with the capability to enable astronaut EVAs as well as the potential to accommodate docking additional elements, observation ports, or a science utilization airlock.

The Airlock is currently planned as the final flight of the Lunar Gateway assembly. The Airlock will provide EVA capability for the Lunar Gateway crew while allowing other crew members to continue working in other Lunar Gateway modules. Multiple concepts are currently being assessed and feasibility studies have identified several different approaches ranging from small, single chamber airlocks to large, dual chamber airlocks with inflatable crew locks. The current design assumes two chambers – an Equipment Lock enabling EVA preparation, including suit servicing, and a Crew Lock allowing egress and ingress. The Equipment Lock provides an alternate ingress path if needed in a contingency. The Airlock also provides an additional docking port and logistics to the Lunar Gateway.

Program Schedule

The Lunar Gateway elements and final configuration are still in the formulation phase. During FY 2019, NASA will make significant progress on establishing milestones, program implementation assignments, and acquisition strategy.

Date	Significant Event
Q1 FY2020	Lunar Gateway System Definition Review (SDR)
Q1-2 FY2021	Lunar Gateway Preliminary Design Review (PDR)
Late 2022	PPE Launch Readiness Date (LRD)

Program Management & Commitments

The Human Exploration and Operations Mission Directorate (HEOMD) AA assigned authority for the Lunar Gateway Program to transition from Headquarters-led to JSC. The Program Manager reports directly to the HEOMD AA in coordination with the HQ Human Lunar Lander and Lunar Gateway Integration Lead.

Program Element	**Provider**
Power and Propulsion Element	Provider: NASA Centers Lead Center: GRC Performing Center(s): GRC and JSC Cost Share Partner(s): TBD
Habitat	Provider: TBD Lead Center: MSFC Performing Center(s): MSFC, JSC, KSC, GRC Cost Share Partner(s): TBD
Logistics	Provider: TBD Lead Center: KSC Performing Center(s): KSC Cost Share Partner(s): TBD
Airlock	Provider: TBD Lead Center: JSC Performing Center(s): TBD Cost Share Partner(s): Potential International Partner

Acquisition Strategy

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The acquisition of the Lunar Gateway will incorporate a hybrid mix of contracted development, international and domestic partnerships, in-house builds, as well as 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. The comprehensive attribute that binds the Lunar Gateway acquisition strategy is adherence to NASA's strategic principles for sustainable exploration.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
PPE (planned for Q3 FY 2019)		
Logistic Services (planned for late FY 2019/early FY 2020)		

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
Formulation Synchronization Review (FSR)	Independent Review Team	February 2019	Equivalent to a strategic requirements review (SRR), the FSR evaluated the program's functional and performance requirements ensuring proper formulation and correlation with Agency, and HEOMD's strategic objectives.	Program cleared to proceed to next phase.	Lunar Gateway Preliminary Design Review (FY2021)
Performance	Independent Review Team (IRT) (GSFC-chaired, NASA members)	Jul 2017	Independent review to support HEOMD DPMC decision to proceed with PPE	Passed	PPE Baseline Completion Review FY 2020*

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Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Independent Review Team (IRT) (LaRC-chaired, NASA members) which will transition to a Standing Review Board (SRB)	Sept 2018	Independent review of Lunar Gateway Formulation Sync Review	Passed	Lunar Gateway SDR FY 2020

HUMAN RESEARCH PROGRAM

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	140.0	--	140.0	140.0	140.0	140.0	140.0

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 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 factor (how crew 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, 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 low Earth orbit.

As NASA prepares to conduct crewed missions in cislunar space using Space Launch System (SLS) and Orion, then on the lunar surface and eventually further in deep space, HRP is developing the scientific and technological capabilities to support missions to the lunar orbiting Gateway and lunar surface. Coordinating with the National Academies, National Council on Radiation Protection and Measurements, and other domestic and international partners, HRP continues to deliver products and strategies to protect crew health and performance during and after exploration spaceflight missions. Current experiments on the International Space Station (ISS), as well as in ground-based analog environments and 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 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.

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), Crew Health and Safety 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 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 low Earth orbit. In addition, as is the case with many space-based medical investigations, this research may also lead to significant advancements in treating patients on Earth.

EXPLANATION OF MAJOR CHANGES IN FY 2020

None.

ACHIEVEMENTS IN FY 2018

HRP researchers conducted approximately eleven ISS biomedical research investigations during each mission increment, completed three 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 for detecting behavioral health risks during exploration missions; 2) exploration food technology assessments on how a repetitive menu affects food acceptability and a study to assess long-term food stowage quality during spaceflight; 3) core measurements on human spaceflight risks from astronauts before, during, and after long-duration missions; 4) human factors assessment on the impacts of switching operational tasks in order to reduce negative consequences and improve individual and team effectiveness; 5) exploration research supporting development of a continuous fresh-food production system; 6) physiological research on quantitative computerized tomography (CT) and Magnetic Resonance Imaging (MRI)-based modeling assessment of dynamic vertebral strength and injury risk following long-duration spaceflight.

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 variation in the astronaut population in response to diverse duration exposures to spaceflight. The primary focus is to ensure that an optimized minimal set of measures is consistently captured from all ISS crewmembers in order to characterize the health of a human in space in preparation for exploration missions. The results will function as a data repository and be available to investigators to develop hypotheses, provide supporting experimental data, or be used in astronaut and Earth-based epidemiology assessments. HRP investigators also continued analyzing the ISS One-Year Mission and Twins Study data to support future publication of results, and made recommendations to ISS regarding future One-Year Missions and use of ISS as an exploration analog to assess impacts of crew isolation.

HRP supported the Translational Research Institute for Space Health (TRISH) as they continued to solicit research as well as educate the next generation of space life scientists and is fully executing on its mission to lead a national effort to translate cutting-edge emerging terrestrial research into mitigation strategies for exploration missions. TRISH focuses on rapidly translating fundamental research concepts into practice, thereby generating tangible health outcomes—in this case, for astronauts. During 2018, TRISH identified biomedical innovations and has 22 projects in the Science and Technology pipeline including three program grants and two flight studies; released two research announcements: i) Biomedical Research Advances for Space Health solicited six deep-space relevant topic areas and ii) the industry solicitation solicited proposals from small U.S.-based companies for technologies that would be essential for self-reliant healthcare in deep space; initiated its industry-focused program, partnering with the Consortia for Improving Medicine with Innovation and Technology; and solicited and funded outstanding postdoctoral fellows and supported training for future NASA’s flight surgeons.

In the area of behavioral health and performance and the effects of isolation, HRP relies on ground analogs to support risk mitigation. In FY 2018, HRP completed four 45-day isolation study campaigns using the Human Exploration Research Analog (HERA) facility. HERA is a unique three-story habitat designed to serve as an analog for isolation, confinement, and remote conditions in exploration scenarios. Each HERA campaign uses crews of four and is supported by a mission control team. A variety of experiments are supported during each 45-day simulated mission. Additionally, HRP continues preparations for long-duration isolation and confinement studies at the NEK facility in Moscow, Russia in collaboration with the Russian Institute for Biomedical Problems. This includes the two-week SIRIUS-17 mission which commenced in early FY 2018 to test the feasibility of systems in support of longer duration missions, along with mission planning, science integration and subject selection for the four-month SIRIUS-18 mission which will commence in the spring of 2019.

HRP also undertook joint NASA/NSF Antarctic analog studies to support behavioral health and performance research. Working with the NSF Polar Program, HRP is integrating behavioral health and performance research studies into the Antarctic winter-over campaign sites that serve as operational research analogs by providing long duration, isolation, confinement, and extreme conditions to stress the research participants. During the 2018 winter-over, HRP conducted a research study using U.S. Antarctic program volunteers located at the McMurdo and Amundsen-Scott South Pole Stations. Over 100 volunteer subjects completed periodic computer-based questionnaires, provided saliva samples, and wore a monitor that recorded sleep and wake cycles. Researchers used these collective tools to look for signs of stress and changes in psychological health of the volunteers during their time in Antarctica. Research in these areas has obvious benefits for living in space but could also prove beneficial to people living and working under similar conditions on Earth.

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. HRP participated in a research study in early FY 2018, funding four investigators whose studies were also implemented in the facility. The objective of the studies was to determine whether 30 days of bed rest with a six-degree head-down tilt under elevated carbon dioxide exposure, similar to what is experienced on the ISS and could occur on future exploration missions, affects physiological and psychological functions. Mission planning, science integration and subject selection for a joint NASA/European Space Agency (ESA) 60-day bed rest study that will commence in the spring of 2019 is currently underway.

In support of future human exploration missions, HRP delivered recommended updates to physiological medical standards to better protect muscle and aerobic capacity and recommendations on methods to maintain team function and performance during isolation and confinement of long-duration missions. Additionally, HRP initiated development of the medical data architecture to support medical operations for deep space missions. The successful implementation of a medical system in the resource-constrained environment of exploration missions will depend on closer coupling of medical resources with other vehicle systems.

Finally, HRP continued space radiation research at the NASA Space Radiation Laboratory (NSRL) with three annual runs (spring, summer and fall) to better understand the health risks to astronauts. In 2018, NASA demonstrated the NSRL Galactic Cosmic Ray (GCR) simulator to rapidly switch ion species and energies, allowing for a more realistic simulation of the actual radiation environment found in space.

WORK IN PROGRESS IN FY 2019

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; implement a research plan that fully utilizes the ISS biomedical research capabilities to test mitigation approaches and validate countermeasures; HRP will collaborate with Crew Health and Safety on ISS studies related to visual impairment, carbon dioxide analysis, exercise systems and cognitive function measures; and HRP will leverage resources and expertise through collaborative research with other NASA programs, international partners and other U.S. agencies such as DoD, DOE, NSF, HHS and the 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) another potential One-Year Mission; 2) ISS as an exploration analog to assess impacts of crew isolation; 3) continue the advanced food technology study to assess long term stowage quality in space; 4) develop the Advanced Twin Lifting and Aerobic System (ATLAS) deep space exercise device for testing and validation as part of exploration system maturation project.

ISS research publications for both the One-Year Mission and Twins Study will be published in early 2019. These publications will document the health impacts of long-duration spaceflight at both the physiological and genomic levels. Initial assessments identified spaceflight-specific changes including decreased body mass, telomere elongation, carotid artery distension and increased intima-media thickness, altered ocular structure, transcriptional and metabolic changes, DNA methylation changes in immune- and oxidative-stress related pathways, gastrointestinal microbiota alterations, and cognitive decline post-flight. Although average telomere length, global gene expression and microbiome changes returned to near preflight levels within six months after return to Earth, increased numbers of short telomeres were observed and expression of some genes was still altered. These multi-omic, molecular, physiological, and behavioral datasets provide a valuable roadmap of the putative health risks for future human spaceflight.

In support of exploration medical capability, HRP will continue to develop the medical data architecture (MDA) 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 their novel Astroskin biosensor, a wearable vest that collects biometric information such as heart and breathing rates, into the prototype medical system.

HRP will implement a bedrest study with the European Space Agency (ESA) to assess the use of artificial gravity as human physiology countermeasure using the DLR :envihab facility. The Artificial Gravity bed rest study consists of two campaigns of head down tilt, each campaign lasting 60 days and including 12 test subjects. During each 60-day campaign, the subjects will be assigned to one of three groups: one group will experience centrifugation for 30 continuous minutes each day; the second group will experience centrifugation in six bouts of five minutes each, with a five minute rest between bouts; and the final group will serve as a control, and will not experience centrifugation. NASA has selected four researchers and ESA has selected seven researchers to participate in these campaigns aimed at better understanding the potential of artificial gravity as a countermeasure to mitigate the effects of long duration space flights.

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 two missions on long-duration isolation and confinement studies in collaboration with Russia which includes the SIRIUS-18 (four-month) and 19 (eight-month) missions, and they will continue the 45-day HERA studies at Johnson Space Center.

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 2020

HRP intends to implement an ISS flight research plan critical to mitigating crew health and performance risks for exploration missions. As part of this ISS research plan, HRP will implement the Standard Measures Project with the objective to ensure consistent capture of a core set of physiological and performance measures from crew members until the end of the ISS in order to characterize the adaptive responses to and risks of long-duration in spaceflight. The data from the Standard Measures Project will support high-fidelity monitoring of countermeasure effectiveness, meaningful interpretation of health and performance outcomes, and support future research on planetary missions. HRP will issue the first ISS Standard Measures report once samples are returned and processed. HRP will continue planning with the ISS program for additional one-year missions to validate exploration countermeasures. HRP will also develop and complete ground testing of an advanced exploration exercise system in preparation for ISS deployment as part of exploration system maturation plans.

HRP will continue leveraging resources through multiple partnerships including international partnering on isolation, confinement and physiology studies with Russia, DLR and European Space Agency. HRP plans to continue future bed rest studies at the DLR :envihab facility in Cologne, Germany and discussing potential opportunities for collaboration and data sharing with European investigators.

HRP's effort to advance mitigation of recognized human health and performance risks and enable future exploration missions will continue including: implement a microbial risk assessment study to ensure crew safety and allow increased dependence on bioregenerative food systems; developing space habitat standards and evaluation tools for use in designing and evaluating vehicle volume and layout to optimize crew performance and health; completing a study to determine optimal methods for detecting individual performance susceptibilities to sleep loss and circadian desynchronization to inform individualized countermeasures during spaceflight, and developing requirements and technical objectives for Gateway and lunar surface missions.

Program Elements

EXPLORATION MEDICAL CAPABILITY

As NASA makes plans to extend human exploration beyond low Earth orbit, 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, etc.) 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 then 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 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 are able to 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 low Earth orbit. Thus, 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.

ISS MEDICAL PROJECTS

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. This includes pre and post-flight activities, 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 at NASA, Johnson Space Center (JSC) and 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
Nov 2018	Delivered recommendations on using High Intensity Interval Training (HIIT) in spaceflight to Space Medicine
Dec 2018	Delivered Medical System Functional Gateway Requirement Recommendations to the Human Health and Performance Directorate Gateway Delegate
Jan 2019	Conduct 2019 HRP Investigators' Workshop
May 2019	2018 Human Exploration Research Opportunity (HERO) NASA Research Announcement Selections
Aug 2019	Release 2019 Human Exploration Research Opportunity (HERO) NASA Research Announcement
Sept 2019	Deliver a Neurobehavioral Conditions Checklist for Space Medicine Operations
Sept 2019	Deliver updated Nutritional Recommendations for Exploration Food System

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 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 Office of the Chief Health and Medical Officer, 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): None
Human Health Countermeasures	Provider: JSC Lead Center: JSC Performing Center(s): ARC and GRC Cost Share Partner(s): None
Human Factors and Behavioral Performance	Provider: JSC Lead Center: JSC Performing Center(s): ARC, GRC, and KSC Cost Share Partner(s): None

HUMAN RESEARCH PROGRAM

Program Element	Provider
Space Radiation	Provider: JSC Lead Center: JSC Performing Center(s): LaRC Cost Share Partner(s): None
ISS Medical Project	Provider: JSC Lead Center: JSC Performing Center(s): ARC and KSC Cost Share Partner(s): None

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 Human Exploration Research Opportunities umbrella NASA Research Announcement (NRA) that will request research proposals across all of 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	National Council on Radiation Protection (NCRP)	Nov 2017	Review of space radiation health risks	Established research priorities for space radiation research	Feb 2019
Quality	Peer Review Panel	Nov 2018	Peer review of NRA	Selected grantees	Mar 2019
Quality	Independent Program Assessment	June 2019	Review of program management policies and practices	Verify adherence to NASA program management policies	June 2021

EXPLORATION TECHNOLOGY

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Early Stage Innovation and Partnerships	91.9	--	**123.4**	118.0	123.0	118.0	123.0
Technology Maturation	151.5	--	**282.5**	227.2	250.3	246.7	328.0
Technology Demonstration	321.7	--	**397.5**	411.8	391.4	362.3	231.2
SBIR and STTR	194.8	--	**210.8**	219.1	230.8	237.5	261.0
Total Budget	**760.0**	**926.9**	**1014.3**	**976.1**	**995.4**	**964.4**	**943.1**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 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.

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Early Stage Innovation and Partnerships	91.9	--	**123.4**	118.0	123.0	118.0	123.0
Technology Maturation	151.5	--	**282.5**	227.2	250.3	246.7	328.0
Technology Demonstration	321.7	--	**397.5**	411.8	391.4	362.3	231.2
SBIR and STTR	194.8	--	**210.8**	219.1	230.8	237.5	261.0
Total Budget	**760.0**	**926.9**	**1014.3**	**976.1**	**995.4**	**964.4**	**943.1**
Change from FY 2019			**87.4**				
Percentage change from FY 2019			**9.4%**				

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

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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.

NASA and Department of Energy successfully completed a full power test of the Kilopower space fission power system in FY 2018. NASA is developing mission concepts and performing additional risk reduction activities to prepare for a future flight demonstration as part of the Lunar Surface Innovation Initiative.

Technology development is essential to achieving mankind's return to the moon, and beginning human exploration of Mars. Exploration Technology investments serve 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)."

Through the Agency's lunar surface exploration efforts, including a new Lunar Surface Innovation Initiative, NASA will advance technology readiness of key systems and components to facilitate lunar surface demonstrations over the next five years leading to more affordable missions that are less dependent on support from Earth.

The new Lunar Surface Innovation Initiative, which aims to spur the creation of novel technologies needed for lunar surface exploration and accelerate the technology readiness of key systems and components, will target the critical technologies needed for lunar surface activities over the next five years, including:

- In Situ Resource Utilization,

- Nuclear surface power, and
- New technologies that enable survival and operation through the cold lunar night.

The Lunar Surface Innovation Initiative activities will be implemented through a combination of in-house activities, competitive programs, and public-private partnerships. The Initiative will bring together the full range of stakeholders, including entrepreneurs, academia, small businesses, industry and the NASA workforce to catalyze technology development. For example, this Initiative will develop and integrate systems used for in situ resource utilization and processing into mission consumables, including oxygen, water, and hydrogen. This capability will reduce mission mass, cost, and risk of human exploration, and increase independence from the Earth's resources. NASA's Kilopower technology will transition into a demonstration mission - building on the 2018 demonstration of a small, lightweight nuclear fission power system that would permit long-duration crewed missions on the surface of the Moon. Furthermore, the Initiative will jumpstart fuel cell development, space weather monitoring, and improve systems and components to allow survival and operation through the cold lunar night.

Beyond the Lunar Surface Innovation Initiative, Exploration Technology is funding an array of efforts to accelerate NASA's broader lunar exploration campaign. For example, the Agency will begin testing a powerful, radiation hardened, multicore processor that will enable advanced precision landing and autonomous operations; and advanced cryogenic fluid management capabilities to enable long term storage of cryogens both in space and on the lunar surface. Such efforts will be pursued through a combination of multiple "Tipping Point" partnerships with industry and NASA led activities.

Exploration Technology investments target crosscutting technologies that benefit both human and robotic exploration, actively engaging with internal NASA organizations, 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, Exploration Technology investments develop and test technologies that drive space exploration. Public-private partnerships enable NASA to share the risk and financial interest with private sector industry to better leverage government investments. The shared gains include incentivizing technical performance and spurring future commercial markets in the process of 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, 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 our Nation's economic engine for decades to come.

EXPLANATION OF MAJOR CHANGES IN FY 2020

This request reflects accelerated and enhanced research and development of lunar exploration technologies, with a focus on middle and lower Technology Readiness Levels. Through this account, NASA will also be implementing a Lunar Surface Innovation Initiative which will coordinate and encourage innovation and commercial participation in future lunar surface developments.

Funding from across NASA's accounts for certain aeroscience capabilities have been consolidated and placed into a single project within Safety, Security, and Mission Service's Shared Capability Asset Program. (Please see the SSMS section for more information.)

ACHIEVEMENTS IN FY 2018

NASA and the Department of Energy demonstrated a new nuclear reactor power system that could provide surface power on the Moon and Mars. The 1kW nuclear fission reactor is scalable to a 10kW-class system which enables abundant energy for surface exploration. The Kilopower project conducted full ground testing at design temperatures in early FY 2018 at the Nevada National Security Site.

Among a host of supported activities, NASA delivered spacecraft for three small satellite missions enabling advanced communications technologies for NASA and industry application. Among them, the Optical Communication and Sensor Demonstration mission successfully completed space-to-ground optical communications for the first time. Designed and built by The Aerospace Corporation in El Segundo, California, the spacecraft sent a laser signal from low-Earth orbit to a ground station at the company's facilities, at a data rate of 200 megabits per second – 100 times greater than typical communication systems for this size spacecraft. The JPL developed reflectarray antenna, pioneered for use in spaceflight for the Integrated Solar Array Reflectarray Antenna mission last July, was an integral part of the successful data relay conducted by the two MarCO spacecraft during the Insight landing on November. The reflectarray was demonstrated to be capable of data rate transmission of up to 100 megabits per second (Mb/s), an order of magnitude over prior CubeSat state of the art.

NASA announced 10 new lunar focused Tipping Point partnerships with six U.S. companies, and awarded more than 550 small business contracts, totaling more than $180 million.

The Restore-L project completed its Preliminary Design Review. A team of engineers completed ground demonstrations of the autonomous capture portion of the Restore-L satellite servicing project.

A team of NASA engineers demonstrated a technology first: fully autonomous X-ray navigation in space, which could revolutionize NASA's ability to pilot robotic spacecraft to the far reaches of the solar system and beyond. Station Explorer for X-ray Timing and Navigation Technology, or SEXTANT, showed that millisecond pulsars could be used to accurately determine the location of an object moving at thousands of miles per hour in space — similar to how the Global Positioning System, widely known as GPS, provides positioning, navigation, and timing services to users on Earth with its constellation of 24 operating satellites.

NASA's three In-space Robotic Manufacturing and Assembly partners (Made in Space Inc., Northrop Grumman Innovation Systems, and Maxar Technologies) completed ground demonstrations of robotic arms, vision systems, additive techniques and other cutting-edge technologies to assemble structures in space.

NASA's Flight Opportunities program funded more than 40 payload flight demonstrations, providing opportunities for researchers to test new technologies and helping mature the suborbital flight industry, including conducting a sounding rocket test of Game Changing Development's umbrella-like heat shield, the Adaptable, Deployable, Entry and Placement Technology (ADEPT) aeroshell. Launched on UP Aerospace's SL-12 Launch, ADEPT achieved full deployment and configuration lock prior to reaching 80 kilometers altitude on descent. Developed by NASA’s Ames Research Center in California’s Silicon Valley, ADEPT’s unique design could be used for planetary lander and sample return missions.

WORK IN PROGRESS IN FY 2019

Exploration Technology investments continue to support a number of technologies being delivered for flight, including Solar Electric Propulsion, Laser Communications Relay Demonstration, Deep Space Optical Communications, and Mars 2020 technologies (Terrain Relative Navigations, Mars Oxygen In-Situ Resource Utilization Experiment, Mars Environmental Dynamics Analyzer and Mars Science Laboratory (MSL) Entry, Descent, & Landing Instrument-2). In addition, a steady cadence of small spacecraft technology missions are conducted each year to further enhance the capabilities of this emerging research and development platform.

NASA's Robotic Refueling Mission-3 concluded a crucial series of tests at NASA’s Kennedy Space Center in Cape Canaveral, Florida. Tests confirmed its electrical compatibility with the space station and validated successful methane operations on the ground. After completing rigorous testing at NASA’s Goddard Space Flight Center in Greenbelt, Maryland, where the module was built, and Kennedy complete, RRM-3 was delivered to the International Space Station in early December to pioneer techniques for storing and replenishing cryogenic spacecraft fuel.

The Deep Space Atomic Clock (DSAC) is a small, low-mass atomic clock based on mercury-ion trap technology that will be demonstrated in space, providing unprecedented stability needed for next-generation deep space navigation and radio science. DSAC offers the promise of 50 times greater accuracy than today’s best deep space navigation clocks and will rideshare as part of the U.S. Air Force STP-2 mission aboard a SpaceX Falcon Heavy booster. Riding along is NASA's Green Propellant Infusion Mission that will demonstrate a propulsion system using a significantly less toxic propellant than hydrazine provides 40 percent higher performance by volume. The launch of both DSAC and GPIM are slated for mid-2019.

Astrobee completed ground testing and delivered a flight unit to the International Space Station (ISS). Once on-orbit commissioning is complete, Astrobee will replace the Synchronized Position Hold, Engage, Reorient, Experimental Satellites (SPHERES). Astrobee builds on the success of SPHERES, NASA’s first generation free-flyer now aboard the ISS that can take on research, housekeeping, and monitoring duties without astronaut supervision.

In early FY2019, 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.

The eCryo project will begin its Structural Heat Intercept-Insulation-Vibration Evaluation Rig (SHIIVER) testing in July 2019 before handing off that technology to interested stakeholders in support of NASA's Exploration activities and industry. This test will 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. This will be especially important precursor demonstration to enable long duration in-space cryogenic storage for the Deep Space Transport vehicle.

NASA will complete a number of Mars 2020 technology developments including Terrain Relative Navigation, Mars Oxygen ISRU Experiment, Mars Environmental Dynamics Analyzer, and Mars Entry, Descent and Landing Instrumentation-2 with deliveries between fall 2018 and spring 2019 to support the Mars 2020 schedule.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

NASA is conducting pre-formulation activities in FY 2019 and FY 2020 to ready critical lunar surface demonstrations, building on successful ground demonstrations of mid-TRL technologies: Cryogenic Fluid Management, a combined surface power and In Situ Resource Utilization demo, and Precision Landing (with High Performance Spaceflight Computing). Each of these capabilities are essential in order to establish and sustain a human presence on the lunar surface.

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.

Upon a successful launch and on-orbit operations of the Green Propellant Infusion Mission, NASA will complete demonstration of the Air Force developed hydroxyl ammonium nitrate propellant formula, thrusters, and the integrated propulsion system, establishing a higher performing, safe alternative to highly toxic hydrazine. In addition, Deep Space Atomic Clock project will demonstrate space clock navigational accuracy improvements for deep space and provide a technology to improve gravity science measurements.

NASA, in partnership with United Launch Alliance, will fabricate an inflatable aerodynamic decelerator technology for a flight test in the Earth's atmosphere to determine the feasibility of this technology in supporting high mass Entry Descent and Landing.

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 exciting 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 bring pioneering approaches to the Agency's difficult and far reaching exploration challenges. NASA sustains these Early Stage investments at eight to ten percent of the overall Exploration Technology budget. This account also 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 and measurable impact, and 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 United States.

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 research and flight demonstration. Technologies are prioritized for alignment with NASA's Exploration Campaign objectives, including technology for lunar surface demonstrations through the Lunar Surface Innovation Initiative.

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 deep space human exploration. This account includes development of Small Spacecraft technologies and demonstration missions, and facilitates access to relevant flight demonstration environments through the Flight Opportunities suborbital flight demonstration platforms.

SBIR AND STTR

Small Business Innovation Research and Small Business Technology Transfer 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 provides 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 Lunar Exploration Campaign.

EARLY STAGE INNOVATION AND PARTNERSHIPS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	91.9	--	123.4	118.0	123.0	118.0	123.0

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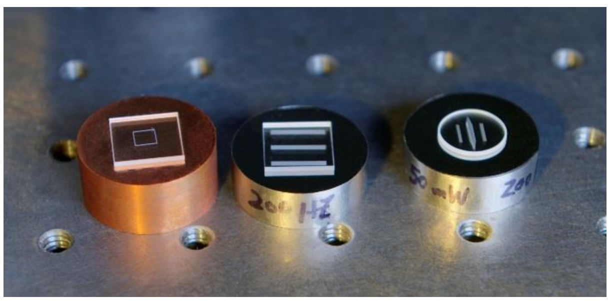


A team of optical physicists at Goddard Spaceflight Center is using an ultrafast laser to bond dissimilar materials, such as the samples in this image, with the goal of ultimately eliminating epoxies that outgas and contaminate sensitive spacecraft components. With support from the Center Innovation Fund, the group is also exploring the technology's use in fabricating and packaging photonic integrated circuits, an emerging technology that could benefit everything from communications and data centers to optical sensors.

In support of the Exploration Campaign, Exploration Technology investments integrate the early stage technology research and development and foundational activities with a primary focus on exploration requirements. This integrated program consists of investments in Early Stage Innovation, Technology Transfer, Prizes and Challenges and Agency Technology and Innovation. Together, these efforts 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 exploration objectives.

Early Stage Innovation supports applied research, and early technology development to spur innovation and transform future capabilities. By leveraging the technical capabilities of the experts across the nation, from academia, industry, entrepreneurs, to the NASA Centers, the Agency gains new ideas and alternative approaches to solving NASA's difficult and far reaching exploration challenges.

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. This includes Centennial Challenges, the NASA Tournament Lab, NASA Solve, and Innovation Connector (iTech) to leverage high public interest and support on 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.

EARLY STAGE INNOVATION AND PARTNERSHIPS

The Exploration Technology account also 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 2020

No Major Changes

ACHIEVEMENTS IN FY 2018

- At the end of FY 2018, approximately 392 Early Stage technologies were active, each with the potential to enable or enhance the next generation of capabilities within and beyond NASA. Selected Early Stage Innovation topics include: Advanced Coating Technology for Space Fission Power and Propulsion Systems; Crosscutting Technologies for Extremely High Frequency Band Space Applications; and Lightweight Multifunctional Lattice Materials for Space Structures.
- The Centennial Challenges Program awarded $220,000 in prize funding after initiating Phase 3 of its 3D Printed Habitat Challenge. NASA also awarded three finalists a total of $150,000 in the NASA Earth and Space Air Prize, a competition being conducted in partnership with the Robert Wood Johnson Foundation to advance the development of aerosol sensor technologies useful in both human space flight as well as on Earth.
- NASA Tournament Lab supported 76 competitions on behalf of NASA and other Federal Agencies. Among its accomplishments, NASA Tournament Lab also shepherded the development and implementation of the NASA Earth and Space Air Prize, NASA's first prize competition run using prize authority granted to all federal agencies and codified within the Stevenson-Wydler Technology Innovation Act of 1980 (as amended).
- NASA's iTech initiative identified 10 finalists to present innovative ideas that address important problems here on Earth and also holds great potential to overcome critical technology hurdles in future space exploration. NASA facilitated a forum for these entrepreneurs to present their solutions to the Agency and potential industry partners. Artificial intelligence, nanotechnology and 3D printing are just a few of the technology threads pitched during the third cycle of the NASA iTech competition.
- NASA has simplified reporting new inventions (New Technology Reports) through launch of the e-NTR system. The new system has standardized and streamlined the agency's invention disclosure process, reducing to a third the number of questions asked.
- The Office of the Chief Technologist continues to coordinate the interagency Science and Technology Partnership Forums, bringing together leaders from the aerospace, defense, science and technology Federal teams to look for areas to partner of mutual interest and priority. Through these collaborations, NASA is gaining insight into other Federal science and technology policy and investment priorities, using that knowledge to forge Federal and American commercial partnerships. The office held multiple Technology Interchange Meetings among other government agencies, industry and academia.

WORK IN PROGRESS IN FY 2019

- In addition to issuing the annual solicitations for NASA Innovative Advanced Concepts (NIAC), Space Technology Research Grants, and the Center Innovation Fund, NASA will select up to two research institutes in the areas of revolutionary propulsion and deep space habitat autonomous operations to enable new technologies that lay groundwork to enhance and enable deep space exploration.

- The Centennial Challenges Program will award up to $250,000 in the first phase of the CO2 Conversion Challenge and will launch Phase 2 of the Space Robotics Challenge by the end of the fiscal year. NASA selected Space Center Houston as the Allied Organization and is working with the Space Robotics Challenge team to finalize the rules and details of a competition to advance robotics software and autonomy.
- The Office of the Chief Technologist is refining the Agency's space technology taxonomy and Technology Integration Framework that will be used to inform the next NASA Strategic Technology Investment Plan and any future technology roadmaps. The office will continue to foster NASA's innovation ecosystem, working with the National Academies of Sciences on a workshop to benchmark the agency's culture of innovation. The office also is co-chairing with the Office of the Chief Information Officer a study on NASA's digital transformation efforts. The study will result in a proposed policy, strategy and implementation plan for digital transformation at the agency.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

- The Centennial Challenges Program will be formulating two new challenges focused on In Situ Resource Utilization, one demonstrating scalable solutions for life support inside a lunar or other planetary habitat.
- NASA Innovative Advanced Concepts intends to implement 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.
- Early Stage Innovation will emphasize investigations in areas such as breakthrough propulsion, challenges in deep space human habitation, space-optimized energy systems, radiation protection, and advanced materials to enhance future exploration missions.
- Using the Early Career Initiative model, up to $5 million per year will be allocated to focus technology projects that will result in new Lunar Surface capabilities. These two to three year efforts will be competitively awarded in the fall of 2019, and encourage NASA Centers to partner with industry and/or academia to rapidly develop technologies for lunar surface operations.
- NASA has commissioned a study of its intellectual property policies to best engage, support, and collaborate with commercial space community partners of all types in various technology development and commercialization activities. The study will propose, define, and analyze options for intellectual property clauses in collaborative agreements such as Space Act Agreements and Cooperative Research and Development Agreements, as well as intellectual property licensing policies and processes. The Technology Transfer program will implement recommendations resulting from this study in FY 2020.

Program Elements

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. This is why a balance of early stage, mid-Technology Readiness Level (TRL), and technology demonstration investments is critical for an effective technology development portfolio.

NASA's Early Stage Innovation activities employ various approaches to engage technical 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 between NASA and various external partners, and will 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 (STRG), NASA Innovative Advanced Concepts (NIAC), and the Center Innovation Fund (CIF), which are described further below:

Space Technology Research Grants

Space Technology Research Grants conducts a series of annual and biannual 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, making space activities more effective, affordable, and sustainable. In the process, close collaborations between U.S. universities and NASA are established and nurtured. Since its inception in 2012, Space Technology Research Grants has funded exciting space technology research via 595 grants - at 107 universities across 43 states and one U.S. Territory. In FY 2018, NASA made 14 Early Stage Innovations awards, 11 Early Career Faculty awards and 56 NASA Space Technology Research Fellowship awards; there are currently more than 275 active awards.

- One recent success was the work performed by Andrew Owens from the Massachusetts Institute of Technology, who developed new spacecraft models for planning supply requirements for long-duration crewed missions beyond Low Earth Orbit. Owens determined that enabling a lower level repair of Oxygen Generation Assembly replacement units leads to a 20 percent mass saving on a 1,200 day Mars mission. In addition, analysis using International Space Station data on current systems found that utilizing in-space manufacturing to develop spares would enable a multi-ton reduction in the total spares mass needed to complete a Mars mission.
- The inaugural Space Technology Research Institutes - The Center for Utilization of Biological Engineering in Space (CUBES), led by the University of California, Berkeley, and The Institute for Ultra-Strong Composites by Computational Design (US-COMP), led by Michigan Technological University, both successfully completed the first year of these five-year awards. CUBES, working to advance the practicality of an integrated, multi-function, multi-organism biomanufacturing system on a Mars mission, demonstrated a microbial electrocatalysis system which reduces Martian dinitrogen levels to the levels needed for sustainable plant production, and developed a method to synthesize a bone regeneration hormone in lettuce leaf tissue as a possible

microgravity countermeasure for crew health. US-COMP, in its efforts to enable computationally-driven development of carbon nanotube tube based ultra-high strength lightweight structural materials, demonstrated an improvement in the microstructure of four ply core spun yarns, completed preliminary mechanical tests, and successfully fabricated small yarn composite samples.

NASA Innovative Advanced Concepts

NASA Innovative Advanced Concepts 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. In 2018, NASA Innovative Advanced Concepts made 16 Phase I and nine Phase II awards across industry, academia, and NASA centers, while completing 15 Phase I and eight Phase II studies. Former Fellow Robert Hoyt's work in on-orbit, cost-saving construction of large space structures continued through both NASA's and DARPA's SBIR programs. Dr. Hoyt's "SpiderFab" study has now developed into three flight experiments scheduled for launch in the next two years: Refabricator will 3D print and recycle materials on the ISS; and the MakerSat and Dragonfly technology demonstration missions will demo 3D printing and assembling large structures in space. NASA Innovative Advanced Concepts intends to implement Phase III studies to complement its portfolio of Phase I and Phase II concepts. 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.

Center Innovation Fund

Center Innovation Fund 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. Center Innovation Fund activities are competitively selected to explore alternative approaches or develop enhanced capabilities that will feed into NASA's Deep Space Exploration objectives. Partnerships with academia, private industry, individual innovators, as well as between 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 such as "Pulsar Navigation for Crewed Exploration of the Solar System" which has been utilized as an instrument on the ISS to provide x-ray data from different pulsars across the sky. The reliable information coming from pulsars provides a GPS-like method of timing and direction measurement to allow independent navigation anywhere in the solar system.

As an element of the Center Innovation Fund, the Early Career Initiative provides the opportunity to grow 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. In order 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 will target specific technology demonstrations to rapidly develop technologies needed to support lunar surface operations, giving NASA civil servant innovators the opportunity to have their technologies demonstrated on the lunar surface.

EARLY STAGE INNOVATION AND PARTNERSHIPS

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 and programs 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.

For example, the Office of the Chief Technologist held several Technical Interchange Meetings in support of NASA's participation in the interagency Science and Technology 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 Meeting topics have included In Space Assembly 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. This innovative interagency collaboration combines the expertise, experiences and perspectives of the national space technology development community and leverages sharing of resources. The activity has created new opportunities for advancing technology while reducing costs to the taxpayer.

The Office of the Chief Technologist is also working on developing a new Technology Strategic Integration Framework, to more efficiently identify and connect technology investments to needs in order to help NASA achieve its aeronautics, science, and human exploration missions, including future deep space exploration to destinations such as the moon, Europa and Mars and strengthen the US industrial base. This effort will better inform future versions of the agency's Space Technology Implementation Plan.

In addition, the Office of the Chief Technologist is the Agency champion for promoting a culture of innovation at NASA, particularly in regard to collaboration and workforce development. The office is working with other stakeholders to develop strategies to expand NASA’s innovation ecosystem to leverage investments and developments outside of our traditional circle; create agility in our engineering and mission support processes to accommodate the accelerating pace of technology; and design a flexible workforce that can adapt skill-sets at the rate of technology evolution. Recent activities have included an innovation workshop hosted by the National Academy of Sciences that brought Agency leadership together with innovation leaders from around the nation to discuss and suggest ways to improve NASA’s innovation ecosystem. An Agency wide innovation portal is being developed to better connect various innovation related activities from around the Agency to mission goals and objectives and improve ideation, innovation, collaboration and communication among NASA employees. The office also serves as the NASA lead for the interagency Science and Technology Partnership Forum. For more information about the Office of the Chief Technologist, go to: http://www.nasa.gov/oct.

EARLY STAGE INNOVATION AND PARTNERSHIPS

TECHNOLOGY TRANSFER AND PARTNERSHIPS

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 (i.e., numbers of new inventions, patents, licenses, cooperative research and development agreements, and software use agreements).

For example, the NASA Technology Transfer System houses all tech transfer information (from licensing to marketing efforts) and serves as the database that informs other tools used by tech transfer (like the NASA Technology Transfer website). In addition, NASA uses the NASA Software Catalog to inventory software tools NASA has created in the course of its work, to make available to industry, academia and other government agencies.

Technology Transfer will continue to streamline and automate internal processes in order to increase ability to conduct outreach to industry. Technology Transfer also intends to work to broaden outreach to areas that have typically not felt the NASA presence, as well as continue to improve and explore new existing tools to maximize use of online marketing of our portfolios. Several successful initiatives have launched, including the NASA Remote Sensing Toolkit (RST). RST was created to help entrepreneurs and other agencies find and use NASA remote sensing data. This toolkit serves as a searchable, all-in-one location for dozens of satellite data repositories, tools to analyze that data, and NASA software to make new, unique tools to analyze data. NASA implemented a coordinated marketing push to inform the public about the new tool including a press release, YouTube video, social media content, and a series of webinars explain the toolkit. RST can be found at: https://software.nasa.gov/remotesensing/.

PRIZES AND CHALLENGES (INCLUDES CENTENNIAL CHALLENGES)

NASA seeks to advance space exploration technologies using a variety of methods. In addition to developing technologies in-house as well as through grants, contracts, cooperative agreements and public-private partnerships, 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 as well as to make payments only once they have received satisfactory solutions to meet their needs. This approach includes utilizing agency platforms such as the NASA Tournament Lab, and Centennial Challenges.

NASA utilizes the NASA Tournament Lab to enlist crowdsourcing to tackle real-world challenges being faced by NASA and other Federal Agencies. NASA Tournament Lab, which is managed by the Center of Excellence for Collaborative Innovation at Johnson Space Center, offers a wide variety of open innovation platforms that engage the crowdsourcing community in challenges to create the most innovative, efficient and optimized solutions.

The strategic use of prize competitions and challenges as well as citizen science and other open innovation tools supports NASA’s R&D objectives and enhances the Agency’s connections with the American and global public. NASA achieves this by examining and taking actions to strengthen NASA policies and infrastructure to support prizes and challenges and other open innovation approaches. Prizes and Challenges activities also include support for 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 aimed to support future NASA missions. The program seeks innovations from diverse and non-traditional sources by directly engaging the public in the process of developing advanced technology. Competitors are not provided government funding for their development; rather, awards are only made to successful teams when the challenges are met. The program partners with organizations inside and/or outside of NASA to manage challenges with the goal of maximizing return on investment to the agency.

NASA is in the process of formulating additional challenges, to include In Situ Resource Utilization production prize competition targeting a large scale, end-to-end, system; and a portable energy storage challenge to enable powering a rover through several cycles of lunar daylight and darkness. These challenges will be announced in early FY 2020. The Budget request includes $10 million in new prize authority (no-year funding) to support these challenges. In addition, the following Centennial Challenges are funded and in progress:

- Cube Quest Challenge - NASA's first in-space challenge, the objective of this challenge is to advance communication and propulsion technologies for small spacecraft. Prizes will be awarded based on the distance the CubeSats go in space, and how long they can communicate with Earth as they travel. Following a series of Ground Tournaments, three winners were selected as secondary payloads on the first integrated flight of NASA's Orion spacecraft and SLS rocket. The next phase of the challenge will start once the CubeSats reach lunar or deep space orbits. Teams will be competing 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.
- 3D Printed Habitat Challenge - The purpose of the 3D Printed Habitat Challenge is to advance additive construction technology to create sustainable housing on Earth and beyond. Seventeen teams have signed up for the third and final phase of the competition which will take place at the Caterpillar Testing Facility in Peoria, Illinois, in May 2019. The teams will demonstrate their abilities to use autonomous additive manufacturing technology to construct 1:3 scale habitats.
- 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 within a three-year timeframe. Twelve teams have signed up for the competition.

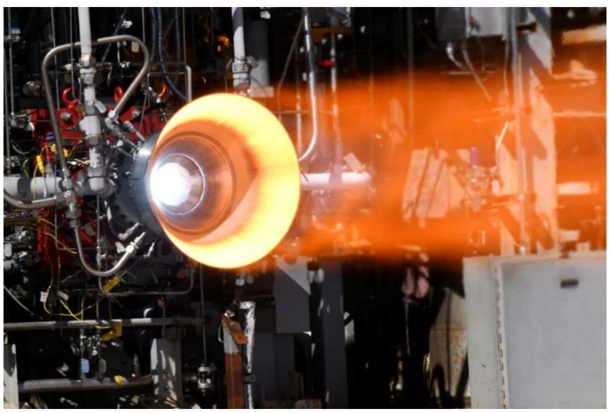
TECHNOLOGY MATURATION

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**151.5**	**--**	**282.5**	**227.2**	**250.3**	**246.7**	**328.0**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



NASA successfully hot-fire tested a 3-D printed copper combustion chamber liner with an E-Beam Free Form Fabrication manufactured nickel-alloy jacket. The hardware must withstand extreme hot and cold temperatures inside the engine as extremely cold propellants are heated up and burned for propulsion.

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 surface activities and space exploration beyond low earth orbit.

These investments will also support the Science Mission Directorate on exploration-related technology and research that also has relevance to achieving science goals.

The Technology Maturation portfolio develops and demonstrates technologies needed to enable exploration, in particular those that address technical challenges faced by human explorers in the following areas:

- In-Situ Resource Utilization;
- Entry, Descent and Landing;
- Power and propulsion technologies;
- Advanced communications, navigation and avionics;
- Advanced materials;
- In-space manufacturing and on-orbit assembly;
- Advanced Environmental Control and Life Support Systems; and
- Autonomous operations.

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, the building of future commercial markets, and a shared financial interest in the development of capabilities. NASA will execute a technology portfolio that enables human exploration, and bring new knowledge and opportunities back to Earth enabled by the high priority technology focus areas described in further detail below.

EXPLANATION OF MAJOR CHANGES IN FY 2020

NASA is initiating a Lunar Surface Innovation Initiative to drive coordination and encourage innovation and commercial participation in future lunar surface developments. Capabilities prioritized through this initiative include: In Situ Resource Utilization technologies to enable conversion of lunar ice to water, water to cryogenic propellant, and regolith to oxygen; lunar dust mitigation; and robotics suitable for exploring extreme terrain under extreme conditions.

ACHIEVEMENTS IN FY 2018

- Completed Critical Design Review for the Mars Entry, Descent and Landing Instrumentation (MEDLI2) and Mars Environmental Dynamics Analyzer (MEDA) technology instrument projects.
- Refined the nuclear thermal propulsion fuel element and reactor conceptual design to include reactor general design, performance analysis, mechanical design, core fabrication development, and fuel fabrication development.
- Completed cold life testing of Bulk Metallic Glass planetary gears to enable more robust mobility systems for future extreme environment exploration and science missions.
- Successful sounding rocket test of the Adaptable, Deployable, Entry and Placement Technology (ADEPT) aeroshell. Launched on UP Aerospace's SL-12 Launch. ADEPT achieved full deployment and configuration lock prior to reaching 80 kilometers altitude on descent.
- The Low Cost Upper Stage project successfully completed a hot-fire test of a combustion chamber and nozzle developed using additive and free form fabrication manufacturing processes. To date, NASA has accumulated more than one hour of hot-fire test time bringing this rocket engine closer to application as a flight certified engine.

WORK IN PROGRESS IN FY 2019

- Technology Maturation began transitioning its focus on the advancement of technologies that are directly applicable to activities on the moon’s surface. In this transition, a number of candidate payloads were identified that could be quickly prepared for demonstration and made available for demonstration on the Commercial Lunar Payload Services (CLPS) landers. The agency selected a number of these technologies as payloads to prepare for flight within the next year, including a Navigation Doppler Lidar system developed by the Johnson Space Center, a neutron spectrometer, and a stereo camera for studying lunar surface plumes.
- NASA will demonstrate the capability of the fuel and fuel element design for Nuclear Thermal Propulsion, and provide an assessment of technical viability and affordability of an engine ground demonstration with confident cost and schedule metrics. The project will also complete the Rocket Exhaust Capture System Subscale Phase 1 testing and conduct the System Feasibility Review.

TECHNOLOGY MATURATION

- In the area of In Space Manufacturing, NASA delivered refrabricator technology to the ISS. This machine can not only print plastic parts, but can also recycle them back into reusable raw materials to make more and/or different parts. In addition, the Agency partnered with three U.S. companies, to create a prototype, on-demand fabrication capability (Interlog Corporation of Anaheim, California; Techshot, Inc. of Greeneville, Indiana; and Tethers Unlimited, Inc. of Bothell, Washington).
- In the area of entry descent and landing systems, the Entry Systems Modeling project in coordination with the MEDLI-2 project will complete the PICA-N High Fidelity Model Validation using the Mars Curiosity MEDLI data, and deliver MEDLI-2 and MEDA flight hardware to Mars 2020. In addition, NASA will conduct ground demonstrations of the navigation Doppler LIDAR and complete prototyping of advanced hazard detection and descent and landing computing capability. NASA will partner with Masten to perform a flight demonstration of Terrain Relative Navigation technology.
- To substantially improve computing capacity of spaceflight computers, NASA will complete a space rated chiplet design and define single board architecture needs, as well as initiate 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.
- NASA will conduct a flat floor functional deployment test for Deployable Composite Boom project that focuses on maturing deployable space structures for small volume spacecraft (i.e. CubeSats) and EELV Secondary Payload Adapters (ESPA) class satellites.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

As a key part of the Lunar Surface Innovation Initiative, Technology Maturation will prioritize and begin development of a number of In Situ Resource Utilization components and subsystems. The project will spend FY 2019 and 2020 buying down technology risk and formulating integrated systems in preparation for several sub-scale lunar demonstrations on commercial landers. These early developments will lead to an integrated system for resource acquisition and processing into mission consumables, including oxygen, water, and hydrogen, that can reduce mission mass, cost, and/or risk of human exploration and led to Earth independence. Ultimately, the aim is to conduct an integrated demonstration in the 2025 timeframe. Key areas of focus and investment in the FY 2020-2024 horizon and will lead to the sub-scale and integrated demonstrations include:

  - Autonomous and robotics systems to enable surface mining/excavation capabilities
  - Mission Consumable Production (O2, H2, Fuel) of propellants for reusable robotic landers, fuel cell consumables and eventual support of life support for crew on surface missions
  - Lunar Polar Water/Volatiles for Polar Regolith
  - Lunar Dust Mitigation/Contamination Control Technologies
  - Architecture studies on power needs for excavation/mining and plant operations.

- After establishing design requirements for embedded heat pipes, head interface designs, and mission concept requirements for a technology demonstration, the Kilopower project will transition from a pre-formulation to a Technology Demonstration Mission.

TECHNOLOGY MATURATION

- NASA's Safe and Precise Landing Integrated Capabilities (SPLICE) project will deliver units of the Navigation Doppler Lidar (NDL), Descent Landing Computer (DLC), Terrain Relative Navigation (TRN), and Hazard Detection Lidar to Blue Origin to support their future sub-orbital flight and potential closed loop demonstration in 2021. All are vital components leading to an integrated suite of technologies for a future lunar demonstration that emphasizes partnerships between NASA and industry.
- NASA will conduct system integration and testing of the High Performance Spaceflight Computing multi-core rad-hard processor before using the processor to conduct a precision landing suborbital demonstration in partnership with Safe and Precise Landing Integrated Capabilities (SPLICE) in the 2023 timeframe.
- NASA's 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 robots on the lunar surface.
- The Evolved Regenerative Fuel Cell project will support the Lunar Surface Innovation Initiative through 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.
- 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.
- Extreme Environmental Space Power will deliver a transformational solar array prototype that is much more efficient than current technology enabling reliable power for science and exploration missions requiring operations through low sunlight intensity and low temperature. The prototype will demonstrate at least 37% greater efficiency at beginning of life and at least 28% greater efficiency at end of life than the state of the art. The industry awardee, Applied Physics Laboratory will supply two of these transformational array strings for the DART mission.
- The Bulk Metallic Glass Gears Project will complete pyroshock and vibration testing to demonstrate that bulk metallic glasses have sufficient toughness to survive shock and vibration loads experienced during launch. Mechanical testing and characterization will be completed to develop a database of design parameters that will enable the design of gear systems to meet future mission specific requirements. Both of these activities will facilitate the adoption of bulk metallic gears in future Lunar and deep space exploration missions (e.g., Europa Lander).

Program Elements

As part of the Lunar Surface Innovation Initiative, NASA will jumpstart efforts on 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 new key lunar surface technology areas that NASA will focus on include (but are not limited to):

- Extreme Access: Demonstrate technologies enabling humans or robotic systems, particularly autonomous systems, to efficiently access, navigate, and explore previously inaccessible lunar or planetary surface or subsurface areas.
- Extreme Environments: Develop technologies and other strategies to enable rovers, manipulators, and other systems to operate throughout the full range of lunar surface conditions including lunar noon (up to 150 C), night (down to - 180 C), multiple day/night cycles, and permanently shadowed regions (down to -240 C).
- Surface Construction: Demonstrate technologies enabling affordable, autonomous manufacturing or construction (e.g., of a landing pad, berm, or shielding) using lunar surface materials.
- Sustainable Power: Demonstrate technologies to enable continuous power throughout the lunar day and night and capable of scaling to tens of kilowatts for long-term surface operations.
- Cryogenic Propellant Management: Demonstrate technologies enabling autonomous transfer and storage of cryogenic hydrogen, capable of scaling to tens of metric tons, with negligible losses for at least a year in space and on the lunar surface.
- Lunar Dust Mitigation: Develop concepts to mitigate lunar dust hazards, enabling affordable, sustained operations both on the lunar surface and with transfers to and from Lunar Gateway or other orbital platforms.
- Space Weather Modeling: Develop technologies to model and enable mitigation of space weather hazards, including 24-hour warning of solar proton event threats.

In-Situ Resource Utilization must first be demonstrated (on the ground and on the Moon/Mars) before it can be mission-critical. This project will target a subscale demonstration of critical technologies on Commercial Lunar Payload Services (CLPS) landers (e.g. excavation, mineral beneficiation, regolith processing) in the early to mid-2020's. The project will design pilot/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, BAAs, RFP, etc.) and competitions. This project will also be instrumental in leveraging a potential ISRU institute as well as challenge ideas.

TECHNOLOGY MATURATION

ENTRY, DESCENT AND LANDING SYSTEMS

In order for NASA to land more mass, more accurately 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, and landing systems, 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:

- Safe and Precise Landing Integrated Capabilities Evolution (SPLICE), a precision landing and hazard avoidance technology, will be infused into future robotic missions. The project will strive to tie entry uncertainty to a safe & precise landing. By the end of the project, the goal is to reach 200m/s with Line of Sight Velocity and greater than 4km in Line of Sight Range. Precision planetary landing, where many high-resolution images need to be processed in seconds, is a particularly demanding operation that benefits from HPSC. The precision landing and high-speed computing experts have collaborated for many years, and the two funded activities (SPLICE and HPSC) are now able to leverage each other in their development paths.
- In August 2018, STMD announced the selection of two Tipping Point technology development partnerships. These activities will accelerate the commercial sector's use of Terrain Relative Navigation (TRN), to be demonstrated on the Mars 2020 mission. Astrobotic plans to develop a commercially-available TRN package, enabling a multitude of future missions to take advantage of the capability to choose a safe landing site within a landing footprint. Their activity will culminate with a lunar flight test. Blue Origin will also adopt TRN, combine it with a Navigation Doppler Lidar (NDL) for precise velocimetry, and mature altimetry and hazard detection capabilities, as well. These will be flight-tested on Blue Origin's New Shepard vehicle, up to an altitude of 100 km, and readied for lunar lander implementation.
- Mars 2020 Entry, Descent and Landing Instrumentation: In collaboration with Science, Exploration Technology will develop the second-generation sensor suite for incorporation into the mission 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.

SPACE POWER AND PROPULSION

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 development of solar array technology that can generate energy in extreme environments including low light intensity and low temperature; with the successful test of a 1kW testing of surface fission power, further investment in Kilopower is underway; and rapid transit nuclear thermal propulsion technology utilizing low-enriched uranium that could potentially provide 20 percent shorter travel time to Mars while substantially improving mission flexibility. Key projects that support this thrust area include the following:

- Nuclear Thermal Propulsion (NTP): In FY 2019, the nuclear thermal propulsion project will test fuel low and moderate temperature thermo-chemical stability, engine environment performance of fuel element design, complete feasibility assessment, and demonstrate ability to capture exhaust in a ground demonstration. Such investments will help efforts to enable more efficient spaceflight by developing improved fuel element sources to support potential future nuclear thermal propulsion efforts.

- High fidelity engineering model hardware, acceptance test data, and validated performance models for a 90K cryocooler with a 150W refrigeration capacity for propellant conditioning, pressure control, and liquefaction of soft cryogens (LOX, LCH4, LN2), and for a 20K cryocooler with a 20W refrigeration capacity for zero boil off storage of LH2 enabling to Nuclear Thermal Propulsion.
- Fuel Cell Development: Develop and demonstrate a primary fuel cell system to support Entry, Descent, and Landing and other applications for a Lunar Mission. Fuel Cells will be required once the spacecraft reaches lunar orbit, operate throughout landing sequence, and 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. FY 2020 will complete 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.
- The Thruster for the Advancement of Low-temperature Operation in Space (TALOS) will bring a new class of thrusters 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. In FY 2019 the project will complete the electrical discharge machining for the Workhorse engine injector and complete the hot-fire testing of the Workhorse Engine. Astrobotic (Pittsburgh, PA) has baselined the TALOS thrusters for its Peregrine lander. 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.
- NASA continues to work with Ad Astra Rocket Company of (Webster, TX), Aerojet Rocketdyne Inc. (Redmond, WA), and MSNW LLC (Redmond, WA) to develop propulsion technology systems in the 50- to 300-kilowatt range to meet the needs of a variety of deep space mission concepts. Companies who are able to conduct vacuum chamber tests of high-power electric propulsion systems for 100 continuous hours will be eligible for follow-on opportunities.
- 600W Hall Thruster Qualification Life Test: Through an Announcement of Collaborative Opportunity in FY 2018, NASA awarded Busek a three-year project to perform life testing of their BHT-600 Hall effect thruster and BHC-1500 hollow cathode assembly coupled to a power processing unit. This technology could be infused into sub-kilowatt power level electric propulsion systems to enable more affordable missions with smaller spacecraft.

ADVANCED COMMUNICATIONS, NAVIGATION AND AVIONICS

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: High Performance Spaceflight Computing 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) contracted to Boeing, Seattle WA, Advanced Rad-hard Memory (led by 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 planetary landing, where many high-resolution images need to be processed in seconds, is a particularly demanding operation that benefits from HPSC. The precision landing and high-speed computing experts have collaborated for many years, and NASA intends to pair high performance spaceflight computing to conduct precision landing demonstrations beginning in FY 2021.
- Software Defined Reliability for Mission Critical Operations: through an FY 2018 public-private partnership award, Astrobotic Technology will mature its software-defined reliability system for computing.

ADVANCED MATERIALS

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:

- 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 Rapid Analysis Manufacturing Propulsion Technology (RAMPT) project 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, assembly schedules (60 percent) and allowing for reduced parts, increased reliability, and significant weight reduction (70 percent). RAMPT will partner with industry through a public-private partnership to design and manufacture component parts of the thrust chamber.
- 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, Virginia, a team of researchers is working with other NASA centers, government agencies, academia, and industry partners to move this technology forward. Eventually, carbon nanotube materials could be used to make rocket and spacecraft components. To do that, NASA needs a much higher production rate of the carbon nanotube material. Using a Phase III Small Business Innovative Research (SBIR) contract with Nanocomp Technologies Inc. of Merrimack, New Hampshire, 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.

TECHNOLOGY MATURATION

IN-SPACE MANUFACTURING AND ON-ORBIT ASSEMBLY

Having an integrated capability for on-demand manufacturing and repair of components and systems during space missions will be integral for sustainable exploration missions. In-space manufacturing and assembly is a rapidly-evolving, disruptive area in which NASA intends to continue working with industry and academia to develop these technologies through collaborative mechanisms.

- In an effort to provide efficient mission and ground operations with reduced dependence on Earth resource, NASA is continuing to invest in in-space manufacturing technologies, including the development of the 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; Technical Interchange Meetings with the Multi-Material Fabrication Laboratory (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 multi-material fabrication laboratory (FabLAB) and conduct Critical Design Reviews, leading to an on-orbit FABLAB in the 2025 timeframe.
- 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 deployable systems. The lack of reliable deployable structural systems for low cost, small volume, rideshare-class spacecraft, such as CubeSats, currently limits the potential of small satellite platforms for use in low-cost science and exploration missions, and in particular, deep space 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 high Delta-V propulsion systems to be included on small CubeSat/ESPA class spacecraft.

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 will be enabling for long-duration human missions. NASA awarded two contracts, Honeywell Aerospace and 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. Future maturation of 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 enabling greater in situ resource utilization and manufacturing by demonstrating the ability to produce high-value products on demand. The project will include investigations in BioNutrients which will culminate in a five-year flight experiment and demonstration in FY 2019 and CO2-Based Manufacturing for Mission Extensibility.

TECHNOLOGY MATURATION

AUTONOMOUS OPERATIONS

Autonomous operations are critical when exploring or operating in an extreme environment, on Earth or in space). This portfolio supports technologies that benefit space exploration and also support manufacturers, businesses and other entities. Key technology efforts include:

- Autonomous Medical Operations: The objective of this project is to develop a “medical decision support system” to enable astronauts on long-duration exploration missions to operate autonomously while 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/enhancing key technologies for the autonomous operation of complex, space based infrastructure that provide the capability to support operations where human intervention is limited as well as provide new capabilities for spacecraft for in-space operations and adaptive vehicle caretaking. At the end of the formulation phase, ISAAC will perform a demonstration to validate the initial MAST (Modular Autonomous Systems Technology) architecture on a Lunar Gateway-analog platform.
- Autonomous Pop Up Flat Folding Exploration Robot: The objective of this project is to enable the “Pop-Up Flat Folding Explorer Robots” (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 is capable of supporting future lunar, Mars and icy moon missions, as well as extreme terrains on Earth.
- Astrobee is a free flying robot to support station keeping on the ISS. Astrobee will be used by mission control to perform mobile sensor and camera work as well as by researchers for zero-g robotics experiments. Astrobee launched to the ISS in early FY 2019. Once on-orbit testing and demonstration is performed, Astrobee will be transitioned to HEO to operate the Astrobee facility, replacing the SPHERES facility.

TECHNOLOGY DEMONSTRATION

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Laser Comm Relay Demo (LCRD)	21.5	17.2	**0.0**	0.0	0.0	0.0	0.0
Solar Electric Propulsion (SEP)	34.2	--	**43.4**	20.9	4.0	2.6	0.0
Restore/In-Space Robotic Servicing (ISRS)	130.0	180.0	**45.3**	45.3	45.3	0.0	0.0
Small Spacecraft, Flight Opportunities & Other Tech Demonstration	136.0	--	**308.8**	345.6	342.1	359.6	231.2
Total Budget	**321.7**	**--**	**397.5**	**411.8**	**391.4**	**362.3**	**231.2**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

Archinaut project manager and fellow Made In Space engineer fine-tune the Extended Structure Additive Manufacturing Machine -- the core of this In Space Manufacturing project's innovative, in-space 3-D printing capability -- during thermal vacuum testing at NASA's Ames Research Center in Moffett Field, California.

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 Exploration Campaign, with an emphasis on lunar exploration technology needs (some of which contribute to the Lunar Surface Innovation Initiative). The areas of technology focus include: power and propulsion technologies, including cryogenic fluid management and solar electric propulsion; advanced communications and navigation demonstrations; in-situ resource utilization; entry, descent and landing; and in-space manufacturing and on-orbit assembly technologies.

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 sector industry and better leverage government investments. For example, in-space manufacturing and assembly offers a broad range of potential benefits while 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.

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 such as prospecting for lunar ice.

EXPLANATION OF MAJOR CHANGES IN FY 2020

The Laser Communications Relay Demonstration launch has slipped to 2020 due to delays with the STPSat-6 bus development.

ACHIEVEMENTS IN FY 2018

- The Deep Space Optical Communications project completed subsystem Preliminary Design Reviews in preparation for the System Preliminary Design Review and Key Decision Point-C to align with the Science Mission Directorate Psyche mission schedule. This system will be capable of delivering information rates at least 10 times faster than conventional systems that use comparable mass and power.
- The three In-Space Robotic Manufacturing and Assembly contractors completed the ground based development and testing phase and submitted proposals for potential follow-on flight demonstrations.
- The Restore-L project held a Preliminary Design Review in early FY 2018 while continuing to make steady progress on robotics, propellant transfer, avionics, and rendezvous and proximity operations subsystem technologies. An Industry Day was held to help enable transfer of the critical satellite servicing technologies to aid the nascent commercial satellite servicing industry.
- The Laser Communications Relay Demonstration payload completed hardware build, system integration and environmental and performance testing.
- The Optical Communications and Sensor Demonstration (OCSD) mission, developed and operated by The Aerospace Corporation, transmitted at an error-free data rate of 200 megabits per second (approximately a 100 times increase over CubeSat state of the art) to a 30cm telescope. A second demonstration successfully completed by OCSD’s twin 1.5 unit spacecraft, involved a propulsive rendezvous with water-fueled maneuvering thrusters to rejoin the spacecraft after a 460km post deployment drift to a closest approach of six meters.
- The Jet Propulsion Laboratory (JPL) developed reflectarray antenna, pioneered for use in spaceflight for the Integrated Solar Array Reflectarray Antenna (ISARA) mission last July, was an integral part of the successful data relay conducted by the two MarCO spacecraft during the Insight landing on November 26th. The reflectarray on ISARA was demonstrated to be capable of data rate transmission of up to 100 megabits per second (Mb/s), an order of magnitude over prior CubeSat state of the art.

WORK IN PROGRESS IN FY 2019

- The Deep Space Atomic Clock (DSAC) is a small, low-mass atomic clock based on mercury-ion trap technology that will be demonstrated in space, providing unprecedented stability needed for next-generation deep space navigation and radio science. DSAC offers the promise of 50 times greater accuracy than today’s best deep space navigation clocks and will rideshare as part of the U.S. Air Force STP-2 mission aboard a SpaceX Falcon Heavy booster. Riding along is NASA's Green Propellant Infusion Mission that will demonstrate a propulsion system using a significantly

less toxic propellant than hydrazine which provides 40 percent higher performance by volume. The launch of both DSAC and GPIM is slated for summer 2019.
- 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.
- The eCryo project will begin its Structural Heat Intercept-Insulation-Vibration Evaluation Rig (SHIIVER) testing in July 2019. Testing will be completed in February 2020, before handing off that technology to interested stakeholders in support of NASA's Exploration activities and industry. This test will 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.
- NASA will complete a number of Mars 2020 technology developments including Terrain Relative Navigation, Mars Oxygen ISRU Experiment, Mars Environmental Dynamics Analyzer, and the Mars 2020 Entry, Descent and Landing Instrumentation with deliveries between fall 2018 and spring 2019 to support the Mars 2020 schedule.
- Masten Space will conduct a terrestrial flight demonstration of the Draper Terrain Relative Navigation camera to support the Exploration Campaign
- The first two Pathfinder Technology Demonstrator missions that will test new small spacecraft propulsion and deep space attitude determination and control technologies will be readied for flight by late FY 2019. Those missions make use of commercial spacecraft provided by Tyvak Nanosatellite Systems Inc. of Irvine, California and services to test small spacecraft subsystem payloads developed through public-private partnerships.
- The Lunar Flashlight mission, led by JPL, will be readied for flight. Once launched on the SLS EM-1 as a secondary payload, Lunar Flashlight will scan the lunar surface to locate and measure ice deposits in shadowed craters at the lunar south pole. Knowledge of the location and concentration of water and other hydrogen volatiles is critical to inform sustainable exploration mission architectures that makes use of in situ resource utilization.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

- As a key component of the Lunar Surface Innovation Initiative, NASA will prepare technologies for conducting precursor demonstrations on the lunar surface including: In Situ Resource Utilization technologies and surface power technologies (follow-on to the successful Kilopower ground demonstration).
- NASA will integrate and perform system testing with the STPSat-6 payload and launch the Laser Communications Relay Demonstration (LCRD) in August 2020. In addition, the Deep Space Optical Communications project will conduct its Critical Design Review.
- The Solar Electric Propulsion Project will complete the Critical Design Review for the electric propulsion subsystem, and build qualification units to conduct qualification testing of the Solar Electric Propulsion engineering development units for the high power electric propulsion string.
- Blue Origin will conduct two suborbital flight demonstrations as part of awarded Tipping Point 2018 awards, ‘Cryogenic Fluid Management-Enhanced Integrated Propulsion Testing for Robust Lander Services’ and ‘Advancing Sensor Suites to Enable Landing Anywhere on the Lunar Surface.

TECHNOLOGY DEMONSTRATION

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

- The CubeSat Lasercom Infrared Crosslink (CLICK) 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 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 (ACS3) mission will demonstrate deployment of an 80 m2 sub-scale composites boom supported solar sail system in low Earth orbit as pathfinder for a future 500 m2 solar sail system suitable for low-cost deep space missions for heliophysics, small body planetary science, and human space flight support.

Program Elements

POWER AND PROPULSION

In addition to the projects below, NASA is developing Solar Electric Propulsion technology with higher-power, longer-life thrusters and power processing units. The first demonstration of this system will be a 50 kilowatt class Power and Propulsion Element for Lunar Gateway. This project in development is described further in a separate section that follows.

Kilopower

A key demonstration as part of the Lunar Surface Innovation Initiative, the Kilopower project will begin in FY 2020, building on the 2018 demonstration of a small, lightweight fission power system that could enable long-duration crewed missions to the Moon, Mars and destinations beyond. In FY 2020, the project will transition into a Technology Demonstration Mission following determination of system level requirements for system configuration, design life, launch/landing/deployment constraints, radiation signature, user load integration, and concept-of-operations in preparation to develop a 1-3kW flight qualified system for the moon. The flight system will optimize engines, flight radiators, radiation hard flight control electronics, and identify launch safety and security requirements with a target demonstration on a midsize lunar lander in the 2026 timeframe.

Upon successful demonstration, the technology is extensible to produce 10 kilowatts needed for surface and space missions, and will address the need for continuous power for day and night operations, and enables mission operations in harsh environments such as permanently shadowed craters.

Evolvable Cryogenics/Cryogenic Fluid Management

The Evolvable Cryogenics (eCryo) project is conducting 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

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 as a whole. 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.

NASA is initiating further development of Cryogenic Fluid Management technologies as a key component of lunar exploration efforts. 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 the fall of 2018. These proposals will include a lunar lander sub-orbital demonstration and a flight test of an advanced insulation.

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. NASA secured a rideshare opportunity for this technology demonstration mission via the STP-2 launch of a SpaceX Falcon Heavy, which is scheduled to launch in May 2019. In addition, NASA continues to work with Aerojet Rocketdyne to revise the one-Newton thruster design to implement improvements to better enable commercial infusion potential following the in-space demonstration, through a public-private partnership collaboration.

IN-SPACE MANUFACTURING AND ASSEMBLY OF SPACECRAFT AND SPACE STRUCTURES

In addition to the projects below, NASA is investing in satellite servicing technologies by leveraging commercial interests to develop servicing tools and capabilities. This project in development is described further in a separate section that follows.

In-Space Robotic Manufacturing and Assembly

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. Presently, launch-shroud size, lift capacity, and launch loads/environments limit the size and capabilities of systems pre-assembled on the ground and deployed using a single launch. With advances in ultra-lightweight materials, additive manufacturing, robotics, and autonomy, in-space manufacturing, assembly, and aggregation concepts are now at a tipping point. Three competitively awarded proposals successfully completed ground development of unique approaches to robotic manufacturing and assembly.

This budget request continues funding to conduct follow-on activities for an affordable flight demonstration of in-space manufacturing and robotic assembly technologies. Two In-Space Robotic Manufacturing and Assembly projects, Space System Loral Dragonfly (Palo Alto, CA) and Made-In-Space Archinaut (Moffett Field, CA), were selected in October 2018 for negotiation of a flight demonstration of their capabilities. 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. These crosscutting technologies could also greatly reduce cost while increasing capabilities for both NASA and commercial space applications.

IN SITU RESOURCE UTILIZATION

Lunar In-Situ Resource Utilization

Following successful Earth-based demonstrations funded through Technology Maturation, NASA will initiate In Situ Resource Utilization (ISRU) technology demonstrations to be conducted on the Lunar Surface beginning with subscale demonstrations of critical technologies on Commercial Lunar Payload Services landers (e.g. excavation, mineral beneficiation, regolith processing) in the early to mid-2020’s. This will be followed by pilot demonstrations of human mission relevant scale ISRU technologies such as mining and processing for oxygen and water; possibly tied to demonstration of nuclear surface power on the Moon in the mid 2020’s. This is a key component of the Lunar Surface Innovation Initiative.

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 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.

ENTRY DESCENT AND LANDING

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 about 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.

TECHNOLOGY DEMONSTRATION

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 in the Earth's atmosphere to determine the feasibility of this technology in supporting high mass Entry, Descent and Landing. This project will also demonstrate capabilities for a high mass return to Earth from Low Earth Orbit that could enable commercial applications such as flight hardware re-use and return of products manufactured in space for terrestrial use. The reentry vehicle will be flown as a secondary payload on a ULA 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 (6m) and at conditions relevant to identified Earth and Mars mission infusion opportunities. 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.

COMMUNICATIONS, NAVIGATION AND AVIONICS

In addition to the projects below, the Laser Communications Relay Demonstration seeks to change the way we send and receive data, video and other information, using lasers to encode and transmit data at rates 10 to 100 times faster than today's fastest radio-frequency systems, using significantly less mass and power. This project in development is described further in a separate section that follows.

Deep Space Optical Communication

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 future advanced instruments, live high definition video, tele-presence, and deep-space human exploration of the solar system. 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.

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 a high bandwidth flight laser optical communication terminal on the Science Mission Directorate's Psyche mission.

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. To be launched in summer 2019, the Deep Space Atomic Clock will demonstrate 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 is planned for launch via rideshare on a SpaceX Falcon Heavy (STP-2), and is funded in a partnership with SCaN.

TECHNOLOGY DEMONSTRATION

FLIGHT OPPORTUNITIES

Flight Opportunities conducted a sounding rocket test of Game Changing Development's Adaptable, Deployable, Entry and Placement Technology (ADEPT) aeroshell. Launched on UP Aerospace's SL-12 Launch, the umbrella-like aeroshell achieved full deployment and configuration lock prior to reaching 80 kilometers altitude on descent.

NASA Flight Opportunities strategically invests in the growth of the U.S. commercial spaceflight industry by providing flight opportunities to test space exploration and utilization technologies on commercially available suborbital flight platforms. These suborbital flight opportunities take technologies from the laboratory into a relevant flight environment that facilitates technology maturation, validates feasibility and reduces technical risks for future missions. These investments help mature innovative space technologies of interest to NASA while simultaneously supporting the development and use of U.S. commercial spaceflight services and capabilities. Flight Opportunities selects promising technologies from academia, research institutes, and private industry, NASA and other government agencies that are in need of rapid and affordable flight testing in space or a space-like environment. The program facilitates the use of U.S. commercial suborbital reusable launch vehicles for technology testing as well as high altitude balloons and flights on aircraft following reduced gravity flight profiles, when those classes of vehicles are appropriate.

Flight Opportunities targets technologies to support sustainable exploration of the lunar and Martian surfaces, the commercialization of low Earth orbit, and the expansion of economic activity into cislunar space. Technology efforts from academia, research institutes, and private industry will be selected to receive funding towards the technology design, development, preparation, payload integration, suborbital flight, and post flight analysis. Where appropriate and beneficial to the growth of the suborbital spaceflight market, Flight Opportunities will also fund demonstrations of the utilization of suborbital spacecraft for other technology development and research applications. In addition to partnering with academia, research institutes, and private industry, Flight Opportunities will work with other NASA programs to support and facilitate the use of U.S. commercial suborbital vehicles for the flight testing of space exploration technologies developed under NASA programs. U.S. commercial vendors providing flight services to date include Blue Origin, EXOS Aerospace, Masten Space Systems, Near Space Corporation, Raven Aerostar, UP Aerospace, Virgin Galactic, World View, and Zero Gravity Corporation. In 2018, the Flight Opportunities program facilitated the commercial suborbital flight testing of 31 technology payloads across three vertical takeoff/vertical lander flight campaigns, three suborbital reusable launch vehicle flight campaigns, six high-altitude balloon flights and two parabolic campaigns.

SMALL SPACECRAFT TECHNOLOGY

NASA develops and demonstrates the capabilities that enable small spacecraft to achieve exploration missions in unique and more affordable ways. Sustainable human activity in deep space requires exploration capabilities that can be fielded faster and at lower cost. Small spacecraft afford an increasingly capable platform to precede and accompany human explorers to the moon, Mars, and other destinations to scout terrain, characterize the environment, identify risks, and prospect for resources. Distributed systems of small spacecraft can responsively provide cost effective communications, monitoring, and inspection infrastructure for human exploration missions and cis-lunar commercial activity.

NASA invests in small spacecraft technology to enable new mission architectures through the use of small spacecraft, expand the reach of small spacecraft to new destinations and challenging new environments, enable the augmentation of existing assets and future missions with supporting small spacecraft, and to help conduct missions that address strategic knowledge gaps for sustainable exploration beyond Earth. NASA public-private partnerships and investments in small spacecraft technologies focus on accelerating the pace of exploration and discovery by leveraging the growing small spacecraft capabilities in U.S. industry and academia.

In support of these objectives, NASA also maintains the Small Spacecraft Systems Virtual Institute (S3VI), 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.

Through 2019 and into 2020, NASA will develop small spacecraft technology and execute missions demonstrating advanced propulsion for small spacecraft, optical communications crosslinks, formation flight, inter-satellite networking, and distributed spacecraft mission capabilities in partnership with other U.S. government agencies. These projects and missions seek to support the sustainable exploration of the Moon and beyond and to aid the expansion of economic activity into cis-lunar space.

TDM LASER COMM RELAY DEMO (LCRD)

Formulation	Development	Operations

FY 2020 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	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	39.8	31.8	20.1	**0.0**	0.0	0.0	0.0	0.0	0.0	91.7
Operations/Close-out	0.0	0.0	1.5	**0.0**	0.0	0.0	0.0	0.0	0.0	1.5
2018 MPAR LCC Estimate	**209.3**	**31.8**	**21.6**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**262.7**
Total STMD Budget	**183.3**	**21.5**	**17.2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**222.0**
Change from FY 2019				**-17.2**						
Percentage change from FY 2019				**0.0%**						
Total NASA Budget	**209.3**	**31.8**	**21.6**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**262.7**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

Laser Communications Relay Demonstration engineers place Flight Modem 2 in the thermal vacuum chamber for testing. LCRD's flight modems are a critical part of the LCRD payload. They encode data into laser light to be transmitted to the ground. Laser Communications Relay Demonstration seeks to prove the utility of bi-directional optical communications relay services between geosynchronous orbit and Earth.

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 area. The outcome of 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 will have major implications for NASA missions, as well as crosscutting application for other agencies, and U.S. satellite manufacturers and operators given the rising demand for bandwidth, consistent with the

TDM LASER COMM RELAY DEMO (LCRD)

Formulation	Development	Operations

responses NASA received from the industry through a Request for Information. Set to fly as a hosted payload with the U.S Air Force STP-Sat 6 mission, this project will demonstrate an order of magnitude leap in communications capability that could be used for the architecture that succeeds today's Tracking and Data Relay Satellite satellites, and enable new capabilities and services for other government agencies and commercial space communications providers. Upon a successful flight demonstration, NASA will provide the communications industry access to the integrated system to test these new capabilities for commercial application.

EXPLANATION OF MAJOR CHANGES IN FY 2020

The Laser Communications Relay Demonstration is scheduled to fly as a hosted payload on the U.S. Air Force's STPSat-6 mission. Due to delays involving the design and manufacture of the spacecraft bus, the launch of this mission has been delayed. The project is currently going through the replan as a result of the spacecraft bus technical and schedule issues, as such, cost and schedule are under review. NASA expects the replan to be completed in March-April timeframe, at which point NASA will have and can provide refined schedule and cost baselines.

PROJECT PARAMETERS

With application to both commercial and NASA operations, 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 2018

The project completed hardware build and payload integration and successfully performed functional and environmental testing.

WORK IN PROGRESS IN FY 2019

The project will deliver the flight payload to the spacecraft integrator for 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.

TDM LASER COMM RELAY DEMO (LCRD)

Formulation	Development	Operations

KEY ACHIEVEMENTS PLANNED FOR FY 2020

The project will support launch and early on-orbit checkout of the LCRD flight payload.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2020 PB Request
CDR	December 2016	December 2016
KDP-C	February 2017	February 2017
System Integration Review	May 2018	July 2018*
KDP-D	August 2018	August 2018*
KDP-E	June 2019	August 2020*
Operational Readiness Review	March 2019	March 2019*
Launch Readiness Review	November 2019	June 2019*
Launch (or equivalent)	November 2019	November 2019*

**Due to delays involving the design and manufacture of the spacecraft bus, the launch of this mission has been delayed until no earlier than August 2020.*

DEVELOPMENT COST AND SCHEDULE

The development cost estimate includes HEOMD/SCaN ($28.6M) funding as well as STMD ($63.1M).

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 Mile-stone Data	Current Year Mile-stone Data	Mile-stone Change (mths)
2017	63.1 (STMD)	70	2019	63.1	0	Launch	Nov 2019	Novem-ber 2019	
2017	91.8 (NASA)	70	2019	91.8	0	Launch	Nov 2019	Novem-ber 2019	

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.

TDM 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:	91.8	91.8	0.0
Aircraft/Spacecraft	9.9	21.0	11.1
Payloads	20.2	25.7	5.5
Systems I&T	4.1	8.2	3.9
Launch Vehicle	0.0	0.0	0.0
Ground Systems	6.3	6.0	-0.3
Science/Technology	2.6	4.5	1.9
Other Direct Project Costs	48.7	26.4	-22.3

**Due to delays involving the design and manufacture of the spacecraft bus, the launch of this mission has been delayed until no earlier than August 2020. Cost estimates will be updated once impact is fully understood.*

PROJECT MANAGEMENT & COMMITMENTS

Element	Description	Provider Details	Change from Baseline
Program Management	Project Management, LCRD Payload, LCRD Mission Operations Center	Goddard Space Flight Center	No change
Optical Ground Station	Optical Ground Stations, RF Ground Station and STPSat-6 Mission Control Center	HEOMD/SCaN	No change
Technology Transfer	Technology Transfer for Payload	Massachusetts Institute of Technology: Lincoln Laboratory	No Change
Ground Station	Optical Ground Station 1	Jet Propulsion Lab	No Change
Spacecraft and Launch Vehicle	STPSat-6 Spacecraft and Launch Vehicle	USAF & Northrop Grumman (Spacecraft vendor); ULA (Launch Vehicle)	No Change

TDM LASER COMM RELAY DEMO (LCRD)

Formulation	Development	Operations

PROJECT RISKS

Risk Statement	Mitigation
Given that the spacecraft integrator schedule performance has been poor, there is significant risk that the launch date will slip beyond the Agency Baseline Commitment date and have associated cost increases to the Agency Baseline Commitment Cost.	Northrop Grumman schedule assessment indicates readiness to launch no earlier than August 2020. Solidifying of cost numbers is anticipated near-term following results of the Senior Steering Group to complete its re-plan.

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 IAW Agency requirements	70 percent CL used to define Program-held UFE above project for KDP-C	N/A

TDM LASER COMM RELAY DEMO (LCRD)

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Standing Review Board/Independent Readiness Team	Various subject matter experts	December 8-9 (technical presentation); December 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	System Integration Review (SIR) that feeds into KDP-D Currently scheduled for 5/2018

TDM SOLAR ELECTRIC PROPULSION (SEP)

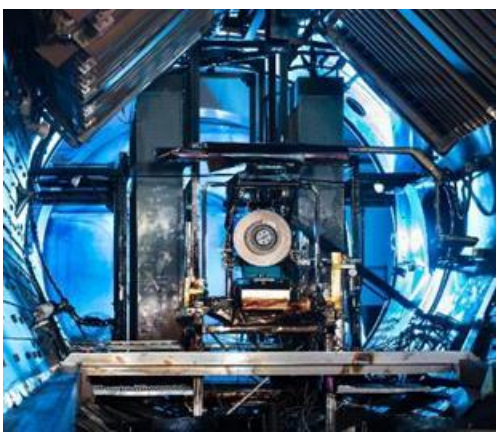
Formulation	Development	Operations

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	34.2	--	43.4	20.9	4.0	2.6	0.0

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



Electric Propulsion thruster in testing. The project will be conducting a spaceflight demonstration of a 30-50kW 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 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.

The SEP system will not only meet the objectives for future NASA exploration purposes, but 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-third of the packaging volume compared to the state-of-the-art, are already being incorporated into commercial satellite product lines. For example, Space Systems Loral and Deployable Space Systems are flight qualifying the Rollout Solar Array (ROSA) for use in its commercial communication satellites, and Orbital ATK 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.

Hall-effect thrusters with magnetic shielding have been developed, tested, and operated at approximately 13 kilowatts, permitting years of continuous operations without degradation. NASA awarded a three-year contract for engineering and qualification unit delivery of thrusters and power processing units in spring 2016 to Aerojet Rocketdyne, Inc. In FY 2018, Aerojet Rocketdyne completed the preliminary design of the electric propulsion string and is nearing completion of engineering test units that will support the final design. In FY 2019, Aerojet Rocketdyne will build and test the engineering test units to ensure the final

TDM SOLAR ELECTRIC PROPULSION (SEP)

Formulation	Development	Operations

design meets performance requirements. Following Critical Design Review scheduled in FY 2020, qualification hardware will be built and qualification testing will begin. Once qualified, high-powered Solar Electric Propulsion will be delivered to Lunar Gateway for the Power and Propulsion Element to demonstrate the technology needed to efficiently propel more ambitious, robotic science and human exploration missions beyond the Earth and into deep space. Furthermore, Solar Electric Propulsion will enable more efficient orbit transfer of spacecraft and accommodate the increasing power demands for government and commercial satellites.

EXPLANATION OF MAJOR CHANGES IN FY 2020

No Change. Cost and Schedule Baselines to be established in FY 2019.

PROJECT PRELIMINARY 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 Solar Electric Propulsion 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 2018

Aerojet Rocketdyne completed the preliminary design of the electric propulsion string and is nearing completion of engineering test units that will support the final design. NASA added the capability to test a second electric propulsion string in the SEP Testbed.

WORK IN PROGRESS IN FY 2019

Aerojet Rocketdyne will build and test the electric propulsion string engineering test units to ensure the final design meets performance requirements.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

The project will begin building qualification units and begin testing.

TDM SOLAR ELECTRIC PROPULSION (SEP)

Formulation	Development	Operations

ESTIMATED PROJECT SCHEDULE

Milestone	Formulation Authorization Document	FY 2020 PB Request
Formulation Authorization	March 2015 (as part of ARRM)	
KDP-A	March 2015 (as part of ARRM)	
Preliminary Design Review	September 2017	September 2017
KDP-C	January 2019	May 2019
Critical Design Review	March 2020	July 2020
System Integration Review (Plasma Diagnostics Package)		May 2021
Deliver to Lunar Gateway for Integration		CY 2021

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 a non-advocate review and/or preliminary design review.

KDP-B Date	Estimated Life Cycle Cost Range ($M)	Key Milestone	Key Milestone Estimated Date Range
7/2016	$230	Transition to Gateway	CY 2021
Note: LCC was based on KDP-B held for the Asteroid Robotic Redirect Mission. SEP requirements were largely maintained for application to the Power and Propulsion Element so a new KDP-B has not been held.			

TDM SOLAR ELECTRIC PROPULSION (SEP)

Formulation	Development	Operations

Project Management & Commitments

Element	Description	Provider Details	Change from Formulation Agreement
Program Management	Manages AR contract, thruster development life testing, Develops SEP Testbed, Plasma Diagnostics Package	Glenn Research Center	No change
Thruster Development	Thruster development life testing support	Jet Propulsion Laboratory	No change
Flight Thruster and Power System Design	Flight thruster and power system design and qualification	Industry - Aerojet-Rocketdyne	No Change

Project Risks

Risk Statement	Mitigation
Given the schedule and cost performance on the AEPS contract, there is a risk that the project will not complete electric propulsion string qualification prior to the date needed to begin flight procurement by the Power Propulsion Element.	Aerojet Rocketdyne completed a project replan in December 2018, submitting a draft Over Target Baseline (re-baseline) and partial requirements for capability-based approach. The project is working to perform a KDP-C review in mid FY 2019.

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

TDM SOLAR ELECTRIC PROPULSION (SEP)

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
PDR	IRT	9/2017	Assess/approve preliminary design	Pass	CDR
CDR	IRT	7/2020	Assess/approve final design		

RESTORE/IN-SPACE ROBOTIC SERVICING (ISRS)

Formulation	Development	Operations

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**130.0**	**180.0**	**45.3**	**45.3**	**45.3**	**0.0**	**0.0**
Change from FY 2019			**-134.7**				
Percentage change from FY 2019			**-74.8%**				

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

Grapple of Landsat-7 mock up by Robot arm. NASA engineers use mock-ups to evaluate and refine concepts.

PROJECT PURPOSE

In Space Robotic Servicing (ISRS), formerly Restore-L, will demonstrate advanced technologies that enable on-orbit satellite life extension. The project advances servicing technologies to operational status, before them transitioning to U.S. industry. Technology areas to be demonstrated include dexterous robotics, autonomous rendezvous, proximity operations and docking, propellant transfer, and interchangeable multipurpose robotic tools.

EXPLANATION OF MAJOR CHANGES IN FY 2020

Consistent with the President's FY 2018 and FY 2019 Budget Request, NASA is proposing to restructure and descope the Restore-L flight project. In its place, for the ISRS project, NASA requests $45.3M in FY 2020 to continue development of the satellite servicing technologies and better position it for the purposes of supporting a nascent commercial satellite servicing industry. NASA believes $45.3M is a realistic and more sustainable budget profile for advancing satellite servicing technologies to TRL 6 while maintaining a strong lunar focus on technology development investments, and will continue to work with industry partners to enable demonstration on their commercial platforms. At this funding level, the Goddard Space Flight Center (GSFC), with its contractor team and robotics partner, West Virginia University, will continue to develop the satellite servicing capabilities unique to the NASA project and make them available for interested partners through technology transfer mechanisms and public-private partnerships.

RESTORE/IN-SPACE ROBOTIC SERVICING (ISRS)

Formulation	Development	Operations

PROJECT PRELIMINARY PARAMETERS

With application to both commercial and NASA operations, ISRS will advance satellite servicing capabilities. Objectives include:

- Autonomous, real-time relative navigation system includes sensors, algorithms and processors join forces, allowing ISRS to rendezvous safely with its client.
- Servicing Avionics control ISRS's rendezvous and robotic tasks.
- Dexterous Robotic Arms provide maneuverable arms for executing servicing assignments. Software comes included.
- 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.

ACHIEVEMENTS IN FY 2018

Following a successful Mission PDR in November 2017, the project demonstrated an end-to-end autonomous capture with space-like reaction forces using a target spacecraft simulator and a payload mockup populated with a suite of subsystem components.

WORK IN PROGRESS IN FY 2019

During FY 2019, the Restore-L project will finalize its critical design and will complete component and subassembly testing. Additionally, the project will advance its ground systems and concept of operations for the mission. This will position the project to conduct a Critical Design Review in September of 2019. In addition, the project will hold its fourth industry day in September 2019. Previous industry events attracted 142 external participants, representing 79 different companies or organizations outside government.

In February, the International Space Station (ISS) crew successfully installed the Robotic Refueling Mission-3 robotic tools, the tool pedestal, and the interface plate on the Japanese airlock slide table. The hardware will remain in the closed airlock until external robotic operations occur, tentatively planned for early April.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

Following Critical Design Review, the project would target completion of the following technologies through qualification (TRL-6):

- Several components of the Navigation System
- Servicing Avionics & software (partially tested)
- Robot Arm & software elements
- Tool Drive System & Tools (tested without zero-G dynamics)

RESTORE/IN-SPACE ROBOTIC SERVICING (ISRS)

Formulation	Development	Operations

The project would also leverage Technology Transfer mechanisms and pursue partnerships with interested U.S. companies through Space Act Agreements.

ESTIMATED PROJECT SCHEDULE

Milestone	Formulation Authorization Document	FY 2020 PB Request
Formulation Authorization		
KDP-A	May 2016	May 2016
KDP-B	January 2017	January 2017
KDP-C	April 2018	July 2019
CDR	November 2018	September 2019
System Integration Review	July 2019	This budget assumes project will be transitioned to a ground demonstration
KDP-D	September 2019	
Operational Readiness Review	March 2020	
KDP-E	November 2020	
Launch	November 2020	

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 a non-advocate review and/or preliminary design review.

KDP-B Date	Estimated Life Cycle Cost Range ($M)	Key Milestone	Key Milestone Estimated Date Range
January 2017	$629 - $756	LRD	June-December 2020

RESTORE/IN-SPACE ROBOTIC SERVICING (ISRS)

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: Lead Center: KSC Performing Center(s): KSC, GSFC	No change
Client Satellite	Provide Landsat-7 to decommissioning orbit for access by Restore-L	Provider: USGS	No change
Spacecraft Bus	Build and deliver a spacecraft bus to carry the Restore-L payload	Provider: SSL Lead Center: GSFC	Contract awarded in 2017
Program Management	Project management, payload development and delivery, mission integration	Lead Center: GSFC	No change

Project Risks

Risk Statement	Mitigation
Given the funding resources required to complete the Restore-L mission with a December 2022 launch, there is a possibility that the higher priority technology development activities needed to enable the lunar exploration objectives will not be achieved.	NASA proposes to turn this project into a ground demonstration to ensure focus on advancing key servicing technologies.

RESTORE/IN-SPACE ROBOTIC SERVICING (ISRS)

Formulation	Development	Operations

Acquisition Strategy

The Robotic Servicing Vehicle is a GSFC in-house activity with subcontractors providing the spacecraft bus and key components of the payload.

Element/Component	Acquisition Method	Developer
Robot Arm	In-house development	GSFC with MacDonald, Dettwiler and Associates (MDA) as major sub
Rendezvous & Proximity Ops (RPO) Cameras	NASA Competition	Neptec Design Group
LIDAR	In-house development	
Vision Sensor Subsystem (VSS) Cameras	NASA Competition	Malin Space Science Systems
Propellant Transfer System (PTS)	Competition/Justification for Other than Full and Open Competition (JOFOC)	Valve Tech, FHM Aerospace, Vacuum and Air Components Company of America, Hoffer
Motors Arm, next generation Tool Drive (ATDS), Pan/Tilt Unit (camera), Motorized Zoom Lenses	Omnibus Multidiscipline Engineering Services (OMES II) contract	CDA InterCorp, Triump, Avior

MAJOR CONTRACTS/AWARDS

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

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Mission Concept Review (MCR)		April 2016	Affirm mission need, examine proposed mission's objectives, and validate the concept for meeting those objectives.	Passed	SRR

RESTORE/IN-SPACE ROBOTIC SERVICING (ISRS)

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
System Requirements Review (SRR)	Standing Review Board (SRB)	Oct 2016	Examines the functional and performance requirements and the preliminary project plan. Ensures 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
Preliminary Design Review (PDR)	SRB	Nov 2017	Demonstrates the preliminary design meets all system requirements with acceptable risk and within cost and schedule constraints.	Passed	CDR
Joint Confidence Level (JCL)	Tecolote	June 2019	Determine realistic 50/70 percent confidence level on budget and schedule to be approved		CDR
Critical Design Review (CDR)	SRB	September 2019	Demonstrate the maturity of the design is appropriate to support proceeding with full scale fabrication, assembly, integration, and test.		SIR

SBIR AND STTR

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**194.8**	**--**	**210.8**	**219.1**	**230.8**	**237.5**	**261.0**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

Made In Space's Zero-G Printer was launched to the ISS on September 21st, 2014, under a partnership agreement with NASA Marshall Space Flight Center. With a Phase I and subsequent Phase II award to build an Additive Manufacturing Facility (AMF) for on-demand fabrication in space, Made In Space successfully deployed its innovation and became the first company to manufacture in zero gravity.

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. 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 in-space propulsion systems to reduce travel time and cost; research to revolutionize space travel with new technologies to generate electrical power and store energy; technologies to enable a growing number of potential applications for small spacecraft; and advances in instruments that can be used as inspection tools for locating and diagnosing material defects like a micro meteoroid impact.

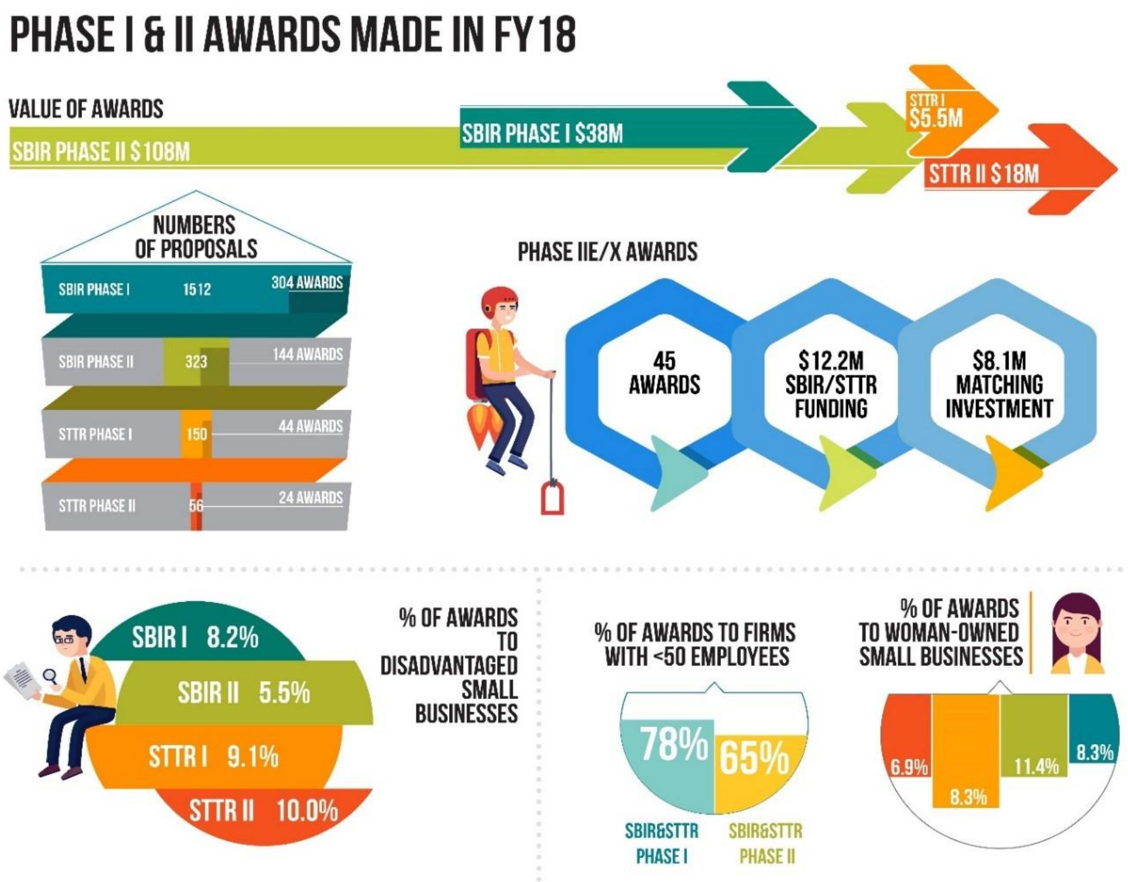
Small Businesses are contributing to NASA's mission through advancements in robotic mobility, manipulation, and sampling, as well as technologies for breaking through barriers to enable greater use of Unmanned Aircraft Systems in NASA research and in civil aviation. These investments seek to achieve 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.

SBIR AND STTR

EXPLANATION OF MAJOR CHANGES IN FY 2020

No Major Changes

ACHIEVEMENTS IN FY 2018



The program's annual solicitation calls for technologies in the areas of aeronautics, human exploration and operations, science and space technology across a breadth of research and development needs. In the 2018 solicitation, the program continued to support small satellites, small launch vehicle technology, additive manufacturing, and Nuclear Thermal Propulsion (NTP). Other technologies funded through the Phase I and Phase II awards include:

- Low-power, ultra-fast, deep-learning neuromorphic computer chips designed for unmanned aircraft systems, such as delivery drones;
- A solid-state oxygen concentrator and compressor designed to minimize hardware mass, volume and power footprint, while still performing at the required capabilities for future crewed space environments;
- Sensors and cameras for detecting and tracking near-Earth asteroids, to help scientists detect, count and track near-Earth asteroids; and

- Distributed electric propulsion to help NASA test the next generation of electric propulsion aircraft.

To assist firms in advancing their technologies and transitioning to commercialization, 42 SBIR and three STTR Phase II awardees received additional assistance through the Phase II E/X initiative. These awards were valued at over $12.2 million, and were matched by over $8.1 million from investors outside the SBIR/STTR program (other NASA programs, other government agencies, and commercial investors). In addition, over $7.8 million was infused into SBIR and STTR companies through utilization of their NASA awarded technologies via 32 Phase III awards. NASA has also continued an interagency agreement with the National Science Foundation to provide training grants for participation in the I-Corps program to enable small businesses to commercialize their innovations. Fourteen SBIR and three STTR Phase I awardees from the 2018 solicitation took advantage of this opportunity.

- The program underwent an operational and technical modernization effort throughout 2018 by rolling out new modules of the program's Electronic Handbook (EHB) system with each process in the cycle. The EHB is the primary technology interface for firms and internal NASA users and typically handles about 1600 proposals, 3000 evaluations, 400 awards, and 4000 deliverables annually on an ongoing basis throughout the year. The modernization effort utilized input collected through more than 100 input sessions throughout FY 2017 and 2018 including: interviews, design sessions, inputs to the 2017 RFI, and suggestions from Industry Day and on the website. Key objectives were to provide an enhanced system that provides: seamless user experience with an intuitive and user-friendly interface; user-centric rather than process-centric business rules; scalability and flexibility for future program and user needs; multi-layer security to protect sensitive and SBC proprietary intellectual property; integrated data analytics and visualization capabilities; accessibility of EHB content to people with disabilities (Section 508 compliance); responsive design for multiple device platforms; focus on federated data access rather than duplicative systems; prevention of data duplication; and increased interoperability with other systems (NASA or other government agency)..
- To enable small businesses to commercialize their innovations, NASA established an interagency agreement with the National Science Foundation to provide training grants for participation in the I-Corps program to six SBIR and five STTR Phase I awardees from the 2017 solicitation.

WORK IN PROGRESS IN FY 2019

- The FY 2019 annual solicitation was released in February. NASA plans to announce new Phase I selections in June, and Phase II SBIR and STTR selections (from the 2018 solicitation) in May and November, respectively.
- NASA will continue to offer Post-Phase II award opportunities through vehicles like the Phase II E/X programs to increase technology transitions and commercialization, and NASA will continue to make I-Corps training grants awards for Phase I awardees to encourage commercialization of technology funded through awards.
- A new cycle of the Civilian Commercialization Readiness Pilot Program (CCRPP) will be offered in early 2019 after taking a year off in 2018, and the program will stand up a Phase II Sequential program in 2019.
- NASA will continue to seek small business feedback to increase collaboration with small businesses through an annual industry day and Request for Information.

SBIR AND STTR

KEY ACHIEVEMENTS PLANNED FOR FY 2020

- The SBIR and STTR Programs will continue to work with the other NASA mission directorates, centers and industry to identify subtopics. NASA plans to release the annual SBIR and STTR solicitations in early 2020, and award new Phase I and Phase II selections the following summer
- The program will stand up a new Phase II Commercialization Assistance Program (CAP) to be implemented starting in FY 2020.
- NASA will continue to offer Post-Phase II award opportunities through vehicles like the new Phase II sequential program and the existing Phase II E/X programs to increase technology transitions and commercialization; and modernize its business capabilities to reduce barriers to entry for firms, to increase the quality of proposals and to improve the value proposition for firms.
- NASA will continue to pilot opportunities to accelerate the program's ability to advance NASA efforts in deep space exploration and those of the commercial aerospace sector, including beginning a pilot with the NSF SBIR program to support growth-oriented commercial space entrepreneurs.

Program Elements

SBIR

The SBIR program was established by statute in 1982 and was 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. In FY 2018, 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 Phase II Extended (II-E/X) contract options with incentives for cost sharing to extend the research and development efforts of the current Phase II contract. NASA also supports 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. 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 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. In FY 2019, the maximum value for an STTR Phase I contract is $125,000 for a period of performance of thirteen 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/X contract options, CCRPP, and I-Corps are also available to STTR participants.

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 implementing role. Cost Share Partner(s): SBIR Phase II-E/X 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 CCRPP matches cost share funding with 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 Enhancement (II-E/X) 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 work collaboratively with NASA Center Chief Technologists (for STTR) and a Mission Directorate Steering Council (for SBIR) during the SBIR and STTR acquisition process. This collaboration, from topic development through proposal review and ranking, supports final selection. 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 into NASA's future missions and systems. Topics and subtopics are written to address NASA's strategic priorities.

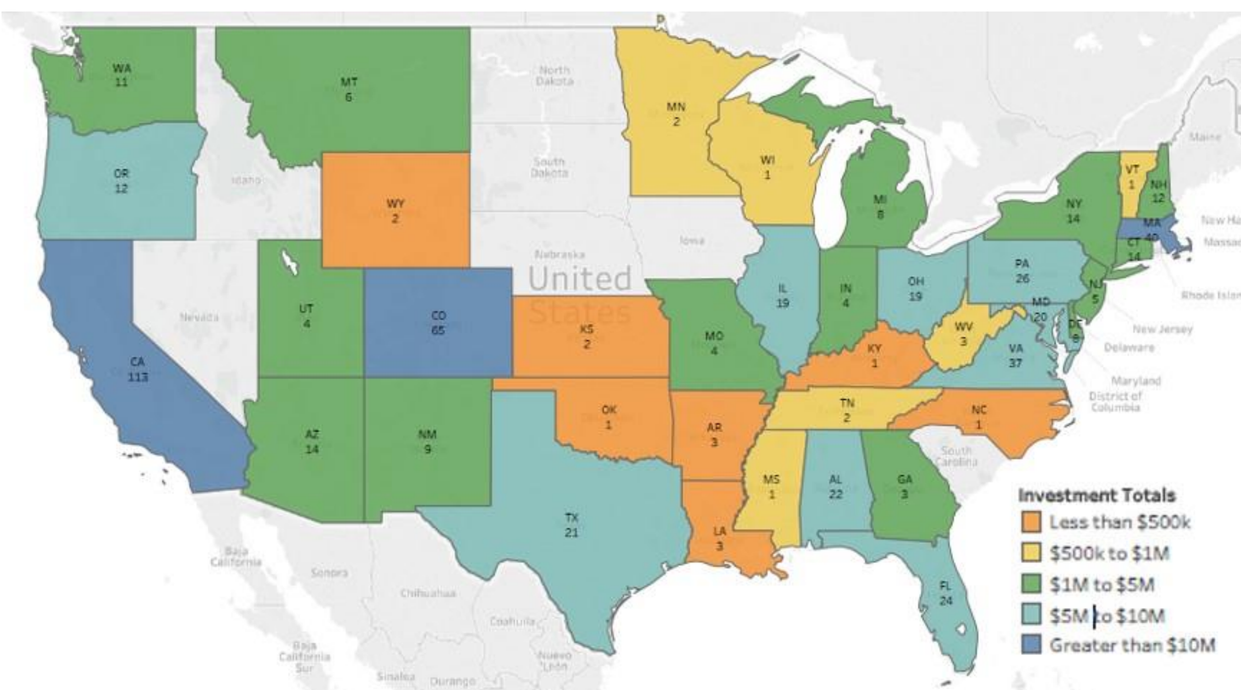
SBIR AND STTR

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Government Accountability Office (GAO)	Ongoing	The GAO has been tasked to assess all SBIR and STTR programs annually for their performance in complying with spending requirements. Additionally, in FY18, the GAO conducted studies about the SBIR/STTR Benchmarks and program efforts to allow for Small Business R&D Venture Capital.	GAO found no concerns to address for NASA.	Ongoing

Historical Performance

The map below represents the FY 2018 SBIR and STTR Phase I, Phase II, Phase II-E/X, and CCRPP that target technologies highly desired by NASA Mission Directorates, by geographic location.



LEO AND SPACEFLIGHT OPERATIONS

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
International Space Station	1493.0	--	**1458.2**	1448.5	1449.4	1352.6	1315.7
Space Transportation	2345.8	--	**1828.6**	1854.1	1814.5	1746.2	1727.2
Space and Flight Support (SFS)	910.3	--	**848.9**	891.9	905.7	911.8	914.5
Commercial LEO Development	0.0	--	**150.0**	175.0	200.0	225.0	225.0
Total Budget	**4749.2**	**4639.1**	**4285.7**	**4369.5**	**4369.5**	**4235.5**	**4182.3**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

LEO AND SPACEFLIGHT OPERATIONS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
International Space Station	1493.0	--	**1458.2**	1448.5	1449.4	1352.6	1315.7
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Commercial LEO Development	0.0	--	**150.0**	175.0	200.0	225.0	225.0
Total Budget	**4749.2**	**4639.1**	**4285.7**	**4369.5**	**4369.5**	**4235.5**	**4182.3**
Change from FY 2019			**-353.4**				
Percentage change from FY 2019			**-7.6%**				

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

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NASA astronauts Kate Rubins (left) and Jeff Williams (right) prepare to grapple the SpaceX Dragon supply spacecraft from aboard the International Space Station.

The Low Earth Orbit (LEO) and Spaceflight Operations account, comprised of International Space Station (ISS), Space Transportation, Space and Flight Support, and Commercial LEO Development, enables NASA to better plan both government and commercial access to space, and 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 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 commercial activities in LEO where NASA is one of many users purchasing those services. As those commercial LEO destinations are available, and without a gap in human 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 of 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 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 contributes to the increase in 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, reduce our current reliance on foreign providers for this service, help stimulate the American aerospace industry, and allow NASA to focus on building spacecrafts and rockets for missions to the Moon and Mars.

Space and Flight Support programs continues to provide mission critical space communications, launch and test services, and astronaut training to support their customer missions. The Space Communications and Navigation program provides communication with missions in LEO and ISS with 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 is being established to focus on demonstrating feasibility of commercially provided data relay services. The Launch Services Program provides expertise and active launch mission management for over 40 NASA and other civil sector 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 missions. To continue with the next step in human space exploration, NASA must prepare the human system for living and working in the hostile environment of space. The Human Space Flight Operations program provides the training and readiness to ensure crew health, safety and mission success.

For further programmatic information, go to https://www.nasa.gov/directorates/heo/index.html.

INTERNATIONAL SPACE STATION PROGRAM

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
ISS Systems Operations and Maintenance	1117.6	--	**1105.5**	1079.8	1088.7	1007.5	983.1
ISS Research	375.4	--	**352.7**	368.7	360.7	345.1	332.6
Total Budget	**1493.0**	**--**	**1458.2**	**1448.5**	**1449.4**	**1352.6**	**1315.7**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

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The International Space Station photographed by Expedition 56 crew members from a Soyuz spacecraft after undocking. NASA astronauts Andrew Feustel and Ricky Arnold and Roscosmos cosmonaut Oleg Artemyev executed a fly around of the orbiting laboratory to take pictures of the station before returning home after spending 197 days in space.

International Space Station (ISS) is the largest and most complex space-based research facility ever constructed by humanity, enabling distinct research opportunities. 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 all parties benefit.

The ISS's crew members orbit the Earth about every 90 minutes and have continuously occupied the facility since 2000. The U.S. segment 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 over 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 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).

NASA will continue research and technology efforts in low earth orbit (LEO) using the ISS to enable exploration with humans to the moon and on to Mars, while continuing to perform research that benefits humanity and leads to a robust ecosystem in LEO, supporting National Lab research by private industry and other organizations, and working towards reducing operations and maintenance costs. NASA is working to implement a step-wise transition of ISS from the current regime of NASA sponsorship and direct NASA funding, to a regime where NASA is one of many customers purchasing services from a LEO non-governmental human space flight enterprise. NASA will gradually transition from current ISS operations to this new regime to ensure that the United States always has access to a crewed space station in LEO. As part of this transition, NASA plans to purchase needed LEO services from a commercial operator of ISS and/or new commercial LEO destinations. The full transition from ISS to new commercial LEO destinations will be gradual. NASA, as the U.S. partner, is shifting its position from owner/operator to being a customer and anchor tenant with a variety of potential models under study. The rationale for this transition is threefold: to encourage and facilitate the development of a robust LEO ecosystem that will lead to economic growth; to turn over LEO operations to the private sector so NASA can focus on the challenges of exploration beyond LEO; and reducing costs for meeting NASA needs in LEO that will help support a sustainable approach for human exploration of the Moon and eventually Mars. NASA will continue leading the International Partnership that forms the basis of human spaceflight continuity and will leverage the Partnership for the next steps beyond LEO at the moon for the Gateway and onto Mars. The Partnership is also being leveraged to define exploration standards that will allow commercial as well as international partnership in the exploration architecture. NASA will continue to leverage its resources and capabilities to enable the development of a commercial market in LEO and alternatives to government directed human spaceflight infrastructure in LEO.

The ISS plays an essential role in facilitating the expanding sphere of human space exploration from low earth orbit to the Moon and eventually to Mars. The ISS is currently the only microgravity platform capable of the long-term testing of new life support and crew health systems, advanced habitation modules, and other technologies needed to expand our exploration horizons. NASA, with commercial and international partners, is working to gradually transition from the ISS to commercially operated LEO destinations. The ISS and follow-on commercial LEO destinations are critical to continue long-term testing of these systems for lunar and Mars exploration missions. 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. 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.

More information on NASA's budgetary and programmatic support for commercial options to fulfill research, science and technology requirements beyond ISS such as commercial orbital platform(s) can be found in the Commercial LEO Development section. The four major focus areas of activity for the ISS program include helping to return benefits to humanity on Earth through space-based research and technology development, serving as a key stepping stone on the pathway to deep space exploration, enabling the development and advancement of a commercial marketplace in low Earth orbit, and 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.

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 program is managed by the Center for the Advancement of Science in Space (CASIS). The focus of CASIS is to increase utilization of the ISS U.S. segment by providing access to academia, the commercial sector, and other Government agencies through partnerships, cost-sharing agreements, and other arrangements for research, technology development, low Earth orbit 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 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 this planet, and furthering the experience and increased understanding necessary to journey to other worlds. Innovative ISS research is of incredible value to the U.S. and its citizens, making the ISS a worthwhile investment for the country.

For additional information 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 2020

NASA has challenged the ISS O&M project to find efficiencies and reduce its budget. These efforts should begin to deliver significant savings in FY 2023 and FY 2024.

ISS SYSTEMS OPERATIONS AND MAINTENANCE

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	1117.6	--	1105.5	1079.8	1088.7	1007.5	983.1

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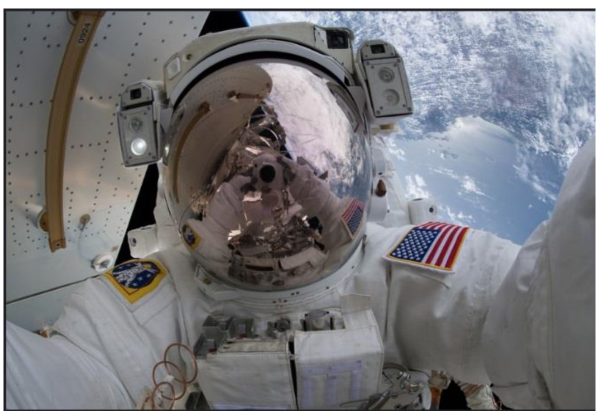

NASA astronaut Ricky Arnold is pictured during a spacewalk he conducted with fellow NASA astronaut Drew Feustel (out of frame) on June 14, 2018. During the six-hour, 49-minute spacewalk the duo installed high-definition cameras to provide enhanced views of commercial crew spacecraft, including the SpaceX Crew Dragon and the Boeing Starliner, as they approach and dock with the International Space Station.

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 critical 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 U.S. Exploration Campaign to the Moon, Mars, and beyond.

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 require 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 monitor and meticulously plan for replacement parts and consumables, such as filters and gas, as well as Orbital

ISS Systems Operations and Maintenance

Replacement Spares (ORUs) like Inlet De-ionizing Bed, Microbial Check Valves, and Multi-Filtration Beds, which are a key component of the Regenerative Environmental Control Life Support System (Regen ECLSS) System. 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 program, provides the crew training to prepare them for their stay aboard the ISS.

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 operational and available to perform its research mission at all times.

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 Gateway and for lunar surface activities.

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 of nine highly complex on-orbit systems made up of hundreds of unique Orbital Replacement Units. 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 2020

NASA has challenged the ISS O&M project to find efficiencies and reduce its budget. These efforts should begin to deliver significant savings in FY 2023 and FY 2024.

Achievements in FY 2018

The ISS Systems O&M project continued to maintain resources both on-orbit and on the ground to operate and utilize the ISS. The O&M project maintained 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 crew and cargo missions to the ISS approximately every three weeks. Each flight required extensive planning and analyses in order 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

ISS Systems Operations and Maintenance

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. This past year, one of the ISS Latching End Effectors (LEEs) failed, prompting a contingency spacewalk by the ISS crew. A LEE has three snare wires to catch the grapple fixture shaft. Canadarm2 has two LEEs, one at each end. Another LEE is on the Mobile Base System's Payload ORU Accommodations (POA) unit. The POA LEE is used to temporarily hold large ISS components. One more is on the Special Purpose Dexterous Manipulator (SPDM, also known as "Dextre" or "Canada hand"). Six LEEs have been manufactured and used in various locations on the ISS. Detailed preparation by the ground team, and coordination with the spacewalkers leading up to their task, led to a successful LEE removal and replacement to ensure continued success of ISS operations.

The team supported two Russian EVAs and eight U.S. EVAs in FY 2018. The three U.S. EVAs in October, January and February supported the LEE inspections, lubrication, and replacement. The EVA in March 2018 installed the External Wireless Communications (EWC) Antennas on Node 3. Extending EWC coverage is important for the external HD camera assemblies. The EVA in May relocated of a pair of Pump Flow Control Subassemblies between external stowage platforms for inspection/data retrieval. The PFCS is the mechanism which circulates ammonia throughout the external coolant loops. The EVA in June deployed High Definition cameras to enable video coverage of docking activity at the Node 2 forward port. Other tasks included Camera Port 8 External TV Camera Group R&R and P1 Radiator Beam Valve Module flex hose retrieval.

With a speed of 17,500 MPH and orbiting the Earth every 90 minutes, the ISS faces innumerable risks. One example, in 2018, includes the August air leak. The crew of the International Space Station worked August 30, 2018 to fix, at least temporarily, a minor air leak in a Soyuz spacecraft docked to ISS. NASA controllers first noticed a minor drop in air pressure within the station at around 7 p.m. Eastern August 29. Flight controllers allowed the crew to continue sleeping since the pressure drop did not pose an immediate risk to the crew, who were notified of the problem when they woke up at their regular time. The station's crew traced the drop in air pressure to a hole about two millimeters in diameter in the orbital module of the Soyuz MS-09 spacecraft docked to the station. They covered the hole with a piece of Kapton tape to slow the rate of the leak temporarily, then an epoxy sealant was applied which stabilized the station's internal pressure.

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 HTV 7. Due to the 56S anomaly in October 2018, the batteries are in storage and will be installed on an EVA in FY 2019.

Work in Progress in FY 2019

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. A recent example is the October 11, 2018 inflight ascent abort and safe return to Earth of the 57 Soyuz flight. Within the very early stages of flight, apparent booster separation issues triggered an automatic ballistic landing of the spacecraft. Russian search and rescue teams were deployed, and the

ISS Systems Operations and Maintenance

cosmonaut and astronaut were safe. The USOS ground crews worked diligently to adjust the schedules, logistics, and resources until the next Soyuz launch. In addition to providing anomaly resolution and failure investigation as needed, they plan and provide real-time support for activities, such as EVA and visiting vehicles.

The team plans to support two Russian EVAs and at least four U.S. EVAs in FY 2019. The first two in the series of U.S. spacewalks will focus on replacing the aging batteries with more efficient lithium-ion batteries. The EVA planned in January will install a jumper cable to provide the ISS robotic arm with backup power in the event the main power supply is lost. The April EVA 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 ISS O&M project is also planning to support the first test flights and mission with U.S. astronauts aboard Commercial Crew flights.

Key Achievements Planned for FY 2020

The ISS program will continue to work closely with the Commercial Crew Program 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 EVA and visiting vehicles.

The team will support six Russian EVAs and up to 18 U.S. EVAs in FY 2020. The U.S. EVAs will support replacing the aging batteries with more efficient lithium-ion batteries, and work on the Alpha Magnetic Spectromoter (AMS)

The NanoRacks Airlock Module is scheduled for launch in FY 2020. This is the first privately funded commercial airlock and it will increase the capability of ISS for transferring equipment, payloads, and deployable satellites. Commercial opportunities through this Airlock begin with cubesat and small satellite deployment from station and include a full range of additional services to meet customer needs from NASA and the growing commercial sector. Currently, cubesats 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 currently cannot be handled by the existing Kibo Airlock.

ISS Systems Operations and Maintenance

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
Dec 2018	Russian EVA
Mar 2019	Two U.S. EVAs
Apr 2019	U.S EVA
May 2019	Russian EVA
July 2019	U.S. EVA
Oct 2019	Russia EVA; Six U.S. EVAs
Nov 2019	Four U.S. EVAs
Mar 2020	Six U.S. EVAs
Apr 2020	Russia EVA; U.S. EVA
July 2020	U.S. EVA
Aug 2020	Three Russia EVAs
Sept 2020	Russia EVA

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, Texas 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 of the ISS segments, end-to-end subsystem management for the majority of the ISS subsystems and specialty engineering disciplines, and U.S. on-orbit segment and integrated system certification of flight readiness.

ISS Systems Operations and Maintenance

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	Aug 2018	Provides independent guidance for the NASA Administrator	No new formal recommendations or findings	2019
Other	NASA Aerospace Safety Advisory Panel	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. crew members until such time that U.S. capability to deliver crew to ISS is established.	2019

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FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**375.4**	**--**	**352.7**	**368.7**	**360.7**	**345.1**	**332.6**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

Cameras outside the International Space Station captured a stark and sobering view of Hurricane Florence the morning of September 12, 2018, as it churned across the Atlantic in a west-northwesterly direction with winds of 130 miles an hour.

International Space Station (ISS) is an orbiting platform that provides the only current capability for human-assisted space-based research and a unique venue for developing technologies for future human spaceflight exploration. ISS enables scientific investigation of physical, chemical, and biological processes in an environment very different from Earth. As a research and development (R&D) facility, ISS supports a variety of science laboratories, external testbeds, and observatory sites - both governmental as well as commercially owned and operated. The research conducted aboard ISS is an integral component of the NASA Strategic Plan where expanding human knowledge through new scientific discoveries is a focus, specifically understanding responses of physical and biological systems to spaceflight.

Research facilities onboard the space station have evolved in recent years 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 15 such facilities in operation at the start of FY 2019 and several more scheduled for deployment as discussed below. The result of these new facilities is a three times increase in the number of active investigations in FY 2018 (492) as compared to the early years of ISS operations. These commercial endeavors help optimize research capabilities and operations aboard ISS.

In addition, expanding capabilities to monitor and operate ISS facilities from the ground frees up valuable crew-time and increases the number of investigations which can be conducted while also allowing adjustments to be made to investigations as data becomes available on a more real-time and consistent

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basis. The SCORPIO-V control center in Hawaii, mentioned in the FY 2019 section as part of the HNu Photonics Mobile SpaceLab (MSL), is a good example of this. MSL will host self-contained experiments which can be controlled and monitored from Hnu's own control center on the ground – minimizing burden not only on crew-time but also any ISS ground personnel or facilities. New remote capabilities and ground facilities such as this contribute to the increasing science return generated by ISS research.

The ISS Research budget funds fundamental and applied research in biological and physical sciences as well as technology development, Earth imaging, and remote sensing activities to enable future human exploration, pioneer scientific discovery in low Earth orbit and expand our understanding of our home planet. At the conclusion of Expedition 56 in September 2018, 106 countries around the world have performed over 2,582 research investigations utilizing ISS with more than 3,400 investigators participating. Over 1,600 R&D results have been published in scientific journals and magazines based on these investigations.

The ISS Research budget also funds multi-user systems support (MUSS) activities, which provide strategic, tactical, and operational support to all NASA sponsored and non-NASA sponsored payloads, including those of the international partners, as well as operation of in-orbit and ground control research facilities. MUSS includes the development of new capabilities and technologies for ISS as well as funding to enable commercial companies to demonstrate applications of microgravity for the development of products that require production in space.

As a research and technology development facility, the ISS provides the capability for human-tended, long-duration space-based research, which is critical to the research and development of technologies supporting the Exploration Campaign. This enables scientific investigation of physical, chemical, and biological processes in an environment very different from Earth, providing new insight into aspects of fundamental physical processes masked by the powerful force of gravity. For example, in microgravity hot air doesn't "rise" and flames behave differently. Scientific investigations on ISS uncovered a new form of combustion occurring at lower temperatures (370°C [700°F] & 200°C [400°F]) than previously observed on Earth (760°C [1,400°F]). As researchers unravel the mechanisms of "cool flames," this new knowledge has the potential to lead to more-efficient, lower-emission liquid combustion engines, as well as new ways to detect and extinguish fires on Earth and in space. Another example is how gravity effects fluid flow on Earth. Fundamental fluid physics investigations on ISS have led to patents that involve technology applications associated with space exploration such as thermal control systems and liquid fuel tanks.

ISS research also supports investigations in human physiology and biotechnology. 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. Research on model systems, spanning from cell culture to rodents, also benefit from the long-term microgravity environment and yield insights relevant for both space exploration countermeasures and human health and disease on Earth.

One set of ISS investigations focused on using nanofluidics to create a new and novel drug delivery mechanism—an implantable nanochannel system capable of controlled dosage of medicines for weeks or months. This device could be approved for human use on Earth by 2021. In 2018, a version was used in an ISS rodent research investigation for delivery of a drug for treating muscle atrophy. Muscle atrophy is

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a serious concern for long-duration space missions, and this research has greatly advanced our understanding and countermeasures needed.

Examples of ongoing and planned research activities presented below, including new facilities for biomedical research, demonstrations of gene sequencing on-orbit, and NIH partnerships for tissue-chip research, show that future research activities are building upon previous findings, further expanding our understanding of the impacts on living and working in space.

Technology development activities supported by ISS research hold the promise of next-generation technologies in health and medicine; robotics, manufacturing, and propulsion; and development of applications that will benefit life on Earth. Additionally, researchers evaluate the extended performance of equipment critical to long-duration exploration missions (such as Gateway) and satellite advancements by testing the hardware's ability to survive in the space environment, determining life-limiting issues and repair capabilities, and evaluating upgrades to improve performance.

In addition to the physical and biological science activities ongoing within ISS and the materials exposure studies taking place externally, ISS Research funding supports many Earth and astronomical observation instruments mounted on the station. Data collected by ISS Earth observing instruments are another example of open-access data.

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 another way in which benefits, in terms of scientific data generated from ISS research, are maximized. ISS is the primary science platform for the Open Science Initiatives of GeneLab and Physical Sciences Informatics, these initiatives enable next generation research by creating publicly available open-access data resources. GeneLab is an open-access resource for space biology. The GeneLab team routinely processes, archives, and provides omics data to researchers around the globe. NASA's Physical Science Informatics (PSI) initiative provides a data repository for physical science experiments performed on ISS. At the start of FY 2019, the PSI system contained data sets for more than 50 previously flown experiments in the areas of Combustion Science, Complex Fluids, Fluid Physics, Fundamental Physics and Materials Science with 100's of additional data sets scheduled for upload. The ability by researchers to review the past flight data and perform analysis across different types of experiments can allow the generation of new knowledge often without the need to fly additional experiments.

The maturation of Earth observation technologies and analysis methods is another example of how products and benefits emerge from the sharing of ISS research data. Once demonstrated on the space station, new sensors, technologies, and methods of data analysis lead to better capabilities in other satellites and Earth observing platforms. For example, since 2014, Visidyne, Inc. has demonstrated the feasibility of studying powerful tropical cyclones from the ISS by measuring the altitudes of the cloud tops within the eyewall. Imagery is gathered by simply aiming a camera that is mounted within the Cupola—the dome-shaped Earth observatory of the ISS. Building on the success of the project to-date, Visidyne has formed a new commercial company with plans to use high-altitude, solar-powered vehicles and microsatellites to collect the data needed to characterize tropical cyclone eyewall clouds. Visidyne will more accurately measure storm intensities, with the goal of achieving lifesaving advancements concerning these devastating storms.

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For much of the world, real-time information on hazardous weather, such as hurricanes, typhoons, and tropical cyclones (i.e., Hurricane Florence as shown in previous photo) is not available. Earth imaging supplied by instruments on the ISS can provide real-time data to researchers, meteorologists and disaster response authorities here on the ground. By improving the accuracy of weather modeling and storm track prediction, these Earth observation data sets provide concrete benefits—both economic and quality of life.

ISS research has also spurred innovations in public-private partnerships. In the vanguard of this, the Center for the Advancement of Science in Space (CASIS) is a non-profit organization that manages the ISS U.S. National Laboratory (or Lab). Supported by the ISS Research budget and NASA’s MUSS capabilities, the ISS National Lab focuses not only on scientific advancement but also on expanding U.S. leadership in commercial space and inspiring the next generation. Under CASIS management, the ISS National Lab enables use of ISS research facilities by the scientific community, the private sector and non-NASA Government agencies to benefit the U.S. economy. Since CASIS assumed management of the ISS National Lab in 2012, 185 new-to-space users and 135 commercial researchers in the life sciences, physical sciences, technology development, and remote sensing have been selected to conduct ISS R&D activities. As described below, these numbers are expected to continue to grow in the next few years ultimately driving new market creation by building demand, enabling supply, and facilitating investment.

The ISS National Lab also provides programmatic and grant-funding support to private sector activities that support this R&D. The growing number of commercially operated facilities are supported by ISS National Lab management and represent a critical supply-side enhancement to the current LEO economy onboard the ISS. More than fifty percent of ISS National Lab grant funding directly supports these commercial facility operators in their implementation of individual ISS National Lab R&D projects. Additionally, increased use of ISS by the private sector for R&D includes projects sourced by the ISS National Lab from Apple, IBM, Lockheed Martin, Merck, Novartis, Eli Lilly, Delta Faucet, Goodyear, and others.

EXPLANATION OF MAJOR CHANGES IN FY 2020

The ISS Research budget includes an additional $5 million for Biological and Physical Sciences, which will support additional research grant awards, increasing ISS utilization and expanding the fundamental knowledge base which supports NASA's human spaceflight and Low Earth Orbit commercialization activities.

ACHIEVEMENTS IN FY 2018

FY 2018 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, 492 active investigations across all ISS partners. NASA and the ISS National Lab combined to sponsor 226 U.S. research investigations, an increase of 27 percent from the previous fiscal year.

This increase in U.S. research was due in part to an increase in available crew time by adding an additional USOS crew member starting in July 2017 through October 2018. Real-time data access for investigators and ground-control capabilities of commercial facilities also increased. However, as

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discussed later in the acquisition strategy section, efficiencies in MUSS integration activities and implementation of the new Research, Engineering, and Mission Integration Services contract (REMIS) also contributed. In FY 2018, REMIS was used for over 20 different research activities with cost savings estimated at over 50 percent as compared to prior processes allowing support for integration and operations of the increased research. Overall, this resulted in an increased capacity for research – thus increasing the return to taxpayers for ISS research dollars spent.

The ISS National Lab continued to focus on academic, private sector, and non-NASA government agency use of the ISS to benefit the U.S. economy. Private sector R&D represented more than 70 percent of the payloads delivered to the ISS National Lab in FY 2018. In addition, FY 2018 saw 50 newly selected projects and programs added to the queue. ISS National Lab new research partners in FY 2018 included Fortune 500 companies, startups, nonprofits, academia, and other government agencies, with many projects individually or sponsor-funded. Furthermore, new ISS National Lab relationships with future potential platform owners and aerospace companies (e.g., Airbus DS North America, Bigelow Space Operations, and Sierra Nevada Corporation) were an important next step toward enabling a transition from the ISS to commercial LEO platforms.

In total, the individual science and technology investigations within the ISS National Lab R&D portfolio leveraged more than $150 million in non-CASIS, non-NASA funding (a 50 percent increase from the previous year). Third-party sponsors of ISS National Lab projects include the National Institutes of Health (NIH), the National Science Foundation (NSF), and Boeing—all previous program sponsors returning to support additional R&D—as well as Teledyne Brown Engineering and Target Corporation (for a program focused on ecological sustainability). The ISS National Lab actively recruits these program-level sponsors to diversify funding for space-based science; and additionally, prioritizes for selection individual projects that commit to substantial cost sharing. For example, projects from IBM (artificial intelligence), Lockheed Martin (radiation shielding), MIT (satellite technology), Palo Alto Veteran's Research Institute (muscle loss), and University of California, Santa Barbara (soil science) are all examples of future investigations (awarded this year) that will require no ISS National Lab funding.

Two new commercially operated facilities onboard the ISS National Lab—the Multi-use Variable-gravity Platform (MVP, a centrifuge operated by Techshot, Inc.) and the Materials ISS Experiment Flight Facility (MISSE-FF, developed by new facility manager Alpha Space Test and Research Alliance, LLC)—entered service in 2018. The ISS National Lab has 14 commercially operated laboratory facilities managed by eight companies. Not only do these facilities open up R&D opportunities for more investigations which can be hosted in a given year, they mitigate business risk, serving as a training ground for private industry in learning how to conduct business in space. In effect, these commercial facilities, along with a growing diverse user base of paying customers, a diverse pool of investors, and the REMIS services contract represent a growing market economy centered around ISS research activities.

Highlights of research accomplishments in FY 2018, representing both NASA and CASIS ISS National Lab efforts included:

Four patent applications published in FY 2018, two of which were granted to Procter & Gamble (P&G) and detail advancements relevant to commercial product function and shelf life. A commercial product containing these enhancements is expected as soon as FY 2019.

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Genelab 'open source database' is sole source to two scientific articles published in high impact journals as a result of new analyses of spaceflight data. In one publication, microgravity was found to alter protein expression as well as key mechanisms involved in inflammation, repair, and death of cells lining the blood vessels of the mouse retina. The other publication identified potential "master regulators" responsible for many increased health risks in spaceflight. Both findings advance our understanding of key crew health threats for long-duration exploration and both made use of data from multiple ISS investigations, demonstrating the power of open-access databases to multiply the benefits derived from ISS research.

The BEST (Biomolecule Extraction and Sequencing Technology) investigation was the first completed test of real-time microbial analysis on ISS. DNA was extracted from microbial samples taken from ISS surfaces and sequenced to identify the types of microbes collected. The BEST investigation also implemented the first-ever direct sequencing in space of RNA (Ribonucleic acid-molecule), one of the four major macromolecules essential for all known forms of life. Previously, swabbed samples had to be returned to Earth for DNA and RNA analysis. On orbit analysis such as demonstrated in BEST is a highly-desired capability both for research and operational (crew health) use, especially for long-duration exploration missions.

The Cold Atom Laboratory (CAL) was installed and is producing clouds of ultracold atoms known as Bose-Einstein condensates (BEC). It is designed to advance scientists' ability to make precision measurements of gravity, probing long-standing problems in quantum physics (the study of the universe at the very smallest scales), and exploring the wavelike nature of matter. This facility is the first of its kind in space, and was the first time BECs have ever been produced in orbit.

The first-ever experiment modeling cryogenic fuel storage in space was conducted. Currently, storage tanks for very cold liquids either dump, or "boil off," some of their fluid to reduce excess pressure or use heavy and complex active control systems. The Zero Boil-Off Tank (ZBOT) investigation used forced jet mixing as an alternative means for controlling tank pressure. Successful use of this process could reduce overall weight and complexity of storage tanks - thus reducing launch mass and decreasing risks associated with cryogenic storage for both life support and propulsion systems for future human exploration-class missions.

Three new biological hardware systems were delivered and validated on ISS. The Advanced Plant Habitat which is using innovative environmental controls to enable advanced omics analysis provided its first crop in space and is informing how food crops may be grown on future exploration missions. Bioculture System is an incubator that supports tissue, cell and microbiological cultures with variable durations and experiment methods. Researchers can use the Bioculture System to study a wide range of biological processes in microgravity that are relevant to human health including: tissue engineering, regeneration, and wound healing. The Biological Research in Canisters (BRIC)-Light Emitting Diodes (LED) was developed as a low-cost rapid turnaround hardware enhancement to increase science output to grow a wider variety of plants with advanced imaging capabilities in a closed system.

In the Earth Sciences arena, the NASA Science Mission Directorate-sponsored instrument ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) is providing a new space-based measurement of how plants respond to changes in water availability. This data can help society better manage agricultural water use. ECOSTRESS's first images captured new imagery of variations in surface temperature patterns in the Los Angeles County area as well as new imagery of wildfires burning in California and Nevada. ECOSTRESS imagery is more detailed than previous imagery largely because ISS's orbit allows acquisition at different times of the day. Such relevant images can be shared with the International Charter for Disaster for Space and Major Disasters (https://disasterscharter.org/).

Rodent research from Houston Methodist Research Institute, in collaboration with Novartis and NanoMedical Systems, focused on muscle atrophy. As mentioned in the introductory section, this study tested an implantable drug delivery system in mice with spaceflight-induced muscle atrophy. This may rapidly translate into a commercial product to safely administer a common treatment over a long period of time without requiring daily injection, thereby improving patient quality of life.

Hewlett Packard Enterprise's (HPE) Spaceborne Computer completed one year of successful operations. This was the first long-term demonstration of supercomputing capabilities from a commercial off-the-shelf computer system in space. Also, by using software to protect against radiation upsets and power interrupts, HPE has eliminated the need for modified, highly shielded and radiation tolerant hardware, which are heavy and have less computing power than today's super computers. Exploration spacecraft will require high speed and capable super computers that are radiation and interrupt tolerant to perform the autonomous operations required of distance operations. Demonstration of this capability with off-the-shelf components means that future exploration missions will not be burdened with the costs of design and manufacture of a specialized computer system.

Made In Space completed the first-ever production of the optical fiber ZBLAN onboard the ISS, demonstrating the feasibility of in-orbit manufacturing for exotic optical fibers. ZBLAN may exceed the performance of other fibers in common use across many sectors—including medical devices, sensors for the aerospace and defense industry, and telecommunications—terrestrially produced fibers suffer from impurities that reduce performance.

Roughly 100 peer-reviewed journal articles were published in FY 2018 detailing results related to ISS research– including 17 tied to ISS National Lab investigations in the fields of biomedical research and particle physics.

Furthermore, FY 2018 saw NASA's Year of Education on Station initiative focus attention on ISS STEM engagement activities for students. This effort included 64 live downlinks (4x greater than the average per year) to U.S. schools and education-focused groups. In total, over 1000 student questions were answered by astronauts with over 300,000 students and teachers attending these events representing 29 states, Puerto Rico, the District of Columbia and Canada. Metrics indicate the social media reach of these activities exceeded two million impressions.

Additional highlights from education and outreach initiatives include:

National Geographic filmed educational content using an ISS National Lab camera for their ten-episode television series "One Strange Rock," which was watched by 81 million viewers globally.

More than two million students, parents, and educators were reached by ISS National Lab outreach activities and educational content produced and managed by the Space Station Explorers consortium.

The Guardians of the Galaxy Space Station Challenge with Marvel Entertainment—a nationwide ISS National Lab research competition—awarded two student investigations that will fly to the ISS National

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Lab. As part of this partnership, Marvel Entertainment developed two videos that explored aspects of real science within the Marvel Universe. These garnered 369,761 views on YouTube, Twitter and Facebook.

The Space Station Ambassador program for educators now consists of more than 500 members (an increase of 200 in FY 2018), offering opportunities to partner in support of ISS National Lab activities.

WORK IN PROGRESS IN FY 2019

FY 2019 planned activities continue to increase new research facilities and Earth observation instruments on ISS, piloting of new capabilities and an increasingly diverse portfolio of commercial, fundamental science, and technology demonstration investigations to be conducted. Commercial projects are expected to continue to comprise more than 50 percent of the ISS National Lab portfolio.

Among the examples of expected new facilities provided below are a mix of commercially managed and government procured. These facilities will increase capabilities in terms of cold stowage (both in-orbit and in-transit) and cell culturing. They will also pilot new concepts for in-space manufacturing as well as bio-printing of both tissues and organs.

As discussed in the introductory section, ISS National Lab partnerships leverage ISS research funding generating a greater amount of research onboard the ISS. Multi-year programs sponsored by NIH and NSF account for $30 million in currently committed grant funding for ISS National Lab projects and provide a powerful opportunity for research discoveries that fuel innovation, new-customer entry, and national prominence. Six ISS National Lab research competitions in collaboration with NIH and NSF, primarily focused on tissue engineering and fluid physics, have produced 20 projects to date, nine of which are planned for launch in FY 2019. Tissue engineering and organ-on-chip research holds promise to accelerate disease research and drug discovery, and fluid physics studies enhance design of advanced materials, electronics, nanotechnologies, and other consumer and healthcare products.

Highlights of research planned in FY 2019, representing both NASA and the ISS National Lab efforts include:

Payloads to be launched include ISS National Lab projects from Goodyear Tire and Rubber Co. (materials science), Delta Faucet (fluid physics), and AstraZeneca (biomedical studies).

Also onboard the ISS National Lab, Made In Space will continue to pursue in-orbit production of the optical fiber ZBLAN. In addition, Fiber Optics Manufacturing in Space and Physical Optics Corporation also plan to launch projects in this area in FY 2019. Initial results in FY 2018 producing high-performance ZBLAN on the ISS have been promising and could pave the way for future large-scale commercial manufacturing of ZBLAN in low Earth orbit. (The fiber optic performance of ZBLAN is such that the high cost of in-space manufacturing may be outweighed by the performance gains.)

Five projects co-sponsored by the NIH and the ISS National Lab will study human physiology research: immune aging and its effects on healing, musculoskeletal disease, the blood-brain barrier, kidney function, and lung immune response. Six investigations co-sponsored by the NSF and the ISS National Lab will study water absorption, droplet spreading, fluid flow through heat pipes, heat removal in aircraft electronics, internal combustion engine modeling, and flame propagation in confined spaces.

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To maximize science return from limited flight samples, Rodent Research Mission 8 will carry mice of two different age groups to the ISS National Lab, biospecimens from which will be later distributed to multiple investigators. Model organisms such as rodents, provide insight into effects of spaceflight that mimic human disease on Earth—for example, bone loss, muscle wasting, heart disease, and immune dysfunction—potentially improving treatments or leading to cures for diseases and aging on Earth.

Sponsored by the Science Mission Directorate (SMD), the Global Ecosystem Dynamics Investigation (GEDI) will produce the first high resolution laser ranging observations of the 3D structure of Earth. The GEDI system uses three lasers which fire 242 times per second, generating a 3D image. The precise measurements of forest canopy height, canopy vertical structure, and surface elevation expected to be generated will greatly advance our ability to characterize important carbon and water cycling processes, and biodiversity and habitat. This data will be of great value for weather forecasting, forest management, glacier and snowpack monitoring, and generation of more accurate digital elevation models.

Also sponsored by SMD, the Orbiting Carbon Observatory-3 (OCO-3) will retrieve vital climate change data. Data obtained is expected to have the precision, resolution, and coverage needed to improve the understanding of CO2 sources and sinks on regional scales (≥1000 km), and refine the significance of human-caused and natural fluxes on this important greenhouse gas.

The Robotic Refueling Mission 3 technology demonstration will test in-space rocket propellant transfer technology. These new technologies, tools, and techniques could eventually give satellite owners resources to diagnose problems on orbit, fix anomalies, and keep certain spacecraft instruments performing longer in space by refueling them during their lifetime.

Each year new facilities expand the R&D capabilities of the ISS National Lab, allowing an increasingly wider range of experiments to be conducted. In FY 2019 several new commercial facilities and tools are expected to become operational:

MicroQ Technologies has applied its expertise in temperature-controlled shipping solutions on Earth to create storage devices that will maintain a controlled temperature environment for experiments as they travel to and from the station. These storage devices will also be capable of running on battery, freeing up limited electrical capacity for other uses, and will have the ability to charge their battery during lower electrical usage periods – a useful capability for long-duration exploration missions.

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. Turbine SCM will expand utilization of the ISS into new commercial product areas not previously investigated. Single-piece turbine blisks have significant advantages over early heritage turbine disk/blade assemblies used in aircraft jet engines and integrated rotors. If produced successfully in microgravity, additional gains can be made in the areas of part mass, residual stress and fatigue.

As mentioned in the introduction, Hnu’s Mobile SpaceLab is a tissue and cell culturing facility that will provide investigators a quick-turnaround, configurable platform to perform sophisticated microgravity biology investigations. Biology experiments can be performed for up to a month without the need for crew operations. New facilities, such as this, contribute to the increasing science return generated by ISS research.

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Techshot's BioFabrication Facility (BFF) will be dedicated to manufacturing human organs and tissues in space, with eventual primary use by patients on Earth. Currently, 22 people (on average) die while on the transplant list each day due to organ shortages. Microgravity may be the missing component required to finally realize the potential of three dimensional printed bioengineered organs as the support structures required on Earth to counter gravity can be eliminated in a microgravity environment. Besides printing tissue, the BFF also could help maintain the health of deep space exploration crews by producing food and personalized pharmaceuticals on demand.

The Life Sciences Glovebox (LSG) will be delivered to ISS as a sealed work area that accommodates life science and technology investigations in a "workbench" type environment. It will provide a 2-person space for conducting rodent operations. The LSG can be used with on-orbit support equipment—including the Bar Code Reader, the Incubator, Cryosystem Vial Freezer (-180ºC), and the Passive Dosimeter for measuring biologically active space radiation during an experiment.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

New processes for payload development and integration 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. Now in its full implementation, improved timelines are meeting the demands of its users, resulting in quicker payload deliveries to ISS (within months in many cases). This transition in payloads planning and processing is also bolstering the value proposition of space-based research and development. Private sector users looking to leverage space-based activities to accelerate time to market for product enhancements have a rapid path from project concept to flight. Similarly, research sponsored by NASA and by commercial entities or 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. This change in flight process has altered the way payloads are manifested, and as a result, the full flight manifest for FY 2020 is still in development. However, key highlights of planned progress and upcoming investigations expected to fly in FY 2020 include:

The Flow 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 Flame Design investigation 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.

The Rodent Research-18 investigation will determine the extent to which an antioxidant, metalloporphyrin, protects against spaceflight changes in retinal function, which could lead to a new countermeasure for exploration and inform possible treatments of similar Earth-based neurovascular-related diseases and retinal disorders.

The Rodent Research-10 investigation will seek to understand the role of gene CDKN1a/p21 in the arrest of bone regeneration that is observed during microgravity exposure/unloading in an effort to mitigate bone loss in long-duration spaceflight. This research also has implications for the treatment of bone-loss

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disease on Earth, and potential mitigation strategies for the astronauts in the NASA Exploration Campaign.

The Plant Habitat-02 study will investigate the total effects of the space environment including weightlessness, radiation, and altered magnetic shielding on growth, nutritional quality, mineral uptake and viability of radish to better understand bioregenerative life support options and potential food sources for long duration space missions.

The Veggie-05 investigation will study bioregenerative food production systems for the space station and long-duration exploration missions and test specific pick and eat crops for micronutrient delivery and consumption using foods like mizuna and tomatoes.

The CO-04 investigation will fly the tardigrade, Hypsibius dujardini, (water bear) to ISS identify both immediate and multigenerational changes in global gene expression induced by space environments in an effort to understand biological responses to stress. Tardigrades are among the most resilient known animals with individual species able to survive extreme conditions that would be rapidly fatal to nearly all other known life forms. They have a compact and well documented genome and a generation time of about two weeks. It can also be cultured indefinitely and cryopreserved, making it an ideal species to study biological responses to the space environment.

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 Water Capture Device will test a new water separation technology capable of operating with various condensing heat exchanger surface properties, resulting in new microgravity data that will inform the development of future exploration Environmental Control and Life Support (ECLSS) Systems.

The ISS National Lab will also continue development of R&D programs to further enable economic development of the LEO platform market, continuing its focus on highly innovative programs with high-impact potential to enable specific markets. Key ISS National Lab R&D focus areas that address larger challenges with terrestrial implications and potential future manufacturing capabilities include advanced materials and tissue engineering:

Advanced materials drive technology innovation and how we communicate and construct the built environment around us. Several NSF-sponsored projects in this area are likely to fly in FY 2020.

Tissue engineering and regenerative medicine improve human health and longevity, and FY 2020 flight projects from multiple sponsors, including both NIH and NSF, will explore a range of related topics from stem cell biology to 3D printing.

Additionally, the ISS National Lab will continue to leverage non-NASA, non-CASIS funding, with a goal of reaching $200 million by year-end FY 2020—more than 2 times the funding provided. ISS National Lab contractual relationships with diverse aerospace companies are expected to multiply and expand in support of future low Earth orbit platforms capable of assisting long-term research and technology development initiatives. In partnership with NASA, the ISS National Lab supports the commercialization of low Earth orbit and the private sector participants working toward that future.

Commercial facility enhancements and additions expected for FY 2020 span the fields of physical sciences, biosciences, and remote sensing/tech development:

Following up on the FY 2019 proof-of-concept work on the Turbine SCM, Made In Space's Turbine CMM begins operation in 2020. This facility allows manufacturing of single-piece ceramic turbine blisk (blade/disk combination) in microgravity for commercial use on Earth. With this facility, both superalloy and ceramic turbine blisk manufacture will have been tested in microgravity.

Hnu plans to continue state-of-the art and remotely controllable microspcopy capabilities aboard the ISS. The Microscopy SpaceLab facility will be a versatile imaging platform for physical and life sciences investigations, in near real-time, with high-resolution bright-field, fluorescence, polarized, confocal and 3D microscopy capabilities. The Microscopy SpaceLab platform will be an integrated, automated, stand-alone measurement instrument with full computational and analytical capabilities.

NanoRacks Bishop Airlock will be the first commercial airlock to operate on ISS and is expected to increase capabilities in both R&D as well as station operations. (An airlock is a module used to transfer payloads, including cubesats, between the interior and exterior of the space station.) The Bishop airlock will have five times more capacity than the current airlock, will increase ISS capacity to downlink data from external instruments, and will accommodate larger satellites (up to 150 kilograms). Technology development and proof-of-concept missions using 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.

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 kg) and small satellites (200–500 kg) 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. The system also has the capacity to deploy a large volume of nanosatellites within a single deployment cycle, supporting frequent and reliable deployment opportunities.

Project Schedule

An increment is a period of time for ISS operations that spans from one Soyuz undock to the next Soyuz undock. There are four increments per year that consist of cargo ship arrivals and departures, as well as activities performed on-board, including the research performed. The table below outlines tentative planned start dates of the upcoming increments to ISS.

Date	Significant Event
Oct 2018	Increment 57
Dec 2018	Increment 58
Mar 2019	Increment 59

ISS RESEARCH

Date	Significant Event
Jun 2019	Increment 60
Oct 2019	Increment 61
Dec 2019	Increment 62
Mar 2020	Increment 63

Project Management & Commitments

Prioritization of research is an important component of maximizing the return from ISS Research funding. The Space, Life, and Physical Sciences Research and Applications Division at NASA Headquarters manages Biological and Physical Sciences (BPS) research. The division, working closely with the Office of the Chief Scientist, establishes the overall direction and scope, budget, and resource allocation for the project, which the NASA Centers implement. Recommendations from experts at the National Academy of Sciences (NAS) drive NASA's strategy for implementing BPS research. These recommendations are documented 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." The ISS program office is the interface with CASIS and manages other ISS Research activities such as MUSS and National Lab enabling activities.

Within NASA, mission directorates also prioritize their research investments based on exploration roadmaps for technologies needed to support NASA's National Space Exploration Campaign goals and recommendations from the relevant National Academies of Science, Engineering and Medicine decadal surveys.

Element	Description	Provider Details	Change from Formulation Agreement
Biological and Physical Sciences	This element includes all 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

ISS RESEARCH

Element	Description	Provider Details	Change from Formulation Agreement
MUSS (includes National Lab activities)	MUSS activities support all research on ISS, both NASA sponsored and non-NASA sponsored.	Provider: ISS program and contractors Lead Center: JSC Performing Center(s): MSFC, ARC, GRC, KSC, JPL Cost Share Partner(s): N/A	N/A

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 selected CASIS to manage non-NASA ISS Research activities. This independent non-profit will further develop national uses of ISS.

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. Biological and Physical Sciences 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 Lab.

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 Lab Management Entity	CASIS	Melbourne, FL

ISS RESEARCH

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	NASA Advisory Council	Aug 2018	Provides independent guidance for NASA Administrator	No new formal recommendations or findings for ISS	2019
Other	NASA Aerospace Safety Advisory Panel	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. crew members until such time that US capability to deliver crew to ISS is established.	2019
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 HEO to increase the scientific productivity of ISS research	2021

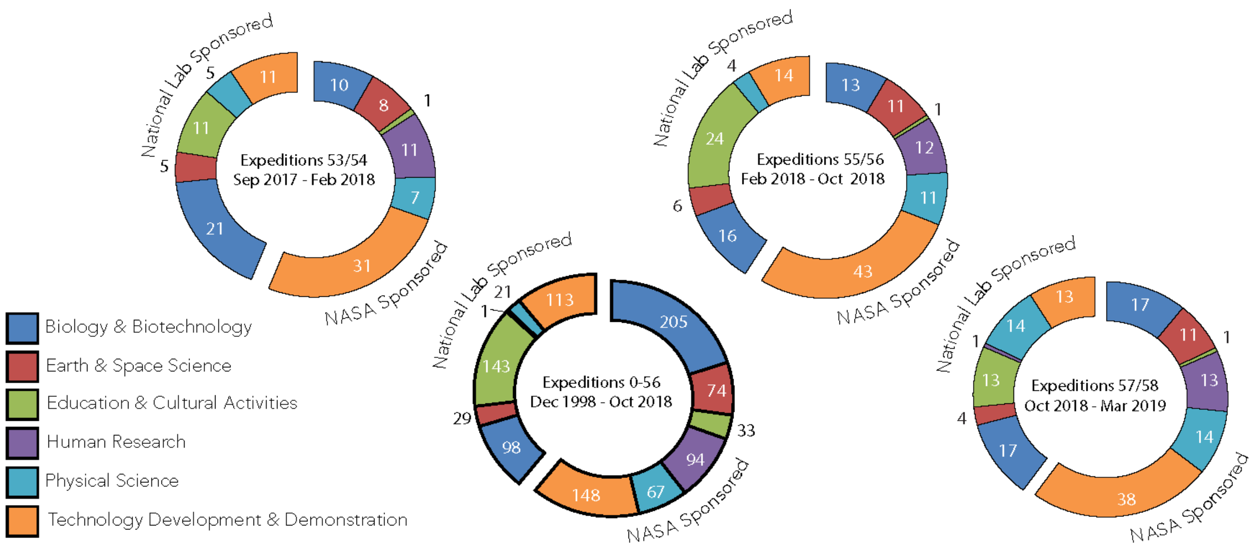
HISTORICAL PERFORMANCE

In FY 2018, NASA estimates ISS partners performed 479 research and technology investigations, including 191 new investigations. During this period, NASA estimates that NASA performed 233 investigations, including 134 new investigations. The charts below display historical data, by partner agency, for research investigations performed on ISS since 1998, and a comparison of FY 2018 NASA-sponsored and National Lab-sponsored investigations.

Research Disciplines of ISS Investigations by Partner Agencies
Expeditions 0-56
December 1998 – October 2018

ISS RESEARCH

Investigations by Research Discipline



SPACE TRANSPORTATION

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Crew and Cargo Program	1613.9	--	**1726.6**	1789.6	1751.2	1683.0	1662.6
Commercial Crew Program	731.9	--	**102.0**	64.5	63.2	63.2	64.6
Total Budget	**2345.8**	**--**	**1828.6**	**1854.1**	**1814.5**	**1746.2**	**1727.2**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

The Northrop Grumman (formerly Orbital ATK) Cygnus resupply ship and its UltraFlex solar arrays figure prominently in this photograph of several ISS components with Earth in the background. At left are a set of basketball court-sized solar arrays. In the foreground is the Cupola and a portion of the Tranquility module. At right is the Soyuz MS-09 spacecraft docked to the Rassvet module.

Insert Space Transportation theme's objective is to transport U.S. astronauts and cargo safely back and forth to space, including America's national laboratory in LEO, 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 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 related activities, such as integration work required to ensure that these visiting vehicles can safely dock or berth to ISS and hardware like the NASA docking system.

SPACE TRANSPORTATION

EXPLANATION OF MAJOR CHANGES IN FY 2020

None.

CREW AND CARGO PROGRAM

Formulation	Development	Operations

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	1613.9	--	1726.6	1789.6	1751.2	1683.0	1662.6

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

The SpaceX Dragon cargo craft is pictured in the grips of the Canadarm2 robotic arm as the International Space Station was orbiting across the central coast of Namibia. Dragon was later released for its splashdown in the Pacific Ocean off the coast of California on May 5, 2018 ending the SpaceX CRS-14 mission.

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, critical supplies and maintenance hardware, but also rotate crewmembers, return critical 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. 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 SpaceX under the original Commercial Resupply Services (CRS) contracts, which will end in 2020. These cargo vehicles provide between 2200 kg - 3400 kg each mission. The cargo provided to the ISS includes crew supplies, operations hardware and numerous science research and technology demonstration investigations. In 2018 for increments 55/56, 237 investigations were performed with 96 of those investigations led by International Partners.

Northrop Grumman, SpaceX, and Sierra Nevada started work under the follow-on CRS-2 contracts for missions beginning in 2020. For these commercial cargo flights to ISS, SpaceX currently and Sierra Nevada will in the future, launch CRS missions from Cape Canaveral, Florida. Both of these providers also have or will have the capability to return science experiments to Earth. SpaceX uses their Falcon 9 rocket to launch their Dragon cargo vehicle, while Sierra Nevada will use the Atlas V rocket to launch their Dream Chaser cargo vehicle. Northrop Grumman primarily launches their Cygnus cargo module on their Antares rocket from the Mid-Atlantic Regional Spaceport at NASA's Wallops Flight Facility (WFF) in Virginia. However, Northrop Grumman has also launched CRS missions on Atlas V rockets from Cape Canaveral, Florida. Northrop Grumman provides trash disposal and conducts additional experiments before the Cygnus spacecraft burns up in the atmosphere after leaving ISS. This is a critical capability to provide studies for fire suppression, launching small satellites at high altitude or other experiments not suited for ISS on board operation. The Crew and Cargo budget supports all milestone payments for these contracted flights to provide for cargo transportation, 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 has yielded a cost savings for 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 improve the CRS-2 contract vehicle and in other programs, such as Gateway, to expand the successful use of public-private partnerships.

Crew transportation is currently provided using the Russian Soyuz vehicle. NASA will continue to use Soyuz for crew transportation until a domestic capability is available. NASA has purchased Soyuz crew transportation services through both the Russian Roscosmos State Corporation and through 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 initial Post Certification Missions (i.e., crew missions) to the ISS; subsequent missions are funded by the Crew and Cargo Program. The first Post Certification Mission to ISS is scheduled for FY 2019.

The Crew and Cargo Program also funds activities supporting visiting vehicles that provide transportation for the ISS, including integration activities and the Low Earth Orbit version of the NASA docking system.

EXPLANATION OF MAJOR CHANGES IN FY 2020

None.

ACHIEVEMENTS IN FY 2018

Northrop Grumman (NG) completed 11 CRS milestones in support of seven commercial resupply flights, including milestones for successful completion of two flights in FY 2018. SpaceX (SpX) completed 17 CRS milestones in support of ten commercial resupply flights, including milestones for the successful

Formulation	Development	Operations

completion of three flights in FY 2018. Under CRS-2, Northrop Grumman, Sierra Nevada, and SpaceX continued to perform integration milestones to complete four milestones collectively. SpaceX has successfully completed milestones through their Preliminary Design Reviews, while Northrop Grumman completed milestones through their Critical Design Review (CDR). Sierra Nevada completed its vehicle drop test which solidified several design aspects for its CRS-2 vehicle as they proceed to CDR. 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.

Starting in March of 2017, Roscosmos reduced their crew size on the Russian segment from three to two cosmonauts until late FY 2018. This provided an opportunity to purchase additional Soyuz crew transportation in order to increase research capability on the ISS. Boeing acquired the rights to these vacant seats, which were then procured by NASA from Boeing. As a result, beginning in September of 2017, NASA increased the U.S. operating segment (USOS) crewmembers on ISS from three to four through October 2018. In total the program supported three Soyuz launches. The program also supported three Progress launches (Russian cargo vehicle) and one HTV (Japanese cargo vehicle) launch that are not funded by NASA.

WORK IN PROGRESS IN FY 2019

NASA expects five commercial resupply flights to deliver research and logistics hardware in FY 2019. Northrop Grumman plans to launch two CRS flights and complete nine milestones in support of six CRS/CRS-2 flights. SpaceX plans to launch three CRS flights and complete 16 performance milestones in support of nine CRS/CRS-2 flights. Sierra Nevada plans to complete three performance milestones in support of two CRS-2 flights. The program will also continue funding CCtCap contract milestones for crew missions with Boeing and SpaceX. Currently those missions are planned to begin in August 2019.

To achieve these planned FY 2019 flights, NASA personnel are reviewing and concurring on 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 closure of all spacecraft requirements by reviewing test and analysis data provided by the CRS contractors.

To ensure a stable crew plan, NASA exercised an option with Boeing which provides Soyuz crew transportation services for three USOS crew members in 2019. NASA is also considering contracting with Roscosmos for two additional Soyuz seats and associated services, one in the fall of 2019 and one in the spring of 2020. Currently, domestic crew capability is scheduled to become available in August 2019 for SpaceX and in December 2019 for Boeing. However, past experience has shown the difficulties associated with achieving first flights on time in the final year of development. Typically, problems will be discovered during these test flights. The consequences of no US crew on ISS warrant protection by acquiring additional seats. The absence of U.S. crewmembers at any point would diminish ISS operations to an inoperable state.

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

Formulation	Development	Operations

initiated enabling the safe return of the crew. A thorough investigation was completed by a Roscosmos commission, identifying the cause of the anomaly being 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.

The program will support a total of five Soyuz launches, including the aborted mission. The program will also support three Progress launches and one HTV launch that are not funded by NASA.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

The Crew and Cargo program will enable continued research and technology development by providing a stable crew and cargo flight plan. Once U.S. commercial crew launch services become available, NASA will be able to permanently increase the crew size on the USOS from three astronauts to four astronauts. On average, this will double the total number of hours of crew time allocated to perform research on board 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 more frequently to reduce risk and accomplish more research.

To achieve these planned FY 2020 flights, NASA personnel are reviewing and concurring on 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 closure of all spacecraft requirements by reviewing test and analysis data provided by the CRS contractors.

NASA expects six commercial resupply flights to deliver research and logistics hardware in FY 2020, including the first CRS-2 flights. Northrop Grumman plans to launch two commercial resupply flights and complete ten performance milestones in support of five CRS/CRS-2 flights. SpaceX plans to launch three commercial resupply flights and complete 13 performance milestones in support of seven CRS/CRS-2 flights. Sierra Nevada plans to launch one commercial resupply flight and complete three performance milestones in support of two CRS-2 flights. 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. They will also support the increased research and investigations enabled by the additional astronaut once commercial crew is available. The flight schedule also includes two Soyuz launches, three Progress launches, and one HTV launch 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 2019 and FY 2020. 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.

CREW AND CARGO PROGRAM

Formulation	Development	Operations

Date	Significant Event
Oct 2018	Soyuz 56S (aborted)
Nov 2018	Progress 71P
Nov 2018	NG-10
Dec 2018	Soyuz 57S
Dec 2018	SpX-16
Mar 2019	Soyuz 58S
Apr 2019	Progress 72P
Apr 2019	NG-11
Apr 2019	SpX-17
Jul 2019	SpX-18
Jul 2019	Soyuz 59S
Jul 2019	Progress 73P
Aug 2019	U.S. Crew Vehicle -1
Aug 2019	Soyuz 60S
Sep 2019	Soyuz 61S
Sep 2019	HTV-8
Oct 2019	NG-12
Dec 2019	SpX-19
Dec 2019	Progress 74P
Dec 2019	U.S. Crew Vehicle -2
Dec 2019	U.S. Crew Vehicle -3
Feb 2020	Progress 75P
Feb 2020	HTV-9
Mar 2020	SpX-20
Apr 2020	U.S. Crew Vehicle -4
Apr 2020	NG-13

CREW AND CARGO PROGRAM

Formulation	Development	Operations

Date	Significant Event
Apr 2020	Soyuz 62S
Jun 2020	3R (Russian Proton launch of Multipurpose Laboratory Module)
Jul 2020	Progress 76P
Aug 2020	SpX-21
Sep 2020	SNC-1

Project Management & Commitments

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 will be used for crew transportation to ISS either though Roscosmos or Boeing. Once available, commercial crew transportation will be provided by Boeing and SpaceX.	Provider: Roscosmos; Boeing; SpaceX Lead Centers: JSC, KSC Performing Center(s): N/A Cost Share Partner(s): Canadian Space Agency (CSA), European Space Agency (ESA), and 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

CREW AND CARGO PROGRAM

Formulation	Development	Operations

Grumman), Sierra Nevada, and SpaceX with cargo transportation services planned to begin in FY 2020. Like the current CRS contracts, CRS-2 contracts are milestone-based, fixed-price indefinite delivery/indefinite quantity (IDIQ) contracts.

NASA has purchased crew launches from Roscosmos through 2018, and crew rescue and return through mid-2019. In addition, 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 provides Soyuz crew transportation services for three USOS crew members in 2019 to ensure a stable crew plan until domestic commercial crew services are available.

In September 2014, NASA's CCP awarded CCtCap contracts to Boeing and SpaceX for commercial crew transportation. CCP is funding milestones on the initial Post Certification Missions. The Crew and Cargo program will fund the subsequent missions. These crewed vehicles will provide a minimum of 220 pounds of cargo as specified by the ISS program.

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	Aug 2018	Provides independent guidance for the NASA Administrator	No new formal recommendations or findings for the ISS	2019

CREW AND CARGO PROGRAM

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	NASA Aerospace Safety Advisory Panel	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. crew members until such time that U.S. capability to deliver crew to ISS is established.	2019

COMMERCIAL CREW PROGRAM

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	731.9	--	102.0	64.5	63.2	63.2	64.6

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

SpaceX Falcon 9 rocket lifts off from Launch Complex 39A at NASA's Kennedy Space Center in Florida for Demo-1, the first uncrewed mission of the Commercial Crew Program. (March 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 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.

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) to partner with domestic companies capable of contributing to the development of a U.S. human spaceflight capability. 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.

COMMERCIAL CREW PROGRAM

CCP entered the final certification phase in late 2014 with the award of two Commercial Crew transportation Capability (CCtCap) contracts. 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, such as controlling costs in the long term and maximizing crew safety, as reinforced in statements by the Government Accountability Office, Aerospace Safety Advisory Panel (ASAP), and NASA Office of Inspector General. 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 providing a strong incentive to perform and does not leave the Government dependent on a sole partner, thereby generally producing lower prices 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 just NASA.

The CCtCap awards represent a significant milestone in U.S. human spaceflight, with the goal of ending our sole reliance on foreign crew transportation to the ISS, and certification of safe, cost-effective U.S. commercial crew transportation systems. In addition, this approach helps stimulate growth of new space transportation industry capabilities available to all potential customers, strengthening America's space industrial base and providing 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) for a total of two. Subsequent PCMs, currently planned in FY 2020 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 2020

None.

COMMERCIAL CREW PROGRAM

ACHIEVEMENTS IN FY 2018

NASA's Commercial Crew Program and commercial partners, Boeing and SpaceX made significant strides in FY 2018 to return human spaceflight launch capabilities to the United States. Under CCtCap development activities, each company continued to develop, test, and integrate their unique space transportation systems to fly astronauts to and from the ISS.

Nine U.S. astronauts, eight NASA and one from Boeing, were assigned to the first test flights and operational missions for Boeing’s CST-100 Starliner and SpaceX’s Crew Dragon in partnership with NASA’s Commercial Crew Program. The astronauts, who will launch aboard new American-made spacecraft and rocket systems, will be the first humans launched from the United States since 2011. Selected astronauts engaged in various training simulations to rehearse each phase of CCP flights, as well as lent their unique expertise, participated in spacesuit checkouts, and practiced interfacing with the provider systems.

Three Boeing Starliners are in production inside the Commercial Crew and Cargo Processing Facility at NASA's Kennedy Space Center (KSC) in Florida. Designed for landing on land, making it reusable up to ten times with a six-month turnaround time between launches, Boeing, NASA and U.S. Army teams rehearsed safely bringing the Starliner spacecraft home to Earth at the White Sands Missile Range in New Mexico. Boeing also completed several design, development, test and evaluation activities in FY 2018, including the ISS Design Certification Review and the Service Module Hot Fire Test.

Boeing is developing the Starliner to fly on the United Launch Alliance (ULA) Atlas V rocket from Space Launch Complex 41 on Cape Canaveral Air Force Station in Florida. In FY 2018, ULA installed the white room, which astronauts will walk through just before boarding Starliner. At the ULA facility in Decatur, Alabama, the company completed the dual engine Centaur for the Atlas V rocket that will launch Starliner in the uncrewed orbital flight test in 2019.

SpaceX continued manufacturing the Crew Dragon spacecraft inside the company’s headquarters and manufacturing facility in Hawthorne, California. In total, SpaceX has six Crew Dragon modules in various stages of production, testing, and integration. This includes a qualification module, a life support system testing module, two spacecrafts for flight tests and two for fully operational missions. This year, SpaceX completed several design, development, test, and evaluation activities, including environmental testing on the Crew Dragon, Merlin engine qualification testing, and vehicle integration checkpoint testing for their uncrewed and crewed demonstrations flights.

At the historic Launch Complex 39A (LC-39A) at KSC, SpaceX installed its Crew Access Arm to provide a bridge between the crew access tower and SpaceX's Crew Dragon spacecraft for astronauts flying to the space station on the company's Falcon 9 rocket. A white room and other structural upgrades were also completed.

Boeing and SpaceX continued test on their respective spacesuits, including flight-suit fit-check tests, to ensure suits perform as designed to meet NASA's safety and functionality requirements.

Both CCtCap partners have experienced some delays that are typical in a complex spaceflight development effort. This is a large, complex development effort whereby the partners are expected to conform to a set of requirements in a fixed price contract. Also, there is a large amount of work required of NASA to verify and validate all requirements have been met. These challenges have resulted in

COMMERCIAL CREW PROGRAM

additional schedule adjustments over the past year, specifically, the uncrewed and crewed test flights for both partners slipped to FY 2019.

Under the previously mentioned CCDev2 and CCiCap SAAs, NASA provides expertise and insight into the partners' spaceflight designs. CCP continued work with Blue Origin and Sierra Nevada to develop and refine their respective spacecraft and launch systems. Sierra Nevada's Dream Chaser spacecraft completed a free flight test at NASA's Armstrong Flight Research Center located on Edwards Air Force Base in California. The tests led to the completion of a major milestone in FY 2018 under CCiCap.

WORK IN PROGRESS IN FY 2019

While technical challenges remain, CCP has dedicated additional resources to both partners that are, focusing on working together to make well-informed, risk-based decisions while leveraging all available resources and data. Boeing and SpaceX are planning to complete several significant CCtCap milestones necessary to develop and test their crew transportation systems. To meet NASA's requirements, the commercial partners must demonstrate that their systems are ready to begin regular flights to ISS.

Two of those demonstrations are uncrewed flight tests, known as Orbital Flight Test for Boeing and Demonstration Mission 1 for SpaceX. Following the uncrewed flight tests, each company is scheduled to carry out a flight test with crew prior to being certified by NASA for operational crew rotation missions. In preparation for these uncrewed and crewed test flights, the primary focus for FY 2019 will be on hardware and qualification testing, vehicle integration testing, flight readiness, and final verifications.

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 United Launch Alliance will make final preparations to the launch pad to ready the Atlas V complex for human spaceflight.

SpaceX will continue design, development, test and evaluation work on their Crew Dragon spacecraft modules the company currently has in various stages of production and testing. Upgrades to LC-39A to support upcoming commercial crew missions will also continue in FY 2019. SpaceX will also continue progress toward completing their final CCiCap milestone, In-flight Abort Test.

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 will complete their uncrewed and crewed demonstration missions in FY 2019. After successful completion of the flight tests with crew, NASA will review flight data to verify the systems meet certification requirements and are ready to begin regular servicing missions to the space station. SpaceX is on contract to complete certification and fly their first post certification mission by August 2019.

NASA will continue to use Soyuz for crew transportation until a domestic capability is available. To ensure a stable crew plan, NASA exercised an option that provides Soyuz crew transportation services for three USOS crew members in 2019. NASA is also considering contracting for two additional Soyuz seats and associated services, one in the Fall of 2019 and one in the Spring of 2020.

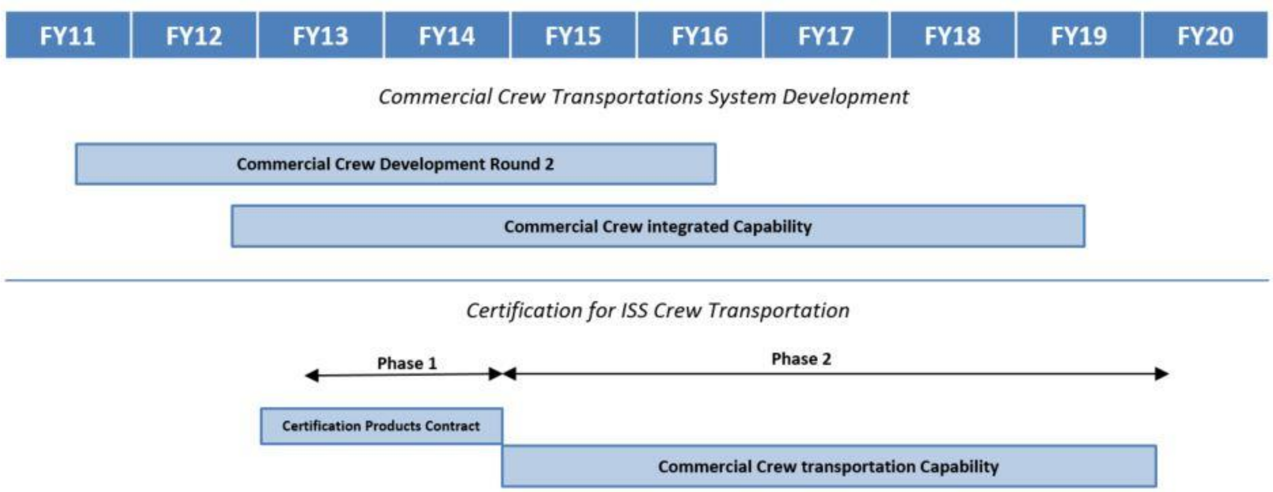
COMMERCIAL CREW PROGRAM

KEY ACHIEVEMENTS PLANNED FOR FY 2020

Boeing is on contract to complete certification by October 2019 and fly their first post certification mission by December 2019. With CCtCap development and certification 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.

Program Schedule

Progression of Commercial Crew development efforts.



COMMERCIAL CREW PROGRAM

Program Management & Commitments

The 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, are 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	Provider: 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 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 vehicle or spacecraft. Subsequently, NASA continued this effort with CCiCap SAA 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 Certification Products Contracts (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, and 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 allows for compliance with NASA's existing mission and safety requirements for transporting crew to and from ISS.

COMMERCIAL CREW PROGRAM

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	NASA Advisory Council	Dec 2018	Provide independent guidance for the NASA Administrator	No new formal recommendations or findings.	2019
Other	ASAP	Oct 2018	Provide independent assessments of safety to the NASA Administrator	ASAP recommended that NASA should confirm and then clearly communicate the required content and configuration for the upcoming CCP test flights (Demo-1 and OFT), specifically those items that must be successfully demonstrated prior to the first crewed flights.	2019
Other	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.	Fall 2019

Historical Performance

Through FY 2018 (funded milestones only).

As of September 30, 2018

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

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	40	2,168.4	29	1,642.0	73%	76%	Active
SpaceX	28	1,206.9	18	825.1	64%	68%	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 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Space Communications Networks	560.2	--	**468.1**	483.4	457.5	448.3	448.6
Space Communications Support	78.7	--	**142.9**	149.0	135.5	114.6	108.5
Total Budget	**638.8**	**--**	**611.0**	**632.4**	**593.0**	**562.9**	**557.0**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

The skeleton of the antenna reflector of the Deep Space Station - 56 (DSS-56) was lifted on its pedestal in November 2018.

DSS-56 is one of two new 34 meter antennas being built in the Madrid Deep Space Communications Complex.

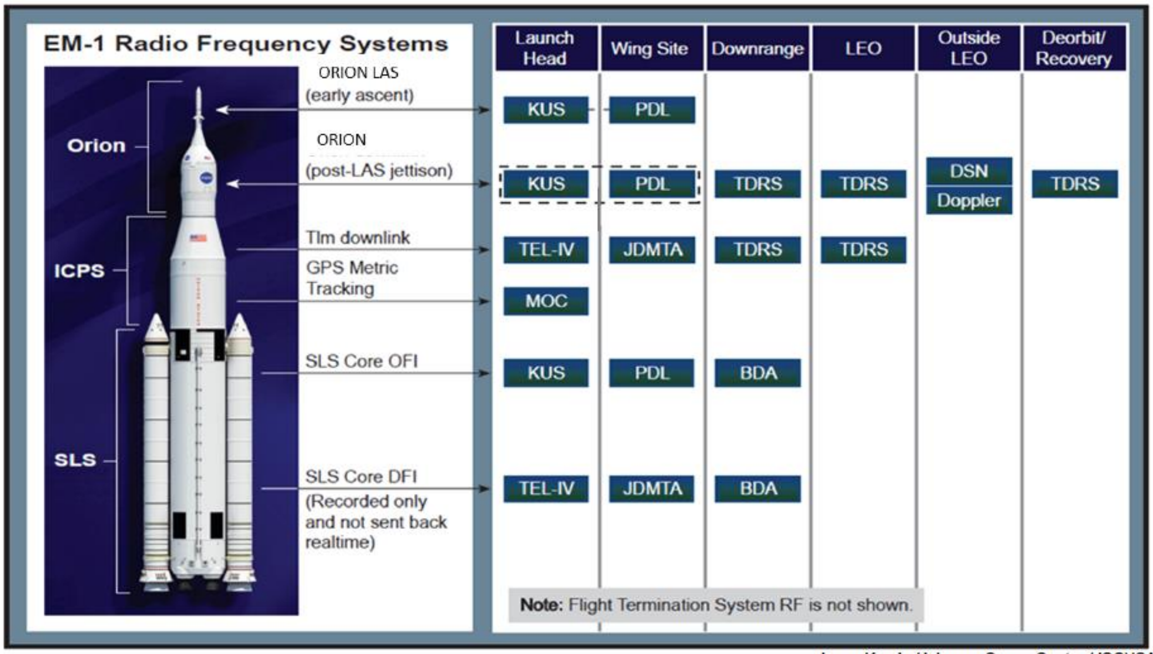
NASA's space communication and navigation capabilities provide mission-critical communications and navigation required by all NASA spaceflight missions. These missions range from high altitude balloons, to satellites in low Earth orbit (LEO), to the most distant manmade object – which is currently over 13 billion miles from Earth — Voyager 1. SCaN retrieves science, spacecraft, and crew health data for all of these missions, uploads commands and sends data to individual control centers. Navigation services determine the precise location of a satellite in order to enable course changes, interpret science data, and position the spacecraft for communication opportunities.

Without services to move data and commands between spacecraft and Earth, customer missions and space hardware worth tens of billions of dollars would be little more than orbital debris. SCaN provides secure, reliable, and adaptable communication services to NASA internal customers, as well as external customers who rely on these space communications capabilities 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 customer missions.

In the future, all three networks will support Commercial Crew providers and launches of the Space Launch System (SLS) and Orion spacecraft as seen in the following diagram. Ponce De Leon (PDL), Kennedy Uplink Station (KUS), and Bermuda (BDA) items seen in the diagram are all systems included in NEN's Launch Communications Segment (LCS)

SPACE COMMUNICATIONS AND NAVIGATION



Jason Kruska/Johnson Space Center (JSC)/CA3
Not SBU

The SN communicates with missions in LEO, such as the Hubble Space Telescope, and provides constant communication with ISS, as well as its commercial and international partner servicing vehicles. The NEN, which supports a number of science and weather missions, communicates with suborbital missions and missions in LEO, highly elliptical Earth orbits, and some lunar orbits which cannot be supported by the SN. The NEN supports a number of science and weather missions. DSN communicates with the most distant missions, such as interplanetary probes.

The three networks require maintenance, replenishment, modernization, and capacity expansion to ensure continued operation. The SCaN program also includes support to ground communications links that move data between ground stations, NASA centers, data centers, and mission operation centers. 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 conjunction. SCaN is working to upgrade this capability to a distance of 42 million miles, which increases the time to develop viable solutions to avoid orbital collision.

Currently, the NEN uses public-private partnerships to support its various customers. The NEN makes use of a mix of Government-owned and commercial ground antennas in order to maximize the network's geographic coverage, minimize the impact of weather-related communications disruptions, and effectively manage financial resources.

Space Communications Support provides efficient planning and integration of current and future network capabilities to meet customer mission needs while reducing costs. These include systems engineering, architecture planning, communications data standards, technology development, testbeds for future capabilities, radio frequency spectrum management, and navigation policy.

SPACE COMMUNICATIONS AND NAVIGATION

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 3G and 4G 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 missions.

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

EXPLANATION OF MAJOR CHANGES IN FY 2020

NASA is developing a strategy to transition from the government-owned and operated Space Network (SN) to a future architecture based on a mix of commercial services and capabilities. The newly proposed Communication Services Program will be responsible for architecture planning and acquisition management for next-generation near-Earth communications networks.

SPACE COMMUNICATIONS NETWORKS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**560.2**	**--**	**468.1**	**483.4**	**457.5**	**448.3**	**448.6**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

The White Sands Ground Terminal in Las Cruces, New Mexico, comprises several antennas that provide communications to spacecraft as part of NASA's Space Network. The Space Network Ground Segment Sustainment (SGSS) project is managing upgrades to SN ground stations which will increase data rates and volumes, improve data quality and user coverage, reduce maintenance requirements and extend the system's longevity.

The Space Communication and Navigation (SCaN) networks are comprised of 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 over 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 over 30 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. In order to continue providing proficiency at or above 95 percent for customer missions, each network requires regular maintenance, modernization and capacity expansion.

NASA's space communications networks provide ongoing services to Agency and customer missions, averaging about 600 tracking passes per day. Without these capabilities, customer missions like Parker Solar Probe (PSP), Joint Polar Satellite System (JPSS)-2, Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight), Ice, Cloud and land Elevation Satellite (ICESat-2), Commercial Lunar Payload Services (CLPS), Lunar Gateway Mission and Transiting Exoplanet Survey Satellite (TESS) would not be able to deliver key science data.

The SN provides continuous global coverage to NASA missions in Low Earth Orbit (LEO), and to launch vehicles during their launch and ascent phase. 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

SPACE COMMUNICATIONS NETWORKS

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. The ground systems operate the TDRS fleet and route customer mission data between TDRS and ground terminals. Maintaining and modernizing this critical network is one of the Agency's top priorities.

The NEN provides space communications to missions in LEO, geosynchronous, lunar and highly elliptical Earth orbits, as well as from certain suborbital launch locations. Comprised of NASA-owned and commercial satellite communication stations, the NEN is located throughout the world. The NASA owned network's ground stations are located at White Sands in New Mexico; U.S. McMurdo Antarctic Station; Wallops Flight Facility (WFF), Chincoteague, Virginia; and University of Alaska, Fairbanks, Alaska. The network also purchases services from commercial providers in Hawaii, Norway, Sweden, Singapore, South Africa, Australia and Chile. The NEN provides telemetry, tracking and command services to an extensive and diverse customer base, including the high-rate Earth Observing System, and several Small Explorer missions. The NEN is currently augmenting its ground station network to provide communications services for future spacecraft including Orion and the Space Launch System (SLS).

The DSN, which has been in operation for over 50 years, provides communication and tracking services to about 35 NASA and non-NASA missions beyond geosynchronous orbit (over 26,000 miles above the Earth's surface). Its three deep space communication complexes, all of which are owned by NASA, are located in Goldstone, California; Canberra, Australia; and Madrid, Spain. The sites are separated by approximately 120 degrees of longitude to ensure that any spacecraft in deep space can communicate with at least one station at all times as the Earth rotates.

The SCaN Program actively seeks to implement operational efficiencies to help fund modernization and upgrade activities. One example of this is Follow-the-Sun Operations. Since the three DSN ground stations are spaced roughly equally apart on the globe, each station is responsible for operating the entire DSN network during their day shift, handing off control to the next site as their day ends. While each station will still need a small emergency staff during their off-shift hours, these remote operations will significantly reduce operating costs at each station. The DSN network will also begin implementation of a second phase of operational efficiencies by moving to Three Links per Operator. This task increases the number of links each operator will manage concurrently while still maintaining the high proficiency levels that customer missions require.

An external evaluation was conducted by the Independent Review Team (IRT) to determine the overall status of health of the Space Network Ground Segment Sustainment (SGSS) project and to determine the credibility of the current cost and schedule estimates to the first Operations Readiness Review (ORR) and Final Acceptance Review (FAR). The IRT's findings were favorable supporting continuation of SGSS to FAR, based on the current path forward. As a result, the Agency approved continuing SGSS to FAR.

The ongoing DSN Aperture Enhancement Project 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

SPACE COMMUNICATIONS NETWORKS

performance as the 70 meter antennas. When not needed by a mission for arraying all four antennas, the 34 meter antennas may 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.

The NASA Communications Services Office (CSO) is a centralized commercial service which provides point-to-point communication services between the three space communications network ground stations, NASA centers, customer mission operations and data centers. While NASA's Office of the Chief Information Officer manages the CSO service, it is funded by the SCaN program.

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

EXPLANATION OF MAJOR CHANGES IN FY 2020

NASA is developing a strategy to transition from the government-owned and operated SN to a future architecture based on a mix of commercial services and capabilities. The newly proposed Communication Services Program will be responsible for architecture planning and acquisition management for next-generation near-Earth communications networks.

ACHIEVEMENTS IN FY 2018

During the fiscal year, the space communications networks supported 93 missions, with over 325,000 hours of tracking and more than 245,000 passes. SCaN networks provided launch to splash-down communication support for nine human spaceflight missions, 25 expendable launch vehicle (ELV) missions, and 62 robotic missions. SCaN continued to replenish networks to upgrade and replace obsolescent equipment to ensure continued tracking and data transmission for its customers in support of current and future missions.

The SN completed its replacement of the uninterruptable power supply module at the White Sands Ground Terminal (WSGT) facility in New Mexico. The planned replacement of the uninterruptable power supply module at the second TDRS Ground Terminal facility in New Mexico, completed a critical design review in July 2018. In addition, other White Sands ground equipment upgrades are providing up to 600 Mbps Ku-band data service. This additional capability is needed to meet ISS requirements and will enable ISS to increase its science capabilities by supporting high definition cameras and the transfer of large amounts of science data quickly and in real time instead of storing the data onboard and waiting for additional time to complete a downlink or for a data recorder to return to Earth.

The SN also completed on-orbit acceptance of TDRS-M. With the TDRS fleet complete and upgrades to the ground sustainment segment ongoing, the SN will have adequate Radio Frequency (RF) capacity for its expected mission set until around 2030.

The SGSS prime contractor General Dynamics completed several FY 2018 milestones in preparation for the initial Operational Readiness Review (ORR) scheduled for late FY 2019. The ORR will follow post level 6 testing, including command and control of TDRS Gen and Gen 2 space craft. Level 6 testing includes customer forward, return and tracking tests. SN led testing on the SGSS system follows level 6

SPACE COMMUNICATIONS NETWORKS

test completion and provides opportunity for additional SN hands-on training. Post level 6 testing will be led by the SN and supported by SGSS personnel.

After completion of the Systems Integration Review and Authority to Operate were completed in May 2018, the SGSS team began training the SN operations and maintenance staff to execute tasks using the upgraded SGSS system.

The NEN continued Ka-Band upgrades at the Alaska Satellite Facility, which are scheduled for completion in FY 2020. NEN continued depot level maintenance of an 11 meter antenna at the Wallops Ground Station, on Wallops Island, Virginia. These activities included steps to proactively inspect and replace cables and mechanical systems that are reaching their failure threshold, and are not otherwise addressed by preventative maintenance. In October 2017, the new AS2 Antenna at the Alaska Satellite Facility became operational, enabling the NEN to support future launches without incurring additional cost. The NEN successfully completed a phase 1 ORR for the Launch Communication Station that included the Kennedy Uplink Station and Ponce de Leon sites. Then NEN also completed enhancement of McMurdo TDRSS Relay System (MTRS) providing an increased data rate for communications up to 600 Mbps.

DSN Follow-the-Sun Operations transition was completed and able to provide critical services during the Canberra Deep Space Communication Complex (CDSCC) labor dispute in Australia. DSN started the next planned operations efficiency task, Three Links per Operator. The DSN Aperture Enhancement Project (DAEP) continued construction of DSS-56 and DSS-53 antennas in Spain; pedestal work for both antennas are nearing completion. Studies for the RF/Optical Hybrid began in FY 2018. The RF/Optical Hybrid is a new concept for providing NASA with cost-effective collection aperture coupled to backend optics and signal processing needed for receiving high data-rate optical downlink from deep space. Currently no capability with adequate collection area exists.

WORK IN PROGRESS IN FY 2019

The three space communications networks will continue to provide a level of service similar to that provided in prior years. This includes over 245,000 tracking passes, totaling more than 325,000 hours, 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. SCaN networks are planning to support 17 human spaceflight, 13 ELV, and 10 robotic mission launches.

The SN will begin working transition activities with customers in preparation for the completion of SGSS. Activities will include support to SGSS for project integration, testing, deployment, training and transition to operations. In October 2018, the SGSS project successfully completed the Systems Acceptance Test at the General Dynamics factory, a critical milestone towards achieving ORR. The SGSS project will continue work and maintain the critical path towards completion of the first ORR scheduled for September 2019.

NEN will continue Depot Level Maintenance on an 18 meter antenna at the White Sands facility. These activities include steps to proactively inspect and replace cables and mechanical systems that are reaching their failure threshold, and are not otherwise addressed by preventative maintenance. NEN will also continue Ka-Band upgrades at the Alaska Satellite Facility scheduled for completion in FY 2020.

SPACE COMMUNICATIONS NETWORKS

DSN will complete the critical design review for the Three Links per Operator efficiency task and begin implementation in FY 2019. This planned operations efficiency task will allow the DSN to maintain the same level of operators as additional antennas are added to the operational network.

In Madrid, Spain, the DSN Aperture Enhancement Project will complete antenna fabrication for DSS-56 and will begin the related installation, integration and test activities to support operations in FY 2020. Installation, integration and test activities will also begin on DSS-53, scheduled for completion in FY 2021. The DSS-53 reflector lift will occur in the last quarter of 2019. DAEP will start work on the actuator study for DSS-23 in order to identify candidate actuators for the final RF-Optical configuration. The study will commence with a review of the actuator specification. A list of viable commercial actuators will be compiled. Actuators will be compared in terms of the specification and cost. Candidate actuators include those used in optical telescopes, high frequency RF antennas with panel and secondary actuation, and Gamma ray observatories, as well as others. Currently no capability with adequate collection area exists. The RF/Optical Hybrid concept leverages existing RF mounts and infrastructure adding optical capability with a small loss in RF performance.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

SCaN Networks will continue to provide communications, tracking and navigation services to over 100 NASA, U.S. Government, civil space agency, and commercial missions at 95 percent or higher proficiency rate. This includes providing launch support on all new human spaceflight, ELV, 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 final milestones required to achieve Final Acceptance Review in FY 2021. SGSS will complete level 5 testing at White Sands Complex, 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 lead testing 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.

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 NISAR, in their requirement for high data-rate support. This will be the highest data rate ever supported for a NASA mission.

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 efficiency of the networks.

The DSN Aperture Enhancement Project 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.

Project Schedule

The table below includes significant SCaN network milestones in FY 2019 and FY 2020.

Date	Significant Event
FY 2019 - Q1	SGSS Systems Acceptance Test Complete
FY 2019 - Q1	DSN Three Links per Operator planned Critical Design Review
FY 2019 - Q3	NEN complete White Sands 18 meter depot level maintenance
FY 2019 - Q3	DSN start implementation of Three Links per Operator efficiency task
FY 2019 - Q3	SN complete STPSat-6 Antenna and Ground Equipment ORR
FY 2019 - Q3	DSN start implementation of Three Links per Operator efficiency task
FY 2019 - Q4	SGSS complete Initial Operation Readiness Review milestone
FY 2020 - Q1	DSN complete Operations Readiness Review of Three Links per Operator
FY 2020 - Q2	SGSS complete formal trainings 5-10
FY 2020 - Q2	DAEP continues DSS-53 Ka installation integration and testing
FY 2020 - Q3	DSN operational use of the Three Links per Operator task begins
FY 2020 - Q4	SGSS manufacturing prep for Post Incremental Technical Support (PITS)
FY 2020 - Q4	SGSS WSC integration and testing level 5 & 6 dry run

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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: 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: JPL Performing Center(s): N/A Cost Share Partner(s): Non-NASA customers	N/A
NASA CSO	Centralized commercial service that provides point-to-point communication services between ground sites	Provider: CSO, through NASA Chief Information Officer Lead Center: NASA HQ Performing Center(s): MSFC, GSFC Cost Share Partner(s): N/A	N/A
TDRS Replenishment	Purchase third-generation TDRS-K, -L, and -M to maintain Space Network communications services to customer missions into the 2020s	Provider: Boeing Space Systems Lead Center: GSFC Performing Center(s): N/A Cost Share Partners: Other U.S. government agencies	Development cost reduced. TDRS-M added to purchase
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

SPACE COMMUNICATIONS NETWORKS

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/Cal Tech	Pasadena, CA
Space Network Operations	Peraton	Herndon, VA
NEN Operations	Peraton	Herndon, VA
TDRS Replenishment and modifications to Space Network ground systems to support these spacecraft	Boeing Space Systems	El Segundo, CA
TDRS-M Launch Vehicle	United Launch Alliance, LLC	Centennial, CO
SGSS	General Dynamics Mission Systems	Scottsdale, AZ

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
SCaN	Standing Review Board	June 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 NETWORKS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
SCaN	SGSS Independent Review Team	June 2018	Continuation Review	Complete SGSS; Continue to evaluate commercial alternatives as part of NASA's Next Generation Architecture Review; and Conduct a risk-based analysis for future sustainment.	N/A

SPACE COMMUNICATIONS SUPPORT

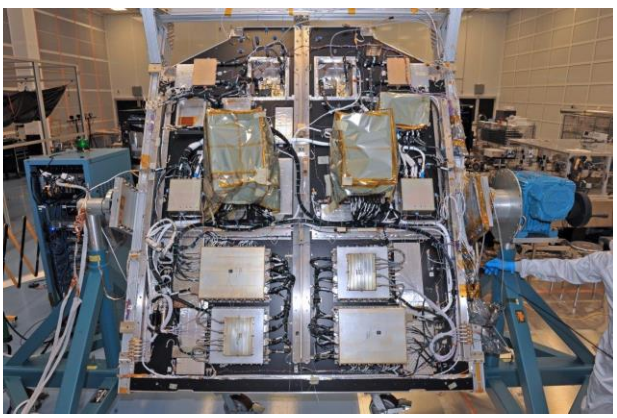
Formulation	Development	Operations

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**78.7**	**--**	**142.9**	**149.0**	**135.5**	**114.6**	**108.5**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



The Laser Communications Relay Demonstration (LCRD) payload 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 practicing 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.

Within the Space Communications Support project, SCaN's systems engineering office defines technical services, capacity, and performance requirements to eliminate duplication across networks, minimize mission-unique requirements, ensure customer missions operate together with NASA networks, and lower development and operations costs.

Evolving space communication systems will transform future NASA mission capabilities. SCaN's technology development effort invests in leading-edge communications technologies, and enables, improves, and matures available spacecraft communication and navigation technologies to build capabilities for both ground and space-based use. Technology items are created and tested in lab 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 SATCOM providers, cognitive networking, and optical communication.

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

NASA's Exploration Technology Mission Directorate and SCaN are jointly developing the Laser Communications Relay Demonstration (LCRD). SCaN is funding ground operations and Exploration Technology 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 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. Construction efforts for LCRD ground stations, use Construction of Facilities funds appropriated in NASA's Construction and Environmental Compliance and Restoration account.

SCaN and Exploration Technolgoy are also working together on the Deep Space Atomic Clock (DSAC) demonstration which will allow a spacecraft to calculate its own timing and navigation data in real time. With existing technology, a spacecraft can be navigated autonomously to the top of the Martian atmosphere with a 1 to 2 km 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 robotic missions or crewed missions.

SCaN is an active member of multiple international organizations (e.g. Interagency Operations Advisory Group, Consultive Committee for Data Standards Systems, etc.) 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 provide cross support to each other, reducing mission risk and reducing or eliminating the need to build and deploy their own space and ground assets resulting in significant cost savings to NASA without reducing services and 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 electromagnetic spectrum necessary to support NASA's mission needs. This includes ensuring interference-free operations and sufficient bandwidth is available. SCaN serves as the Agency's Spectrum Manager and provides the NASA representatives to domestic and international spectrum governing bodies. In the U.S., NASA provides representatives to the Interdepartment Radio Advisory Committee at the National Telecommunications and Information Administration (NTIA). Internationally, NASA provides a U.S. delegate to multiple forums, the most important of which are the World Radiocommunication Conferences, which convene every three to four years and include delegates from more than 150 nations. Among the purposes of these conferences is to review and revise the International Telecommunication Union's Radio Regulations which govern the use of 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.

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

NASA spacecraft in Earth's orbit employ GPS timing signals for precision positioning, navigation, and timing for vehicles in space. This allows 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 major role on the 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 2020

None.

ACHIEVEMENTS IN FY 2018

SCaN continued work on new capabilities for higher bandwidth, on-demand services, Delay/Disruption Tolerant networking (DTN), and autonomous navigation. SCaN worked with the Exploration programs to define the communication and navigation capabilities needed to support future exploration. In September 2018, SCaN released a NextSTEP Broad Agency Announcement (BAA) to study the feasibility of a collaboration with commercial entities to develop and introduce new operational capabilities that NASA user missions will use, through shared investment, standards, and risks. The project office received and adressed 42 questions from industry as well as engaged the community in multiple forums in preparation for the BAA Request for Proposal rollout.

SCaN also continued new technology development work. New technologies, such as cognitive communications, advanced RF technologies, and optical communication will enable significant reductions in system acquisition and operations cost while improving network bandwidth flexibility, scalability, and security. In accordance with the NASA Transition Authorization Act of 2017, NASA is developing a plan to meet the Administration's projected space communications and navigation needs for LEO and deep space operations for the next 20 years. Towards that effort, NASA engaged with the interagency and industry communities through a variety of venues during FY 2018. Furthermore, in March 2018, BridgeSat Inc. announced an industry-first reimbursable agreement with NASA designed to develop a commericalized laser-based free space optical communications system.

SCaN continued to work with Exploration Technology on LCRD. Both OGS-1 (Optical Ground Station) at Jet Propulsion Laboratory's Optical Communication Telescope Laboratory (OCTL) facility in California and OGS-2 (in Hawaii) will begin their integration and testing work, which are key milestones for completion. The Integrated LCRD LEO User Modem and Amplifier Terminal (ILLUMA-T) will work with LCRD to demonstrate laser-based technologies. This new terminal will be based on a next generation design with significantly lower size, weight, power, and cost than the current state-of-the-art radio solutions. The Optical to Orion (O2O) project leverages laser communications technology for use on Orion. Laser communications provides higher data rates that will significantly improve the crew's ability to connect with NASA and society as a whole while in space. For example, it will allow for high-definition (HD) images and streaming video (80 Mbps+) during flight which would otherwise not be

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

available with current RF technology (the baseline Orion communications system is limited to 1 Mbps of capacity). This capability provides the technical community with continuous and detailed flight data which will significantly increase NASA's ability to analyze flights in real time. The capability will also allow NASA to provide real-time high-quality video from the Orion crew and the moon to the American public.

SCaN continued to partner with the Science and Exploration Technology Mission Directorate on the Deep Space Optical Communication (DSOC) payload to increase data rates by a factor of 10-100, without increasing mission burden in mass, volume, power and/or spectrum. SCaN completed the System Readiness Review (SRR) and will complete detailed design of uplink and downlink stations and begin fabrication to support an operational readiness date in late FY 2021 for the ground terminal.

The U.S. Air Force (USAF) will host the Deep Space Atomic Clock (DSAC) demonstration unit as part of the 's 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 a year of operations. The clock will make use of GPS satellite signals to demonstrate precision orbit determination and confirm its performance. In June 2018, the DSAC project held a successful Mission Readiness Review in which the project was able to satisfy the success criteria necessary for launch and mission operations. DSAC will proceed with Key Decision Point (KDP)-E in preparation for launch, which has a current window of April to June 2019.

In October 2017, SCaN held a NASA Space Communication Data Standard Webinar for the U.S. industry with 53 participants from NASA and 17 U.S. companies to engage the U.S. commercial sector in space communication data standards, including space-to-ground, ground-to-space, and space-to-space. A standard is also being developed for data exchanged between onboard software applications and hardware devices to enable missions to exchange electronic interface specifications across agencies.

SCaN's Spectrum Management Office secured continued use of wideband S-band telemetry for SLS beyond Exploration Mission (EM)-2 which required agreements from the Department of Defense, the Aerospace and Flight Test Radio Coordinating Council, and NTIA before the operational certification was approved. The Spectrum Office, on behalf of the Commercial Crew Program and other agencies, coordinated spectrum use for commercial vehicles transporting crew to ISS. Further, NASA performed compatibility analyses with on-going spectrum sharing initiatives to enable bi-directional access to spectrum between the U.S. Government and the commercial sector.

WORK IN PROGRESS IN FY 2019

SCaN will continue its work with Exploration Technology on LCRD. SCaN will complete both OGS-1 and OGS-2 to support the LCRD launch. The LCRD payload, which will be completed in FY 2019, is a hosted payload aboard the U.S. Air Force’s Space Test Program Satellite-6 (STPSat-6). As a result, the availability of STPSat-6 will determine the launch date. The ILLUMA-T and Orion EM-2 O2O projects will complete their Critical Design Reviews (CDR) and begin payload integration and test. The DSOC optical ground station project will complete its Preliminary Design Review (PDR), noting that it is about 10 months after the flight hardware PDR as supported by Exploration Technology. Promising technologies will be advanced in FY 2019, leading to future Cubesat demonstrations such as the TeraByte

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

InfraRed Delivery (TBIRD) in FY 2020 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.

Through participation in the Interagency Operations Advisory Group and Consultative Committee for Space Data Systems, 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 which may be used in NASA's Next Generation Space Communications and Exploration Architectures.

As NASA's Spectrum Manager, SCaN will continue to participate in domestic and international meetings to ensure interference-free use of the electromagnetic spectrum supporting requirements for NASA's current and future missions. SCaN will focus on planned agenda items at the World Radiocommunication Conference in FY 2020, and working within the U.S. Delegation, will seek to ensure continued access to the RF spectrum supporting NASA's mission requirements, the U.S. Government space interests, and the U.S. commercial space community. In addition, SCaN will continue to coordinate spectrum use for all domestic and international deep space missions, as well as NASA near-Earth missions. Further, SCaN is committed to support the NTIA, through the Policy and Plans Steering Group, in developing a National Spectrum Strategy, in support of the 2018 Presidential Memorandum on Developing a Sustainable Spectrum Strategy for America's Future, as well as supporting regulatory goals established by the National Space Council.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

SCaN will continue its work with Exploration Technology in preparation for the LCRD launch. Final payload to spacecraft integration and testing will be completed in FY 2020 with launch now estimated to be in late FY 2020.

NASA plans to launch the TBIRD cubesat mission in early FY 2020. TBIRD will demonstrate a revolutionary new approach for large volume data delivery from LEO, 5-10 terabytes per day to a single low cost ground station. Component test and integration for the ILLUMA-T and O2O hardware will also be completed in late FY 2020. In FY 2020, initial development of CATSAT communication systems with cognitive software and waveforms will be completed, resulting in a PDR.

Through participation in the Interagency Operations Advisory Group and Consultative Committee for Space Data Systems, 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.

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

SCaN will represent NASA at the 2019 World Radiocommunication Conference to ensure continued access to the RF spectrum supporting NASA's mission requirements, the U.S. Government space interests, and the U.S. commercial space community. In addition, SCaN will continue to coordinate spectrum use for all domestic and international deep space missions, as well as NASA near-Earth missions.

Project Schedule

The table below includes significant Space Communication Support milestones in FY 2019 and FY 2020.

Date	Significant Event
FY 2019 - Q1	DSOC Ground Terminal Preliminary Design Review (COMPLETE)
FY 2019 - Q2	TBIRD CDR – April 2019
FY 2019 - Q2	DSAC Launch
FY 2019 - Q2	LCRD Mission Readiness Test
FY 2019 - Q2	LCRD Operations Readiness Review
FY 2019 - Q3	LEMNOS (includes O20 and ILLUMA-T) CDR
FY 2019 - Q3	OGS-2 ORR
FY 2019 - Q4	Cognitive Application Technology Satellite-CATSAT Cubesat Demo MCR
FY 2020 - Q1	TBIRD Ground Station Delivery
FY 2020 - Q1	TBIRD launch
FY 2020 - Q1	LOCNESS MCR
FY 2020 - Q3	O2O and ILLUMA-T Testing and Integration Complete
FY 2020 - Q4	LCRD launch

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

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

Acquisition Strategy

Space Communications Support functions use multiple small contracted efforts, most of which are support services functions.

MAJOR CONTRACTS/AWARDS

None.

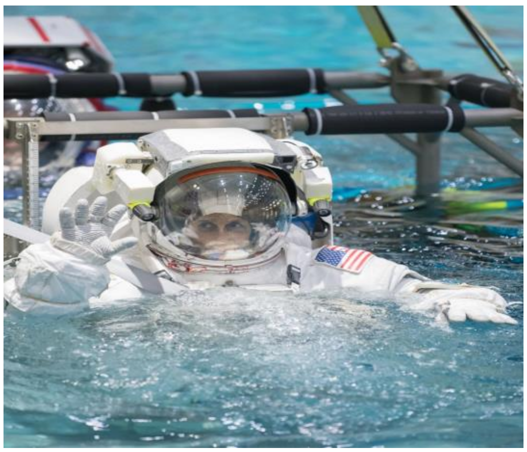
HUMAN SPACE FLIGHT OPERATIONS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**124.4**	**--**	**99.8**	**99.9**	**109.5**	**111.4**	**112.4**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



Crew Health and Safety monitored Astronaut Sunita Williams in the Neutral Buoyancy Laboratory in a prototype Z-2 Extra-Vehicular Activity (EVA) suit.

The Human Space Flight Operations (HSFO) Program supports the training, readiness, and health of crew members before, during, and after each spaceflight mission to the International Space Station (ISS) as well as supporting preparation for future exploration missions. 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 training while the Crew Health and Safety (CHS) element manages all aspects of astronaut crew health.

To prepare for the next step in human space exploration, the Agency is developing the transportation system 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 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.

HUMAN SPACE FLIGHT OPERATIONS

EXPLANATION OF MAJOR CHANGES IN FY 2020

This request consolidates funding from across NASA mission directorates for certain aeroscience capabilities into a single project within Safety, Security, and Mission Service's Shared Capability Asset Program. This includes the transfer of the Aeronautics Evaluation & Testing Capability Project (AETC). AETC will continue to provide the necessary support for both Aeronautics and other Agency large ground test needs.

ACHIEVEMENTS IN FY 2018

SFCO provided training requirements and mission operations support for the first commercial test flights of NASA U.S. commercial spacecraft (SpaceX Dragon and Boeing Starliner) launch vehicles, as well as continuing support for Russian Soyuz spacecraft launches. SFCO also continued training the 2017 Astronaut Candidate (ASCAN) class, supported ISS flight crew training requirements and mission operations which increased in crew size from six to seven.

To support the four ISS mission increments in FY 2018, CHS provided pre-flight, in-flight and post-flight medical, behavioral health management, and physical conditioning services to NASA crewmembers, and tracked and monitored emerging hazards for NASA's new flight programs: Commercial Crew and Orion. For example, CHS evaluated progress on radiation environmental data to inform future Exploration Mission crewed flights. The program provides preflight and operations support to test flights of SpaceX Dragon and Boeing Starliner commercial spacecraft carrying NASA astronauts. CHS also expanded its Lifetime Surveillance of Astronaut Health (LSAH) program for former crew members to better understand the long-term health consequences of space exploration. The evidence acquired through this program not only benefits the health of former astronauts, but also helps make future spaceflight missions safer.

WORK IN PROGRESS IN FY 2019

In FY 2019, SFCO will continue to support ISS flight crew training requirements and mission operations for Russian Soyuz spacecraft launch vehicle and U. S. commercial spacecraft, the SpaceX Dragon and Boeing Starliner, crewed missions. 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. Four NASA astronauts will launch on Soyuz to ISS in FY 2019. ISS mission operations support will increase with the change in crew size from six to seven. SFCO will complete training for the 2017 ASCAN class and will work with the Agency to decide whether to recruit a FY 2021ASCAN class. SFCO will continue operation and maintenance of the T-38 high performance jets in support of space flight readiness training as well as the Super Guppy aircraft for transporting oversized cargo.

To support mission increments, CHS will provide preflight training, medical, behavioral health management, physical conditioning and baseline occupational surveillance. In addition, CHS will provide preflight through post flight medical, behavioral and physical conditioning support of NASA crewed SpaceX Dragon and Boeing Starliner commercial spacecraft. Test personnel and medical guidance will be provided to support the EM-2 mission. CHS will implement the "To Research, Evaluate, Assess, and Treat" (TREAT) Astronauts Act, to include expanding the LSAH program for former crew members to better understand long-term health consequences of space exploration. Data analytics capabilities will be expanded to support medical diagnostic capabilities for Exploration Campaign missions including Gateway.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

CHS will maintain the Astronaut Occupational Health program that includes clinical certification for active astronauts, health and fitness through training, flight, and post mission recovery. CHS will continue development of the LSAH program and implementation of the TREAT Astronauts Act to monitor, diagnose, and treat former astronauts and enhanced behavioral health and medical data collection. To support mission increments, CHS will provide preflight training, medical, behavioral health management, physical conditioning and baseline occupational surveillance.

SFCO will provide trained astronauts for NASA human space flight efforts, direct and manage flight crew activities for Expedition 61 through 64, and select astronaut candidates for space flight missions beyond Expedition 64. SFCO will continue to operate and maintain program support aircraft for space flight readiness training and direct crew return, including the T-38 high performance jets in support of space flight readiness training and the Super Guppy aircraft for transporting oversized cargo. Selection of the FY 2021 ASCAN class will also begin in FY 2020, if necessary. This will depend on the number of astronaut retirements and potential changes to future mission plans.

Program Elements

SPACE FLIGHT CREW OPERATIONS (SFCO)

SFCO directs and manages flight crew activities, selects astronaut candidates, recommends flight crew assignments, and maintains all aircraft, including the fleet of T-38 high performance aircraft used for astronaut spaceflight readiness training. In addition, SFCO ensures that spaceflight readiness training requirements continue to support ongoing ISS operations, planned exploration, and commercial development.

SFCO is also responsible for all astronaut training. As part of its annual planning, the project ensures astronaut training is consistent with ISS and Exploration manifest requirements. The number of spacecraft seats U.S. astronauts will fill in the next four years of human spaceflight determines the manifest requirement. The manifest includes ISS via Soyuz, as well as projected Commercial Crew and Orion/Space Launch System (SLS) development flights. Today, it takes three years from the decision to select a new astronaut class until the process is completed. Once selected, new astronauts must complete 12-18 months of training for eligibility and then 30 months of ISS training before a new astronaut is qualified for an ISS mission. Astronaut training activities, overseen by SFCO include launch and landing operations, ability to respond in an emergency/high-stress environment, high performance aircraft operations skills, flight vehicle maintenance, payload and science experiment operator skills, extravehicular activities, Russian language skills, robotics (including free-flier capture), and ISS systems knowledge. Requirements for future missions, for example to Gateway and the Moon, will be planned as those missions become better defined.

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 prevent and mitigate negative long-term health consequences from exposure to the spaceflight environment. Using HRP research and other findings, CHS implements changes to astronaut occupational health protocols to ensure crew health and safety. CHS also medically assesses astronaut candidates as part of the selection process. 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 expand the research findings that can be used to improve NASA health protocols, including collaborative opportunities with other Federal agencies and academia.

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 the human health before, during, and after spaceflight. CHS documents and assesses all emerging health risks, such as Spaceflight Associated Neuro-ocular Syndrome (SANS). CHS has continued to collaborate with several non-NASA organizations, including the National Academies, to inform the risk decisions associated with long duration and exploration missions.

Program Schedule

Date	Significant Event
Spring 2019	Develop the Interim Rule for the TREAT Astronauts Act

Program Management & Commitments

Program Element	Provider
SFCO	Provider: SFCO Lead Center: JSC Performing Center(s): JSC Cost Share Partner(s): None
CHS	Provider: CHS Lead Center: JSC Performing Center(s): JSC Cost Share Partner(s): None

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

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	National Council on Radiation Protection and Measurements (NCRP)	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 one 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 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	86.8	--	88.6	88.6	88.6	88.6	88.6

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

The final United Launch Alliance Delta II rocket lifts off from Space Launch Complex 2 at Vandenberg Air Force Base in California, on Sept. 15, 2018, carrying NASA's Ice, Cloud and Land Elevation Satellite-2 (ICESat-2). Liftoff was at 9:02 a.m. EDT (6:02 a.m. PDT).

The Launch Services Program (LSP) ensures access to space for the Nation's civil sector satellite and robotic planetary missions.

The civil sector has multiple space-based missions. In addition to NASA's science and discovery missions, there are civil communications, geographic survey, and civil weather missions that 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," whether going to low Earth orbit or some other Earth-centric orbit, LSP has unique launch system expertise involving payloads containing nuclear power sources, and for launching "one-of-a-kind" science exploration missions sent to other planets, the sun, or other locations in space. NASA relies on LSP to provide robust, reliable, commercial, and cost-effective launch services. 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 and Commercial Crew Program (CCP), along with "launch advisory" support to NASA payload missions using launch services contributed by a foreign partner, to other government agencies, and to the launch industry as a whole.

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 the 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 2020

None.

ACHIEVEMENTS IN FY 2018

Six major payloads were successfully launched utilizing LSP-acquired services:

Launch Date/Location	Launch Vehicle	Payload	Customer	Mission Objectives
Nov 2017 Vandenberg Air Force Base	Delta II	JPSS-1	NASA SMD	First of three satellites that will provide global environmental data used in weather prediction models for forecasts, and scientific data for climate monitoring which will increase timeliness and accuracy of forecasts of climate and weather events, thus reducing potential loss of human life and property.
Mar 2018 Cape Canaveral Air Force Station	Atlas V	Geostationary Operational Environmental Satellite (GOES)-S	NOAA, NASA SMD	Follow on mission in the GOES-R Program series of satellites that will provide continuous imagery and atmospheric measurements of Earth's Western Hemisphere and space weather monitoring.
Apr 2018 Cape Canaveral Air Force Station	Falcon 9 "Full Thrust"	Transiting Exoplanet Survey Satellite (TESS)	NASA SMD	Space telescope designed to survey the brightest stars near the Earth utilizing an array of cameras. The all-sky survey will study the mass, size, density and orbit of a large cohort of small planets, including a sample of rocky worlds in the habitable zones of their host stars.
May 2018 Vandenberg Air Force Base	Atlas V	Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight)	NASA SMD	Will address fundamental issues of planet formation and evolution with a study of the deep interior of Mars.
Aug 2018 Cape Canaveral Air Force Station	Delta IV-Heavy	Parker Solar Probe	NASA SMD	Flying into the Sun's atmosphere (or corona), for the first time, the Parker Solar Probe will employ a combination of in situ measurements and imaging to achieve the mission's primary scientific goal: to understand how the Sun's corona is heated and how the solar wind is accelerated.

LAUNCH SERVICES

Launch Date/Location	Launch Vehicle	Payload	Customer	Mission Objectives
Sep 2018 Vandenberg Air Force Base	Delta II	Ice, Clouds, and Land Elevation Satellite (ICESat)-2	NASA SMD	Second generation satellite used to collect altimetry data of the Earth's surface to measure ice sheet mass balance, cloud and aerosol heights, while also generating an estimate of global vegetation biomass.

LSP's customers own and manage the payload mission objectives described above.

LSP continuously works with the U.S. commercial launch industry, assessing their designs and providing advice, in an effort to expand the selection of domestic launch vehicles available to NASA's missions, thereby nurturing a competitive commercial launch service environment.

LSP acquired launch services for two future science missions:

Launch Date/Location	Launch Vehicle	Payload	Customer	Mission Objectives
Nov 2020 Vandenberg Air Force Base	Falcon 9 "Full Thrust"	Sentinel 6A	NASA SMD	To collect high resolution vertical profiles of temperature, using the GNSS Radio-Occultation sounding technique, to assess temperature changes in the troposphere and stratosphere and to support Numerical Weather Prediction.
Dec 2020 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.

LSP's customers own and manage the payload mission objectives described above.

With the certification of the Delta IV Heavy launch vehicle completed, LSP was able to successfully support the Parker Solar Probe mission that flew in August 2018. 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 concluded its independent review for the September 1, 2016, Falcon 9 anomaly. The independent review took a more in depth look into the results of the SpaceX led Accident Investigation Team. The NASA independent team recreated probable scenarios replicating fire damage of composite overwrapped pressure vessels; conducted testing and analysis and implemented corrective actions in an effort to prevent further occurrences. This effort directly contributed to the successful launch of the TESS mission in April 2018.

LAUNCH SERVICES

NASA and LSP continue to partner with several universities and NASA Centers to launch small research satellites through the CubeSat Launch Initiative (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 disciplines, thereby strengthening the Nation's future workforce. To date, CubeSats have been selected from 39 states across the United States, with 84 missions launched and 37 manifested on NASA, National Reconnaissance Office, United States Air Force, and commercial missions. In FY 2018, 21 CSLI CubeSats were launched.

WORK IN PROGRESS IN FY 2019

LSP provides expertise and active launch mission management for over 60 NASA scientific spacecraft missions in various stages of development. LSP will continue work towards certifying new commercial launch vehicles to launch high value payloads. LSP completed Category 3 certification of the SpaceX Falcon 9 "Full Thrust" launch vehicle in October 2018. Pre-certification activities are active with Blue Origin's "New Glenn", United Launch Services' "Vulcan", Northrop Grumman's "Omega", and SpaceX's Falcon Heavy launch vehicles.

In FY 2019, the program will continue to acquire new launch services for future NASA missions. One science mission and two Venture Class Launch Services (VCLS) missions are planned for launch in FY 2019. The program is in the process of competitively awarding launch service task order for the NASA Science Mission Directorate's GOES T, Imaging X-Ray Polarimetry Explore (IXPE), and Double Asteroid Redirection Test (DART) missions. The launch service task order for NASA's science mission "Lucy" was awarded to United Launch Services, LLC in January 2019. The mission will launch in October 2021 on an Atlas V 401 rocket from launch complex 41 at Cape Canaveral Air Force Station in Florida.

Launch Date/Location	Launch Vehicle	Payload	Customer	Mission Objectives
NET Spring 2019 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.

LSP's customers own and manage the payload mission objectives described above.

VCLS contracts for CubeSat satellites foster a commercial launch market dedicated to flying small satellite payloads thereby serving as an alternative to the current rideshare approach in which 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. Virgin Orbit's LauncherOne is scheduled to launch in the spring of 2019.

LAUNCH SERVICES

Launch Date/Location	Launch Vehicle	Payload	Customer	Mission Objectives
December 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.
March 2019 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.

Along with full end-to-end launch service management, the program 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 the
- NASA-Indian Space Research Organization Synthetic Aperture Radar (NISAR) missions.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

LSP will continue launch service acquisition activities necessary to support NASA and other approved government missions, and will continue providing launch related mission support to over 60 NASA 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. In addition, LSP will begin to acquire commercial logistics acquisition services for Gateway, and provide launch advisory services for Webb and NISAR. 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 be managing and conducting the launch activities for two NASA missions in FY 2020, Solar Orbiter and Mars 2020:

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 which need to be answered about the development of planets and the 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.
July 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 not only seek signs of habitable conditions on Mars in the ancient past, but will also search for signs of past microbial life itself.

Program Management & Commitments

Program Element	**Provider**
Expendable Launch Vehicle (ELV) Launch Services	Provider: United Launch Services (ULS), Northrop Grumman Innovation Systems (NGIS) (formerly Orbital ATK), SpaceX, Rocket Lab USA, Virgin Orbit Lead 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 ELV 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, such as not-to-exceed prices; indefinite delivery/indefinite quantity contract terms; and firm-fixed-price, competitive, launch service task-order-based acquisitions. The NLS II ordering period has been extended to June 30, 2025. To ensure active ongoing 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 active contract.

LSP is also able to contract separately from the NLS contract mechanism if such an approach is necessary to meet a particular mission or customer need. For instance, for the Parker Solar Probe mission funded by NASA SMD, the launch service was competed outside and separate from the NLS II contract due to the special needs of that mission. In addition, the VCLS awards for very small launch vehicles were conducted outside and separate from the NLS II contract in order 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 contracts are up for recompete. The East Coast Commercial Payload Processing Contract-4 (ECCPP-4) was awarded in April 2017, with a period of performance ending April 2022. The West Coast Commercial Payload Processing Contract-3 (WCCPP-3) solicitation was cancelled and will be re-competed at a later date.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Venture Class	Virgin Orbit, Rocket Lab USA	Long Beach, CA Los Angeles, CA
NLS-II-U	ULS, LLC	Centennial, CO
NLS-II-S	SpaceX	Hawthorne, CA
NLS-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-3	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

NASA has scheduled the LSP Program Implementation Review (PIR) in calendar year 2019.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Post Implemen-tation 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.	2019*

**This 2019 milestone for LSP will be assessed by the Human Exploration and Operations Mission Directorate (HEOMD) Associate Administrator and a determination made whether or not a PIR is required, or if it can be delayed another two years. The 2019 milestone is also subject to change depending on LSP's manifest/launch schedule for that year.*

Historical Performance

LSP managed ELV Missions from inception through FY 2018.

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	OSC	1	1	0
Pegasus XL	OSC	15	15	0

LAUNCH SERVICES

Launch Vehicle Configuration	Provider	Number of Launches	Successful Launches	Unsuccessful Launches
Taurus XL	OSC	2	0	2
Titan II	Lockheed Martin	3	3	0

ROCKET PROPULSION TEST

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**46.0**	**--**	**46.5**	**47.6**	**47.6**	**47.6**	**47.6**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

RPT continues to prepare the B-1/B-2 test stand for SLS Core Stage testing 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 United States and provides a single entry point for any user of the rocket test stands. RPT retains a skilled workforce, capable of performing tests on all modern-day rockets including supporting complex rocket engine development. RPT evaluates customer test requirements and desired outcomes, minimizing test time and costs. It also streamlines facility usage and eliminates redundant capabilities by closing and consolidating NASA's rocket test facilities.

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. 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 additional programmatic information, go to: https://rockettest.nasa.gov/

ROCKET PROPULSION TEST

EXPLANATION OF MAJOR CHANGES IN FY 2020

None.

ACHIEVEMENTS IN FY 2018

During FY 2018, RPT safely performed 1,056 tests of rocket engines and components at various levels of thrust. Hot fire test time totaled 12,765 seconds. In addition to the hot fire tests, RPT performed facilities checkouts and conducted 326 hours of thermal vacuum testing for vehicle certifications. These tests were completed with only seven facility-caused test delays resulting in a 99.3 percent test stand availability, exceeding the Agency Performance Goal of 90 percent as defined in Space and Flight Support (SFS) section 18-2 of the NASA Management and Performance Report.

In FY 2018, RPT performed six RS-25 engine tests on the Stennis Space Center (SSC) A-1 test stand. The tests accounted for 2,209 seconds of hot fire test time in a multi-year effort to certify the engine for use on Space Launch System (SLS) core booster stage. In addition to the RS-25 tests performed on the A-1 test stand, SSC performed 10 tests within 240 hours in support of the Defense Advanced Research Projects Agency (DARPA) XSP program. Other test activities included testing support for SpaceX, Aerojet Rocketdyne, other NASA programs, and DoD projects such as the U.S. Air Force (USAF) designed and developed Hydrocarbon Boost components, which is a critical effort to support the DoD objective of replacing the RD-180 engine used in the Atlas V launch vehicle. In addition to the USAF hydrocarbon program, NASA continued performing Aerojet Rocketdyne hydrocarbon component testing on E-1 Test Stand, Cell 2.

At the Johnson Space Center (JSC) White Sands Test Facility (WSTF), engineers conducted tests to support NASA's Orion and Commercial Crew Programs, Aerojet Rocketdyne, the Missile Defense Agency, the USAF Peacekeeper missile safing project, and hot fire test for the USAF Minuteman missile life extension program. On Test Stand 301, 301A, 401 and 406, RPT continued testing the Orion ESA Service Module and Boeing CST-100 Service Module, Launch Abort Engines, Reaction Control System and Orbital Maneuvering and Attitude Control thrusters.

At Glenn Research Center Plum Brook Station (GRC-PBS), following refurbishment in 2017, the In Space Propulsion Facility (ISPF) validated the updated systems and performed the thermal vacuum certification testing for the Commercial Crew Program SpaceX Dragon Crewed Capsule. RPT also continued collaborating with the Glenn Research Center to refurbish the ISPF to perform propulsion related testing for systems up to 30k lbf with 300 seconds of run time.

At Marshall Space Flight Center (MSFC), RPT continued testing rocket engine components manufactured using select laser melting and other additive manufacturing processes furthering the capabilities of both NASA and RPT.

WORK IN PROGRESS IN FY 2019

At SSC, RPT will continue testing the RS-25 engine in support of the SLS program. Development testing will continue for commercial companies seeking to test their engine systems on a reimbursable basis. These include performing tests on the USAF designed and developed Hydrocarbon Boost components for the RD-180 replacement project and Aerojet Rocketdyne hydrocarbon engine certification. Planned refurbishment and repair activities for critical enabling infrastructure include: continuing repair of SSC's liquid oxygen and liquid hydrogen barges; upgrading 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. SSC will also complete the construction of the joint Michoud Assembly Facility/SSC Consolidated Fluid Component Processing Facility.

The WSTF team will conduct propulsion system development and certification testing for the NASA Orion ESA Service Module and complete certification testing for the Commercial Crew Program Boeing CST-100 Service Module. Other testing will include activities for Aerojet Rocketdyne, the Missile Defense Agency, USAF, and U.S. Navy.

MSFC will continue 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 Glen Research Center-Plum Brook Station (GRC-PBS) Interactive System Productivity Facility (ISPF), RPT will complete improvements for future space exploration propulsion needs through Evolvable Cryogenics Project (eCRYO) in partnership with the Space Technology Mission Directorate and will support research to reduce boil-off rate on large cryogenic upper stages with Structural Heat Intercept, Insulation and Vibration Evaluation Rig (SHIVER) in a simulated space environment (vacuum and thermal). The ISPF will also support the Science Mission Directorate Balloon program. GRC-PBS will also complete the 30k/300 second refurbishment activity.

The RPT Program Office continues to pursue two initiatives to meet the changing needs of the propulsion systems developers. The first initiative is the development of two small test capabilities that can be operated with a minimum crew for development projects. The first of these test capabilities is the completion of a 5,000 lbf portable test rig. The second capability is a collaborative initiative utilizing early-career engineers from the participating RPT centers to design and develop a larger 10,000 lbf to 15,000 lbf thrust portable test capability. In addition to the actual design of a test capability, the early-career engineer initiative is designed to offer the participants an opportunity to gain critical experience in NASA's design processes, enhance communications skills, and build relationships amongst the centers.

The first of the two capabilities will be completed and made operational in FY 2019. The second, employing the early career personnel will move to the next phase in FY 2019 utilizing lessons learned from the first. Additionally, RPT will complete its Benchmarking Initiative for Test Efficiencies and Affordability and begin implementing changes designed to reduce its operation costs.

KEY ACHIEVEMENTS PLANNED FOR 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 Exploration Mission-1 (EM-1) and EM-2. These tests will provide critical data to validate baseline designs, increase confidence in technical performance while reducing risks and 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 the SLS RS-25 engine on SSC's A-1 test stand and begin testing for SLS core stage on the B-2 test stand. The core stage uses four RS-25 engines to propel the SLS core stage upon launch. 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.

In addition, at SSC, RPT will continue testing the Exploration Technology's Nuclear Thermal Propulsion Subscale Exhaust Capture System, participating in the advancement of nuclear technology to become a key ingredient of NASA's future exploration prowess.

At PBS, RPT will complete all planned modifications of the ISPF and begin testing for the NASA commercial partner, Northrop Grumman's upper stage for their OmegA launch system.

At the White Sands Test Facility (WSTF), RPT will continue testing activities for the Orion ESA Service Module. RPT will also continue providing critical propulsion test services to the Missile Defense Agency, Aerojet Rocketdyne and USAF test articles.

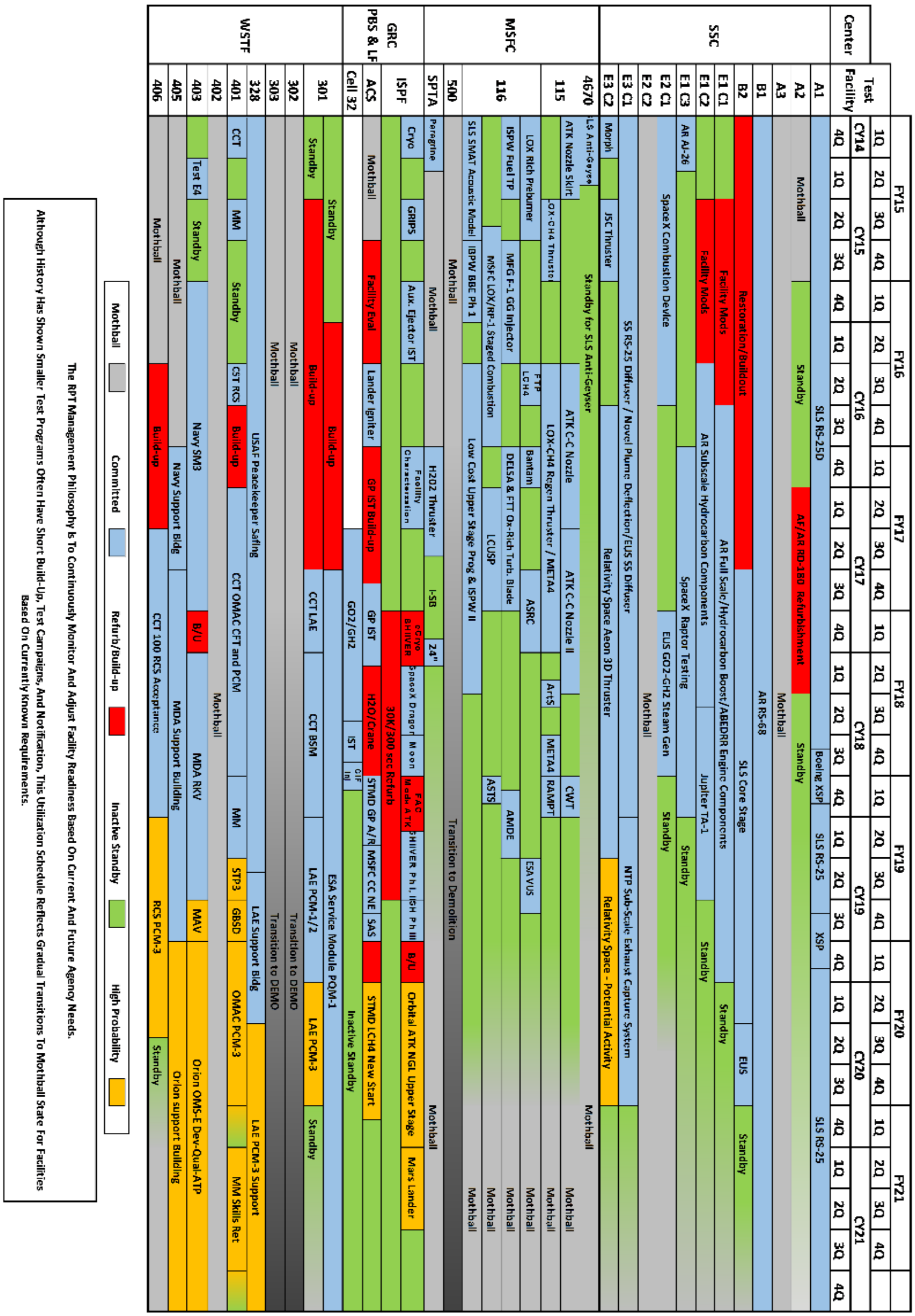
All RPT facilities and personnel will continue maintaining and modernizing these unique national assets which are critical for testing future space vehicles in a simulated space environment and ambient conditions.

Program Schedule

The following chart shows past, current, and planned test campaigns at Stennis Space Center (SSC), Marshall Space Flight Center (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 2020 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.

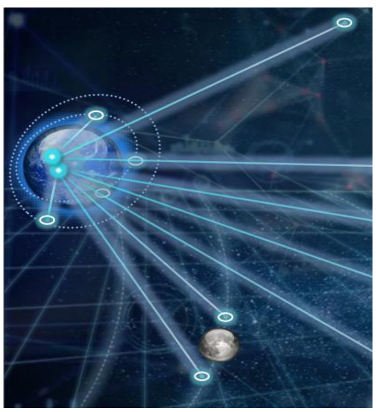
COMMUNICATIONS SERVICES PROGRAM

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**0.0**	**--**	**3.0**	**23.4**	**67.0**	**101.2**	**108.9**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



The Communications Services Program is being established to support commercially provided data relaying services to more efficiently meet future needs.

EXPLANATION OF MAJOR CHANGES IN FY 2020

The Communication Services Program (CSP), led out of Headquarters, is being established to focus on demonstrating the feasibility of commercially provided data relay services. The Next Generation Capability project, formerly within the Space Communications and Navigation Program, is being transferred to CSP. As an initial activity, the CSP will pursue opportunities that will allow future NASA missions to deploy flight qualified capabilities for near-Earth users to get support from commercial providers. Over a longer time horizon, the CSP will be responsible for the acquisition management of the next generation operational communications capability as current Tracking and Data Relay Service (TDRS) satellites are retired. 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. NASA expects to partner with multiple commercial entities to phase out reliance on NASA owned and operated systems. This 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.

The initial funding being requested in FY 2020 for this new program will support the management, engineering, and acquisition functions required to establish the program, develop an initial pilot acquisition vehicle for commercial communications services, and begin formulating a future communications architecture based on these services. Funding for management, engineering, and acquisition functions will remain modest as the program builds out the future communications architecture with the funding held in the Next Generation Capability project. The initial program team will also study whether the program, once established, should be led out of a NASA Center or will remain at NASA Headquarters.

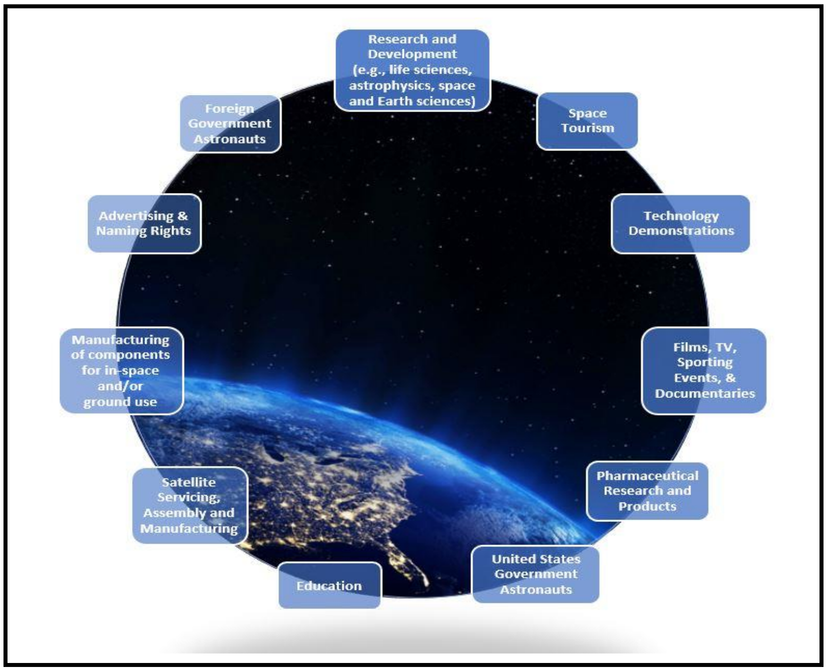
COMMERCIAL LEO DEVELOPMENT

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**0.0**	**--**	**150.0**	**175.0**	**200.0**	**225.0**	**225.0**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



NASA seeks to achieve a continuous U.S. human presence in low Earth orbit (LEO) – both with government astronauts and with private citizens – in order to support the utilization of space by U.S. citizens, companies, academia, and international partners and to maintain a permanent American foothold on the nearest part of the space frontier. NASA is undertaking the Commercial LEO Development program as a focused effort to develop a commercial space economy in LEO that will support these goals for the Nation. 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 commercial activities in LEO such that NASA is but one of many users purchasing those services. As those commercial LEO destinations become available, and without a gap between ISS and future platforms, NASA intends to implement an orderly transition from current International Space Station (ISS) operations to the new commercial enterprise as laid out in NASA's ISS Transition Report of March 30, 2018.

To achieve the Commercial LEO Development program's overall goals, NASA will utilize a multi-faceted approach. The activities to be undertaken will address three main areas key to the development of a commercial market in LEO as identified by the ISS Transition Report - policy, enabling commercial supply, and enabling demand. The policy work led by the Commercial LEO Development team will support acquisition activities funded by this program, as well as ongoing research, technology demonstration, research, and commercialization activities conducted by the ISS program. Until now, NASA has evaluated many proposed commercial initiatives related to ISS on a case-by-case basis. New,

COMMERCIAL LEO DEVELOPMENT

forward-looking policies developed by the Commercial LEO Development team will provide more transparency to prospective space station users by setting expectations about activities that may be conducted on ISS based on current statute. In addition, new policies will provide more certainty that NASA will avoid competing with commercial entities offering the same or similar services. Finally, NASA will focus on increasing its understanding in a variety of areas including the appropriate role of the United States Government in enabling and expanding commercial LEO development, real and perceived barriers to entry from both supply and demand sides, and understanding marketplace needs and issues.

To gain better insight and help inform recommendations for how the program will move forward with both policy and acquisition efforts, NASA entered into agreements with twelve industry partners in FY 2018 to study the commercialization of LEO. These studies, which were funded by the ISS program, were designed to solicit industry's commercialization concepts, business plans and viability for habitable platforms in LEO, whether using ISS or free flying, that would enable a commercial marketplace in LEO where NASA is one of many customers. The studies also sought to understand the role of government and the evolution of ISS in the roadmap to the commercialization of LEO and how private demand for commercial LEO services could be stimulated in order to sustain a long-term LEO marketplace with primarily non-NASA commercial revenue. An independent executive panel, established to evaluate results from each industry partner, observed that crew/cargo transportation cost is a major barrier to LEO commercialization, impacting both space station operations costs and market demand. Additionally, the panel observed that a long-term LEO marketplace with primarily non-NASA commercial revenue is not viable without a significant transition period during which the U.S. Government continues to make investments in the market and purchases services from it. During this transition period, which will be years in duration, the study participants reported expecting NASA to be an anchor tenant. Based on these observations and several others, the panel will develop a solicitation strategy for Commercial LEO Development and make recommendations to Agency leadership for final acquisition strategy approval.

To enable the supply of commercial space station services, NASA will work with commercial partners on development of capabilities that could serve the needs of the private sector, NASA, and others around the globe. These efforts will focus on enabling, developing, and deploying commercial orbital destinations that would allow NASA to transition from ISS for its low Earth orbit research and technology demonstration requirements, as well as meeting non-NASA demand for such commercial LEO activities. NASA has demonstrated great success through partnerships with industry in developing multiple commercial capabilities for delivery of cargo and crew to the ISS, then competitively purchasing delivery services using those capabilities. NASA intends to apply a similar model for the development of commercial LEO destinations through the Commercial LEO Development program. One of the primary purposes of the Commercial LEO Development program is to ensure that the United States has access to an orbital platform on which to conduct research and develop new technologies.

The Commercial LEO Development program will conduct an open competition for development of commercial LEO destinations in FY 2019. This competition will pursue public-private partnerships to develop LEO destinations that could be module(s) and/or platform(s) attached to the ISS or free flying in LEO. Ultimately, these destinations are intended to meet NASA's long-term needs and ensure that there is not a gap in NASA access to LEO capabilities during the ISS transition. The industry studies commissioned by NASA revealed several credible concepts for commercial LEO modules or platforms, including modules initially attached to ISS then transitioned to free flying destinations; however, several study participants opined that a commercially owned/operated ISS was not considered desirable nor feasible, including its prospective operation as a public-private partnership. Proposals submitted for this competition will also include market analysis and business plans for non-NASA activities. NASA intends to select winning proposals and make initial awards prior to the end of FY 2019.

NASA will also implement a mechanism for funding new emerging ideas beyond the initial module-focused solicitation. The partners engaged through this mechanism will be encouraged to utilize LEO destinations for commercial for-profit activities that are beyond NASA's and the ISS National Laboratory's missions. In the longer term, activities currently supported by NASA and the ISS National Laboratory will be transitioned onto these new destinations once available. This will allow private industry to seek out new emerging commercial activities and demonstrate the viability of commercial human spaceflight markets.

To further enable demand, NASA will engage and collaborate with the Department of Commerce and the Federal Aviation Administration to understand and address real and perceived barriers to entry associated with emerging and potential markets. NASA will also solicit proposals and award demand development activities that may include manufacturing and advanced research capabilities and activities. NASA is continuing to increase the cooperative use of the ISS to enable increased commercial investment and transition to more public-private partnership models. The end goal is where NASA is one of many customers of a commercial market in LEO. Today on ISS, NASA has already enabled increased commercial investment and partnerships through the National Laboratory, agreements such as Nanoracks/Boeing Commercial Airlock, and contracts for commercial services once performed by NASA. The ISS, Commercial Crew, and Crew and Cargo programs will continue working together to solidify the important commercial successes that were enabled by these programs and NASA's commercial and international partners.

Additional studies in focused areas, market surveys, workshops or other activities will be conducted in FY 2019 and FY 2020 to help ensure NASA is making the most effective policy and investment decisions to achieve its long-term goals. As an example, NASA will develop a policy that ensures that NASA or ISS National Laboratory activities avoid competing with the capabilities provided by commercial LEO destinations. Legal, technical and programmatic issues will require further study and coordination among the International Partners and commercial industry to ensure a smooth transition.

Commercial LEO Development will advance the Nation's goals in LEO and exploration by furthering the development and maturity of the commercial space market. This 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 private industry innovation and commercial market incentives.

EXPLANATION OF MAJOR CHANGES IN FY 2020

None.

SCIENCE

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Earth Science	1921.0	--	**1779.8**	1785.6	1779.7	1666.5	1674.6
Planetary Science	2217.9	--	**2622.1**	2577.3	2629.4	2402.4	2350.9
Astrophysics	850.4	--	**844.8**	902.4	965.2	913.5	907.7
James Webb Space Telescope	533.7	375.1	**352.6**	415.1	175.4	172.0	172.0
Heliophysics	688.5	--	**704.5**	638.6	769.3	692.0	709.8
Total Budget	**6211.5**	**6905.7**	**6303.7**	**6319.0**	**6319.0**	**5846.5**	**5815.0**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

SCIENCE

Heliophysics

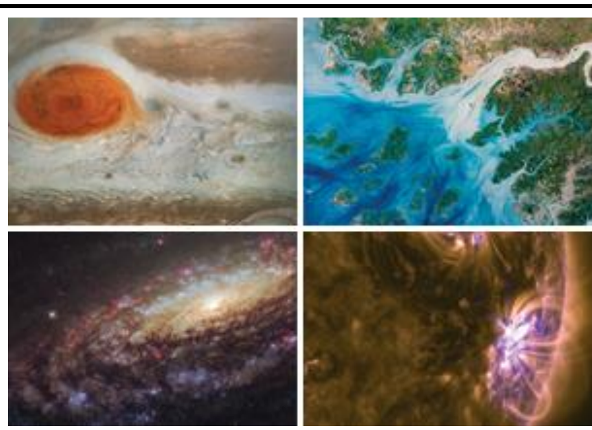
SCIENCE

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Earth Science	1921.0	--	**1779.8**	1785.6	1779.7	1666.5	1674.6
Planetary Science	2217.9	--	**2622.1**	2577.3	2629.4	2402.4	2350.9
Astrophysics	850.4	--	**844.8**	902.4	965.2	913.5	907.7
James Webb Space Telescope	533.7	375.1	**352.6**	415.1	175.4	172.0	172.0
Heliophysics	688.5	--	**704.5**	638.6	769.3	692.0	709.8
Total Budget	**6211.5**	**6905.7**	**6303.7**	**6319.0**	**6319.0**	**5846.5**	**5815.0**
Change from FY 2019			**-602.0**				
Percentage change from FY 2019			**-8.7%**				

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



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 science programs focus on three interdisciplinary objectives:

- Discovering the secrets of the Universe
- Searching for life in the Solar System and beyond
- 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 over time? 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.

SCIENCE

NASA uses the recommendations of the National Academies' decadal surveys as an important input 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, actual budgets, existing technological capabilities, partnership opportunities, and other programmatic factors.

EXPLANATION OF MAJOR CHANGES IN FY 2020

The FY 2020 Budget Request of about $6.3 billion for Science is a significant increase over the FY 2019 Request ($5.9 billion).

This budget continues to reinvigorate robotic exploration of the solar system by providing $2.6 billion for Planetary Science. On November 29, 2018, NASA announced that nine U.S. companies are now eligible to bid on NASA delivery services to the lunar surface through Commercial Lunar Payload Services (CLPS) contracts, as one of the first steps toward long-term scientific study and human exploration of the Moon and eventually Mars. CLPS and other activities in the Lunar Discovery and Exploration program will accelerate in FY 2020. The budget request proposes to launch the Europa Clipper in 2023 on a commercial launch vehicle and initiates a Mars Sample Return mission for possible launch as early as 2026. A Europa Lander mission, which was not supported by the science community in the Planetary Science decadal midterm report, is not funded.

The budget provides $1.78 billion for a focused, balanced Earth science portfolio that supports the priorities of the science and applications communities. The budget restores funding for the Orbiting Carbon Observatory (OCO)-3 and Deep Space Climate Observatory (DSCOVR) Earth-viewing instruments. The budget also supports a robust Venture Class mission cadence and supports the launch of upcoming missions such as Landsat-9, NASA-ISRO Synthetic Aperture Radar (NISAR), Surface Water and Ocean Topography (SWOT) and Sentinel-6A. Consistent with the FY 2019 request, the budget assumes termination of the Pre-Aerosol, Clouds, and ocean Ecosystem (PACE) and Climate Absolute Radiance and Refractivity Observatory (CLARREO) Pathfinder missions. Given present fiscal constraints, existing ocean and climate monitoring missions, and future mission plans from National Oceanic and Atmospheric Administration (NOAA) and international partners, demonstrating expanded measurement capabilities is a lower priority.

The budget provides $845 million for Astrophysics. 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 2021. Funding both Webb and WFIRST at the same time would have required redirecting funding from other programs, disrupting the balance of the overall science portfolio.

The budget provides $353 million for the James Webb Space Telescope. Funding for Webb is consistent with the revised launch date of March 2021.

The budget provides $704 million for Heliophysics. It continues to support the Diversify, Realize, Integrate, Venture, Educate (DRIVE) initiative, the highest priority recommendation in the Heliophysics decadal survey, and enables space weather-related interagency efforts, with a focus on strengthening the feedback between space weather research and operational forecasting needs.

ACHIEVEMENTS IN FY 2018

SCIENCE RESULTS

NASA investments continue to generate productive science and interesting results. In Planetary Science, combined data from three Mars years of observations from the Curiosity rover shows strong seasonal variation of methane at the Martian surface. This variation is much greater than that predicted from the annual surface pressure cycle or ultraviolet variations. These measurements are consistent with small localized sources of methane released from the Martian surface or subsurface reservoirs. There are correlations of the background methane values with atmospheric water vapor and surface temperatures. These suggest possible seeps from buried methane reservoirs and indicate that there remain unknown atmospheric or surface processes occurring in present-day Mars.

In Astrophysics, NASA announced the potential discovery of a huge exomoon around a gas giant planet, Kepler-1625b, which is three times more massive than Jupiter. Astronomers using NASA’s Hubble Space Telescope and Kepler space telescope have assembled compelling evidence for the existence of a moon orbiting a gas-giant planet located 8,000 light-years away. If confirmed by follow-up Hubble observations, this would be the first case of finding a moon outside of our solar system. The candidate exomoon may have edged away from its planet over time, so it could have been much closer billions of years in the past.

In Earth Science, NASA researchers developed a Landslide Hazard Assessment for Situational Awareness model to indicate potential landslide activity in near real-time. The model uses historical satellite-based precipitation data, and a landslide susceptibility map derived from information on slope, geology, road networks, fault zones, and forest loss. When rainfall was extreme and susceptibility values were moderate to very high, a “nowcast” was issued to indicate the times and places where landslides were more probable. The scientists evaluated the nowcasts with an actual global landslide catalog, and found the probability of detection to range from 8 percent to 60 percent. This system provides a near real-time global summary of landslide hazard that may be useful for disaster response agencies and international aid organizations.

In Heliophysics, the Global-scale Observations of the Limb and Disk (GOLD) mission was the first NASA science instrument launched aboard a commercial spacecraft. From its location parked over the western hemisphere in geostationary orbit, the mission enables scientific understanding and situational awareness of ionospheric phenomena that can cause dramatic impacts on communications and other space weather effects. In August, NASA launched the Parker Solar Probe, the first spacecraft to fly into the solar corona (the solar atmosphere), the fastest human-made object and the closest object to the Sun. Already, the small sample of downlinked data is showing that the corona is even more dynamic then ever anticipated.

NASA highlights these and many other scientific results in the pages that follow.

COST AND SCHEDULE PERFORMANCE

SCIENCE

In June 2018 NASA announced a launch delay and cost growth on the James Webb Space Telescope. NASA is currently assessing cost growth on the Mars 2020 mission. 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 20 Science missions, with a total net budget underrun of three percent. Twelve of those missions launched by NASA's original commitment date.

In the last twelve months, NASA launched six orbital Science missions. Four of them (Transiting Exoplanet Survey Satellite (TESS), Gravity Recovery and Climate Experiment (GRACE) Follow-On, Parker Solar Probe, and Global Ecosystem Dynamics Investigation Lidar (GEDI) were under budget. Investigations, Geodesy and Heat Transport (InSight) and Ice, Cloud, and land Elevation Satelitte-2 (ICESat 2), while over their original budgets, saw decreases in expected costs in the last year.

WORK IN PROGRESS IN FY 2019

NASA Science includes about 100 missions and about 85 U.S.-built spacecraft. Most Science missions involve collaboration with international partners or other U.S. agencies. Work on over 35 missions in formulation and development continues; NASA plans to launch OCO-3 and Ionospheric Connection Explorer (ICON) by the end of FY 2019. 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.

Earlier in FY 2019, NASA selected ten proposals for the Development and Advancement of Lunar Instrumentation (DALI), selected the next Heliophysics Explorer Mission of Opportunity (MO), selected the next Astrophysics Medium Explorer, and named nine companies now eligible to bid on NASA delivery services to the lunar surface through Commercial Lunar Payload Services (CLPS) contracts.

By the end of FY 2019, NASA plans to select the next New Frontiers mission, the next Heliophysics Small Explorer missions, the next Astrophysics MO, and the Earth Venture Instruments-5 (EVI-5) instrument. NASA plans to release Announcements of Opportunity for the next Discovery mission, the next Astrophysics Small Explorer and Mission of Opportunity missions, and the next Heliophysics Medium Explorer mission.

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 between NASA and commercial partners. NASA has also launched a pilot program to evaluate how Earth science data from commercial small-satellite constellations could supplement observations from the agency's fleet of orbiting Earth science missions. On September 28 2018, NASA awarded sole-source contracts to acquire test data sets from three private sector organizations.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

In FY 2020, NASA plans to make initial selections of Discovery, Astrophysics Small Explorer and Missions of Opportunity, and Heliophysics Medium Explorer for further study; in FY 2021 NASA will make final selections for development. NASA also plans to launch Mars 2020 and Solar Orbiter, and support the launch of key NASA-provided components on the European Space Agency's Exobiology on Mars (ExoMars) 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 improves 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 (2017 - 2027). The primary recommendations were:

- <u>Complete the program of record, including maintaining the Venture Class program and completing missions currently in formulation and development.</u> This budget supports the recommendation, except for proposals to terminate funding for PACE and CLARREO Pathfinder.
- <u>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.</u> The budget supports the recommendation.
- <u>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).</u> The budget supports the recommendation, enabling the start of one Designated Observable mission within the budget window.
- <u>Establish a new competed "Explorer" flight line to provide opportunities for cost-capped medium-size instruments and missions.</u> Due to budget limitations and other priorities, this budget does not establish an Earth Explorer program.
- <u>Establish an "Incubator Program" to mature specific technologies for important – but presently immature – measurements.</u> The 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 will develop 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 also is building the next Mars rover, which will launch in 2020 and 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 completed the first fly-by of a Kuiper Belt Object; NASA is also operating spacecraft at Mars, Jupiter, and the Moon, and has begun to orbit and study the potentially hazardous asteroid Bennu, with the intention of capturing and returning a sample to Earth.

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 Announcements of Opportunity (AO), 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. The out-year budget supports an approximate 30-month cadence for future launches. In addition, the newly created Lunar Discovery and Exploration program will encompass the Lunar Reconnaissance Orbiter and Lunar Future missions' projects.
- 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 will result in the selection of one new mission in 2019.
- 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 continued formulation of the Europa Clipper project. The budget includes $109 million in FY 2020 for studies and technology development towards a Mars sample return mission.
- 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 that 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). 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, the 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.

SCIENCE

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 Astro2010 Decadal Survey assumed 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, continued operations of SOFIA beyond the end of its prime mission in FY 2019, and 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 participation in X-ray Imaging and Spectroscopy Mission (XRISM), Japan's planned recovery mission.
- 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. This budget proposes termination of the WFIRST mission in FY 2020 due to its significant cost and higher priorities within NASA, including completing the delayed 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 is estimated to cost $3.2-$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, and 2019.
- 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. 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 will receive the recommendations from the Senior Review of operating Astrophysics missions, which could inform 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, but also relate directly to our ability to live in space as they produce space weather, which can affect human technological infrastructure and activities. 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 assumed launch of Van Allen Probes by 2012, Interface Region Imaging Spectrograph (IRIS) by 2013, 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 will launch the ESA-led SOC mission by FY 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 supports 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 2-3 years. NASA launched IRIS in 2013, GOLD in 2018, and this budget supports the launch of ICON in 2019. The proposed out-year budgets, if realized, would enable the next launch around 2022, and 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 4-year cadence. This budget supports launch of the IMAP mission in about 2024. NASA will competitively select STP strategic missions from principal investigator-led proposals. The program will also directly benefit from current investments in the CubeSat/SmallSat initiative.
- Implement a large Living with a Star (LWS) mission to study Global Dynamic Coupling with a launch in 2024. NASA has initiated a Science and Technology Definition Team for the Geospace Dynamics Constellation (GDC) mission to leverage technical advancements and enable cost-effective solutions, in anticipation of soliciting mission concept studies around 2020.

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)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Earth Science Research	461.6	--	**447.9**	466.9	484.1	508.1	532.4
Earth Systematic Missions	899.4	--	**719.2**	701.5	664.1	501.5	481.3
Earth System Science Pathfinder	242.0	--	**275.4**	255.1	253.0	265.2	248.3
Earth Science Data Systems	204.4	--	**214.4**	229.0	239.3	250.1	267.7
Earth Science Technology	60.4	--	**69.6**	79.2	82.8	84.6	86.4
Applied Sciences	53.2	--	**53.3**	53.9	56.3	57.0	58.5
Total Budget	**1921.0**	**--**	**1779.8**	**1785.6**	**1779.7**	**1666.5**	**1674.6**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

Earth Science

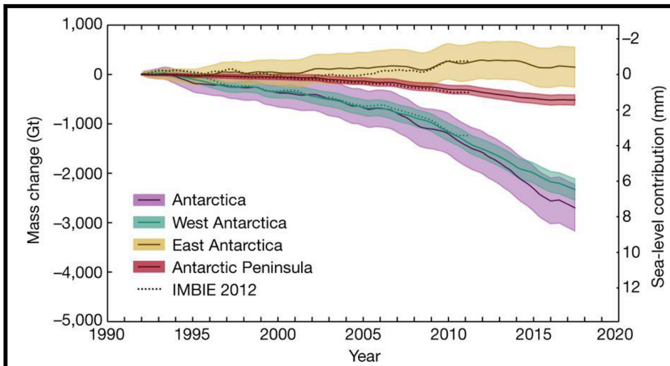
EARTH SCIENCE RESEARCH

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Earth Science Research and Analysis	344.3	--	**296.2**	314.2	320.0	322.3	325.7
Computing and Management	117.4	--	**151.7**	152.7	164.2	185.9	206.7
Total Budget	**461.6**	**--**	**447.9**	**466.9**	**484.1**	**508.1**	**532.4**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



The Antarctic Ice Sheet is an important indicator of climate change and a driver of sea-level rise. Using modeling of satellite observations of the ice sheet's changing volume, flow and gravitational attraction, this chart shows that the surface mass balance (the net balance between the processes of accumulation and ablation on a glacier's surface) lost 2,720 ± 1,390 billion tons of ice between 1992 and 2017, which corresponds to an increase in mean sea level of 7.6 ± 3.9 millimeters (0.3 ± 0.15 inches).

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 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.

- 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 2020

Consistent with the 2019 Budget, the request eliminates funding for new Carbon Monitoring System (CMS) awards and continues the funding for 2018 and 2019 awards. The funding for the continued CMS awards is in the Earth Science R&A project. Missions that monitor carbon such as Orbiting Carbon Conservatory-2 (OCO-2) will continue operations and Orbiting Carbon Conservatory -3 (OCO-3) will launch later in FY 2019.

ACHIEVEMENTS IN FY 2018

Observations at the NASA Micro-Pulse Lidar Network site in Fairbanks, Alaska reported unusually deep wintertime cirrus clouds, exceeding 13 km above mean sea level. Such occurrences are quite rare, both regionally and seasonally, based on a 2006–2015 climatology record developed from Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) measurements. The data indicate that polar meteorology is undergoing significant change and cloud macrophysical properties as well as occurrence characteristics may prove important to predict potential changes in the polar climate.

Recently published research provides observational evidence for feedbacks that amplify the short-term hydrological response associated with the warm phase of the El Niño-Southern Oscillation (ENSO). The study used Atmospheric Infrared Sounder (AIRS) observations and were crucial to investigate the regional intensification of the tropical hydrological cycle during ENSO, and showed that much larger local changes to clouds and precipitation occur than would be expected. Other studies demonstrated the use of AIRS observations in new ways in order to improve tropical cyclone and typhoon forecasts.

Following the delivery of science products from the Cyclone Global Navigation Satellite System (CYGNSS) mission, researchers conducted intensive calibration/validation activities during the very active 2017 Atlantic hurricane season using coincident "ground truth" wind speed measurements by the National Oceanic and Atmospheric Administration (NOAA) P-3 hurricane hunter aircraft (specifically, using dropsondes and the Stepped Frequency Microwave Radiometer sensors carried on those aircraft). Over the past year, scientists reported results from these validation activities and published a number of additional papers in this period, which document various aspects of CYGNSS performance. These include improvements in hurricane forecasting using CYGNSS data, improvements in temporal and spatial sampling of tropical convective systems with CYGNSS, and most notably, the ability to measure soil moisture and image flood inundation over land.

EARTH SCIENCE RESEARCH

Over the past year, NASA researchers developed a Landslide Hazard Assessment for Situational Awareness (LHASA) model to indicate potential landslide activity in near real-time. The combined satellite-based precipitation estimates from the multisatellite precipitation analysis products (based on Tropical Rainfall Measuring Mission data) and the integrated multisatellite retrievals (based on the Global Precipitation Measurement data) with a landslide susceptibility map were derived from information on slope, geology, road networks, fault zones, and forest loss. When rainfall was considered to be extreme and susceptibility values were moderate to very high, a “nowcast” was issued to indicate the times and places where landslides were more probable. The scientists evaluated the LHASA nowcasts with a global landslide catalog, and found the probability of detection to range from 8 percent to 60 percent, depending on the evaluation period, precipitation product used, and the size of the spatial and temporal window considered around each landslide point.

A study published in FY 2018 used satellite remote sensing and climate reanalysis data to fingerprint the sensitivity of Alaska’s ecosystems to changing environmental conditions and disturbances. Approximately 13 percent (~174,000 ± 8700 km2) of Alaska has experienced change over the last 32 years, with the majority of change processes occurring in coastal, riverine, and boreal ecozones (e.g. wildfire, glacial retreat, shrub expansion). Increasing air temperatures have generally promoted vegetation growth, while increases in evaporation have resulted in drought stress predisposing vegetation to mortality from other stressors.

Researchers developed species monitoring tools that track species distribution and abundance using a combination of in-situ and satellite data. The mapping application for penguin populations and projected dynamics project uses Landsat measurements to forecast global Adélie penguin population and inform conservation decision making in the Southern Ocean. This toolset has been used by several other projects to identify previously unknown populations of Adélie penguins, determined that the Danger Islands off the northern tip of the Antarctic Peninsula serves as a seabird hotspot, and has been applied to discovery of other Antarctic bird populations.

The EXport Processes in the Ocean from RemoTe Sensing (EXPORTS; https://cce.nasa.gov/ocean_biology_biogeochemistry/exports/index.html) project was a major field campaign designed to advance the utility of NASA ocean color assets to predict how changes in ocean primary production impact the global carbon cycle. Competitively selected researchers that comprised the EXPORTS science team held three science and planning meetings over 2017-2018, and began the first campaign in August-September 2018. This 2018 campaign took place in the Northeast Pacific and employed two research vessels as well as a wide array of autonomous platforms to complement the shipboard data.

The fourth and last North Atlantic Aerosols and Marine Ecosystems Study (NAAMES; http://naames.larc.nasa.gov) cruise in the North Atlantic was completed in April 2018 with a four-week duration. The project combines atmospheric and oceanographic airborne and ship observations with continuous satellite sensor records to define environmental and ecological controls on plankton communities and to improve predictions of their structure and function in a warmer future ocean. To date scientists have published fifteen peer-reviewed papers.

The NASA-European Space Agency ice sheet mass balance intercomparison project demonstrated, from a comprehensive suite of satellite measurements, that Antarctica is losing mass overall and that East Antarctica is in balance to within measurement uncertainties. The East Antarctic result is particularly important, because previous assessments had yielded contrasting estimates. Consistent with this result, a new study, using Landsat imagery, showed increased West Antarctic and unchanged East Antarctic ice discharge over the last seven years, which became one of the journal's most downloaded papers.

Details of ice-ocean interaction continue to be revealed, and in the last year researchers developed new approaches to both quantification and characterization of the processes. Researchers reviewed overall links between tides and the ice sheets, making recommendations on the data needed to ascertain tidal effects. For Greenland, parameterizations of fjord thermal energy fluxes demonstrated the critical role of fjord-glacier geometry and discharge plume dynamics. Another investigation demonstrated how differences in geometrical setting modulate response to oceanic warming for two glaciers in Northeast Greenland.

For Antarctica, researchers reviewed their projected increased heating and melting impacts of tides on the Filchner-Ronne shelf. A fully coupled ice-ocean model better reproduced the observed retreat of the Thwaites Glacier and projected continued mass loss at a sustained rate over the coming decades.

For Asia, NASA's High Mountain Asia Team entered its second year with the publication of various results. Most importantly, scientists, in three separate publications, developed the first, broad-scale high-resolution digital elevation models for the High Mountain Asia (HMA) region from stereo satellite imagery. In addition, researchers assessed rainfall-triggered landslide hazards for HMA and the rest of the globe, and created a new approach to assessing challenging debris-covered glaciers. The researchers also studied the controls on glacial lake formation and evolution, which is critical to hazard assessment for glacial outburst flood events. The American Geophysical Union's EOS magazine highlighted this article as a research spotlight in May 2018.

A team of researchers used observations of temperature and salinity from NASA's Oceans Melting Greenland mission to illustrate how vigorous entrainment of warm subsurface water causes accelerated mass loss, thinning, and retreat of a glacier in northwest Greenland. Similar to Greenland, the ocean's destabilizing effect on land ice sheets is also evident in Antarctica. Another study identified ocean warming as a primary contributor to the failure and eventual breakup of the Antarctic ice shelf, and ocean circulation as the main control in the distribution of melt waters within the Antarctic shelves.

A new study demonstrates how the use of sea surface salinity improves the predictive skill of extreme precipitation over the continental U.S., ranking salinity as the most important predictor compared to the other ten climate indices. Owing to its sensitivity to freshwater flux, salinity serves as an indicator of the ocean water cycle in the subtropical Atlantic, which plays the dominant role in sustaining the moisture supply over the mid- and southwestern United States. Utilizing pre-season information of sea surface salinity in the subtropical ocean significantly improves AI-based rainfall prediction.

NASA scientists released a new product of the Estimating the Circulation and Climate of the Ocean (ECCO) global ocean state, based on a variety of multi-decadal NASA observations (e.g. altimetry, SST, GRACE, Aquarius,) and dynamical physical constraints. ECCO continues to be a flagship ocean reanalysis, supporting a range of applications in climate research, including sea level and heat transport, global sea surface temperature, vertical heat redistributions, and high latitude and sea-ice dynamics. A number of recent studies position ECCO as a strong member within the global ocean synthesis and reanalysis system, highlighting ECCO's estimates of regional sea level, Arctic sea-ice covers, and mixed-layer variability and teleconnection patterns.

Groundbreaking research analyzed GPS vertical displacements recording solid Earth's elastic response to infer changes in water storage across the western U.S. from January 2006 to October 2017. They found that of the 24 mm of uplift of the Sierra Nevada from October 2011 to October 2015, just 5 mm is produced by Central Valley groundwater loss, less than 2 mm is tectonic uplift, and 17 mm is solid Earth's elastic response to water loss in the Sierra Nevada. They track tens of cubic kilometers of water volume gain and loss throughout the study, including the loss of 45 cubic kilometers of water during severe drought from October 2011-2015. They proposed that uplift of the adjacent Sierra Nevada Mountains is either tectonic uplift or solid Earth's elastic response to unloading of Central Valley groundwater.

Fast-moving, highly destructive debris flows triggered by intense rainfall are one of the most dangerous post-fire hazards, but assessing debris flows with remote sensing has been challenging. A study used Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) data spanning the 2017 Thomas fire in southern California, and researchers developed an innovative approach to analyze UAVSAR high-resolution L-band Synthetic Aperture Radar (SAR) data with both polarimetric and interferometric imagery to map the fire extent, which enabled them to characterize debris flow paths. The results also compare nicely with imagery from Planet Labs Dove satellites. This study shows the potential to track debris flows with synthetic aperture radar.

The Airborne Science project conducted several major airborne campaigns including Operation IceBridge, HyspIRI California, HyspIRI Hawaii, Long Island Sound Tropospheric Ozone Study, India Hyperspectral imaging, flight of AVIRIS-ng in Europe (coordinated with the University of Zurich and the European Space Agency), and the Arctic-Boreal Vulnerability Experiment (ABoVE) in Alaska and northwest Canada. In addition to these major campaigns, the Airborne Science project conducted multiple smaller investigations including imaging the effects of Hurricane Florence and Irma as well as monitoring Mt Kilauea eruption flows.

UAVSAR conducted 81 science/engineering flights totaling 402 flight hours. Scientists published overall science results based on UAVSAR data in 30 refereed journal papers, covering topics in solid-Earth science, applied science, cryosphere, hydrology, land cover/land use change, space archaeology, and terrestrial ecology. See continuously updated publications at: http://uavsar.jpl.nasa.gov/cgi-bin/publications.pl.

The computing infrastructure at the NASA Center for Climate Simulations supported experimental weather forecasts of 12 km atmospheric global resolution and other higher resolution experimental runs and experimental re-analyses. NASA completed the integration of the second module in the prototype Modular Computing Facility (MCF) within the High-End Computing Capability project, allowing the Electra computing system housed in the computing modules to expand to 8.32 thousand million million floating-point operations per second (petaflops). NASA also completed the design of the future MCF; site preparation and construction started in early summer of FY 2018.

NASA's Space Geodesy project continued the development and deployment of a modern network that includes co-located next-generation Very Long Baseline Interferometry, Satellite Laser Ranging, Global Navigation Satellite System (GNSS), and Doppler Orbitography and Radiopositioning Integrated by Satellite stations. NASA completed the modernization of the Global GNSS Network, initiated in 2016. Modernized GGN stations will provide NASA and the public with access to measurements from all major GNSS constellations (global positioning system (GPS), GLONASS, BeiDou, and Galileo).

The Global Learning and Observations to Benefit the Environment (GLOBE) project completed a community-driven strategic planning process and released a new five-year strategic plan in the spring. Focus then turned to engaging the GLOBE community in identifying their role to achieve the planned objectives. Over the summer, NASA sponsored the sixth GLOBE learning expedition in Killarney, Ireland, bringing together almost 400 teachers, students, and scientists from 40 countries for an intensive week of scientific, education, and cultural exchange. NASA also made improvements to the GLOBE website, visualization system, and data system to improve usability for the community. The GLOBE project added a new carbon cycle protocol and released the land cover module in the GLOBE Observer.

WORK IN PROGRESS IN FY 2019

Earth Science Division (ESD) research will continue with competitively selected projects from prior year Research Opportunities in Earth and Space Science (ROSES) solicitations.

NASA’s Operation IceBridge continues to make measurements of ice sheet and sea ice thickness in both the Arctic and the Antarctic using both NASA DC-8 and P-3 research aircraft. In addition to the usual spring and fall flights in each hemisphere, there will also be an Arctic summer-time "melt season" campaign using NASA's Gulfstream V aircraft. This will be coordinated with observations in support of Arctic Boreal and Vulnerability Experiment (ABoVE) since researchers can synergistically use the same remote sensing payload for studies of land and ice at northern high latitudes.

NASA plans to fly the Gulfstream III with the L-band SAR to collect data along with ground measurements in the central United States in preparation for the NASA-ISRO Synthetic Aperture Radar (NISAR) Mission. UAVSAR will collect a series of observations simulating the collection pattern and NISAR with the data converted to that NISAR data format. This activity will coordinate with the NASA-Indian Space Research Organization (ISRO) L-band/S-band activity also planned for 2019.

The Space Geodesy Project (SGP) in collaboration with the University of Texas will continue building the facilities for the new multi-technique McDonald Geodetic Observatory in Texas. The build of the new NASA very long baseline interferometry global observing system (VGOS) antenna and its signal chain is underway and scheduled for implementation at the site and commissioning in early 2019. In addition, the development for the new NASA satellite laser ranging station in Ny-Ålesund, Svalbard is underway based on an agreement with the Norwegian Mapping Authority. The unique station location above the Arctic Circle will be particularly valuable in supporting the tracking of NASA’s polar orbiting satellites. 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.

A key aspect of the GLOBE project is the content management system that supports GLOBE observations, facilitates teacher training, and enables students and researchers to access GLOBE observations from around the world. This system will undergo a major software upgrade during FY 2019. While this is ongoing, GLOBE will continue activities including three major global Earth system science campaigns that connect to NASA missions and research: Trees around the Globe, Mission Mosquito, and Urban Heat Island. These campaigns will engage students and other citizen scientists in authentic experiences that add to our understanding of the Earth environment.

EARTH SCIENCE RESEARCH

KEY ACHIEVEMENTS PLANNED FOR FY 2020

ESD research will continue with competitively selected projects from prior year ROSES solicitations. Notable new research solicitations are: i) the implementation of a new Interdisciplinary Research in Earth Science solicitation with several interdisciplinary themes of emerging high priority research and ii) a repurposed Satellite Calibration Interconsistency Study solicitation, changed to focus on development of additional and/or enhanced products from operational geostationary satellites.

NASA will select new airborne campaigns from the ROSES 2019 solicitation, and begin implementing these activities in FY 2020. Some of these large field campaigns may have small "precursor" campaigns in 2019.

Additional observations (both airborne and surface-based) for a snow-focused effort (a successor to the 2016 SnowEx campaign) will be carried out, making use of multiple approaches (both active and passive) that will improve our knowledge of the measurement of snow distribution and properties (including snow water equivalent).

ABoVE's second major coordinated airborne campaign in Alaska and northwestern Canada as follow up to the 2017 campaign.

NASA and ISRO are actively considering the possibility of flying a combined L-band/S-band radar instrument aboard a NASA platform in the U.S., which could start as early as FY 2019 depending on availability of the instrument, platform, and implementing agreements. The focus of this would include terrestrial ecology, cryospheric science, terrestrial hydrology, Earth Surface/Interior, and disaster-related observations. This would be a precursor effort to the planned NISAR satellite mission planned for launch in 2022.

Earth Day 2020 will mark the 25th anniversary of the GLOBE Program. NASA has begun to plan for this major milestone, including ways it can serve as a springboard into the next phase of GLOBE science.

Program Elements

CARBON CYCLE SCIENCE TEAM

Carbon Cycle Science Team funds research on the distribution and cycling of carbon among Earth’s active land, ocean, and atmospheric reservoirs. After FY 2020, NASA will fund carbon cycle science through the Carbon Cycle and Ecosystems focus area under the Research and Analysis project.

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.

EARTH SCIENCE 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. For example, 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, it 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 base 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

The Space Geodesy Project encompasses the development, operation, and maintenance of a global network of space geodetic technique instruments, a data transport and collection system, analysis and the public disseminations 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. Geodesy is the science of measuring Earth's shape, gravity, and rotation and how these properties change over time. The SGP manages the operations and development of NASA's space geodetic network that is comprised of the following major space geodetic observing systems: Very Long Baseline Interferometry, Satellite Laser Ranging, and Global Navigation Satellite System. It currently develops the next generation space geodetic stations. The Space Geodesy project began in 2011. It is a Goddard Space Flight Center and Jet Propulsion Laboratory partnership, with participation from the Smithsonian Astrophysical Observatory.

EARTH SCIENCE DIRECTED RESEARCH AND TECHNOLOGY

Earth Science Directed Research and Technology 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 Earth System Science Projects to study the dynamics of Earth's environment, focused on atmosphere, hydrology, soil, and land cover. Students take measurements, analyze data, and participate in research in collaboration with scientists.

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 the ability to analyze large volumes of satellite data quickly. The system currently has approximately 90,000 computer processor cores.

HIGH END COMPUTING CAPABILITY (HECC)

HECC focuses on the Endeavour, Merope, Pleiades, and Electra 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 346,000 computer processor cores, support NASA's aeronautics, human exploration, and science missions. For example, the systems are used to model the aerodynamic characteristics of the Space Launch System at different attach angles and different air speeds. The systems also analyze the Kepler mission observation data to search for habitable exoplanets.

EARTH SCIENCE RESEARCH

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 2019	ROSES-2018 selection within six to nine months of receipt of proposals
Q2 FY 2019	ROSES-2019 solicitation release
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

Program Management & Commitments

Program Element	Provider
Carbon Cycle Science Team	Provider: Various Lead Center: HQ Performing Center(s): HQ, JPL, GSFC Cost Share Partner(s): USGCRP and Subcommittee on Ocean Science and Technology (SOST) agencies
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): None
Scientific Computing	Provider: GSFC Lead Center: HQ Performing Center(s): GSFC Cost Share Partner(s): None
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 and Analysis	Provider: Various Lead Center: HQ Performing Center(s): All NASA Centers Cost Share Partner(s): USGCRP and SOST agencies

EARTH SCIENCE RESEARCH

Program Element	Provider
High-End Computing Capability	Provider: ARC Lead Center: HQ Performing Center(s): ARC Cost Share Partner(s): None
Directorate Support	Provider: Various Lead Center: HQ Performing Center(s): All NASA Centers Cost Share Partner(s); None
Fellowships and New Investigators	Provider: Various Lead Center: HQ Performing Center(s): All NASA Centers Cost Share Partner(s): None
Space Geodesy	Provider: Various Lead Center: GSFC Performing Centers: GSFC, JPL Cost Share Partners: None
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): None

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.

EARTH SCIENCE RESEARCH

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Relevance	Earth Science Advisory Committee	2018	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	2019; annually

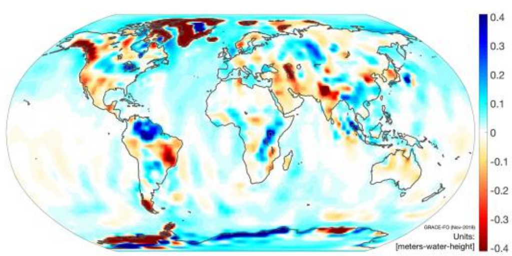
EARTH SYSTEMATIC MISSIONS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Surface Water and Ocean Topography Mission (SWOT)	105.9	109.1	**82.2**	63.9	32.8	11.5	9.5
NASA-ISRO Synthetic Aperature Radar (NISAR)	67.1	146.0	**114.0**	68.2	81.0	32.4	22.8
Landsat 9	175.8	162.3	**108.9**	94.2	10.8	2.9	3.0
Sentinel-6	53.4	70.4	**64.5**	20.4	14.9	35.3	52.9
Other Missions and Data Analysis	497.2	--	**349.7**	454.8	524.7	419.4	393.2
Total Budget	**899.4**	**--**	**719.2**	**701.5**	**664.1**	**501.5**	**481.3**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



In this preliminary GRACE-FO mass change map from early November 2018, the measured mass loss (warm colors – red) and mass gain (cold colors – blue) will enable detailed assessments of how the worldwide water cycle and resources are evolving on global and regional scales relative to long-term averages.

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 a central element throughout the ESM program. More than half of 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 2020

Consistent with the FY 2018 and FY 2019 Budget Request, 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 selected ocean color and atmospheric aerosol measurement capabilities ensuring continuity and additional capability in the measurement record, particularly for ocean color. 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 the early stages of implementation and are eliminated to achieve cost savings.

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION

Formulation	Development	Operations

FY 2020 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	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	199.4	105.9	109.1	**82.2**	57.0	17.9	0.0	0.0	0.0	571.5
Operations/Close-out	0.0	0.0	0.0	**0.0**	6.9	14.9	11.5	9.5	4.0	46.7
2019 MPAR LCC Estimate	**336.1**	**105.9**	**109.1**	**82.2**	**63.9**	**32.8**	**11.5**	**9.5**	**4.0**	**754.9**
Total Budget	**336.1**	**105.9**	**109.1**	**82.2**	**63.9**	**32.8**	**11.5**	**9.5**	**4.0**	**754.9**
Change from FY 2019				**-26.9**						
Percentage change from FY 2019				**-24.7%**						

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 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 the understanding of 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, through broad swath altimetry, will make high-resolution measurements of ocean circulation, its kinetic energy, and its dissipation. 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 precise measurement 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.

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

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION

Formulation	Development	Operations

cycle: 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 2020

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 2018

The SWOT project completed the payload system and project Critical Design Reviews (CDRs), initiated build of the KaRIn instrument, completed testing of the Advanced Microwave Radiometer (AMR) instrument, and completed development of the LRA and X-band Telecom subsystem.

WORK IN PROGRESS IN FY 2019

The SWOT project will complete the development of the GPSP instrument and deliver it to CNES, initiate integration and testing of the KaRIn instrument, and initiate integration and testing of the nadir payload module.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

The SWOT project will complete the System Integration Review (SIR), the development of the KaRIn instrument, the nadir payload module integration and testing, and the integrated payload module integration and testing.

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

The milestones remain consistent with the confirmation baseline date, with the exception of 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 2020 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

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 (mths)
2017	571.5	>70	2019	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 (*j*oint *c*onfidence *l*evel); all other CLs (*c*onfidence *l*evels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION

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:	**571.5**	**571.5**	**0**
Aircraft/Spacecraft	0	0	0
Payloads	181.6	275.8	94.2
Systems I&T	4.9	4.7	-0.2
Launch Vehicle	131.3	107.8	-23.5
Ground Systems	34.7	28.8	-5.9
Science/Technology	46.7	34.3	-12.4
Other Direct Project Costs	172.3	120.2	-52.1

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): None	N/A
GPSP	Provides orbit determination	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): None	N/A

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
LRA	Provides orbit determination	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): None	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): None	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
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): None	N/A

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: The KaRIn RFU delivery from the CNES is not timely, Then: It will delay delivery of the KaRIn instrument.	The project is working closely with CNES to reduce the impact on the KaRIn development schedule; the RFU Engineering Model may serve as an alternate for the Flight Model during selected testing, and the team may reorder KaRIn Flight Model integration & test activities, if necessary.

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.

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

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
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 APERATURE RADAR (NISAR)

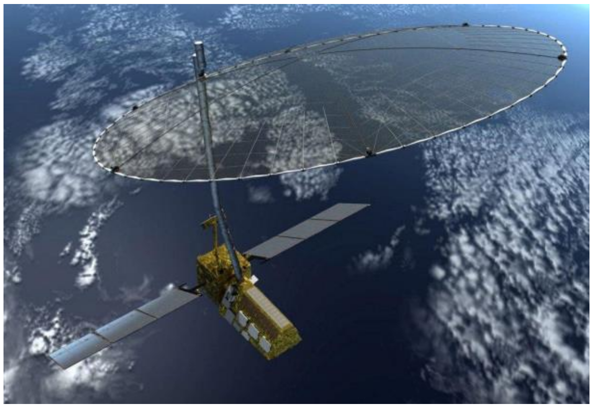
Formulation	Development	Operations

FY 2020 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	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	211.9	67.1	146.0	**114.0**	68.2	60.1	0.0	0.0	0.0	667.4
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	20.9	32.4	22.8	24.9	100.9
2019 MPAR LCC Estimate	**328.9**	**67.1**	**146.0**	**114.0**	**68.2**	**81.0**	**32.4**	**22.8**	**24.9**	**885.3**
Total Budget	**328.9**	**67.1**	**146.0**	**114.0**	**68.2**	**81.0**	**32.4**	**22.8**	**24.9**	**885.3**
Change from FY 2019				**-32.0**						
Percentage change from FY 2019				**-21.9%**						

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



The NISAR satellite, 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, such as 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 Surveys endorsed the NISAR science objectives. NISAR is a collaborative mission with the Indian Space Research Organization (ISRO).

NASA-ISRO SYNTHETIC APERATURE RADAR (NISAR)

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2020

None.

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 higher resolution and testing, and spacecraft operations. NISAR has a prime mission of three years.

NISAR will implement enhanced data acquisition and data downlink capability 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.

ACHIEVEMENTS IN FY 2018

The project completed all subsystem Critical Design Reviews (CDRs) as planned in FY 2018 and started building flight hardware after successful manufacturing readiness reviews. The project successfully completed all engineering model testing except for the power distribution unit and pyro firing assembly. The project worked closely with ISRO and signed all joint Interface Control Documents.

WORK IN PROGRESS IN FY 2019

The project successfully completed the CDR in October 2018. The project will support the S-band SAR Detailed Design Review and the Spacecraft CDR conducted by ISRO during FY 2019. The project will continue building and testing flight hardware and system integration and testing of the L-band SAR. The project will begin the development of the SNWG's recommended data acquisition and data downlink capability enhancements during FY 2019.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

In FY 2020, the project will receive the S-band SAR and start system integration and testing of the L-band and S-band SAR. The project will continue its system integration and testing of the entire payload along with the reflector and boom assembly in advance of the pre-shipment review in FY 2021.

NASA-ISRO SYNTHETIC APERATURE RADAR (NISAR)

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2019 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	Dec 2019
Payload delivery to ISRO	Feb 2021	Feb 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 (mths)
2017	661	>70%	2019	667.4	0.1%	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 (*j*oint *c*onfidence *l*evel); all other CLs (*c*onfidence *l*evels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

NASA-ISRO SYNTHETIC APERATURE 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**	667.4	6.4
Aircraft/Spacecraft	77.1	92.7	15.6
Payloads	211.1	265.8	54.7
Systems I&T	23.0	20.1	-2.9
Launch Vehicle	0.6	0.4	-0.2
Ground Systems	72.6	61.7	-10.9
Science/Technology	28.2	29.0	0.8
Other Direct Project Costs	248.4	197.6	-50.8

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
Spacecraft	Provides platform for the payload	Provider: ISRO Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ISRO	N/A

NASA-ISRO SYNTHETIC APERATURE RADAR (NISAR)

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
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 launch vehicle reliability does not meet the NASA-ISRO joint requirements, Then: There may be a significant delay in the launch date.	The project documented a requirement of five successful launches of the GSLV prior to the NISAR launch. ISRO completed four successful GSLV launches in 2015, 2016, 2017 and 2018. NASA expects that ISRO will successfully complete the remaining launch before the NISAR launch. If there is a launch delay, the project carries reserve to mitigate the potential schedule risk.
If: The NISAR reflector does not deploy in-orbit properly, Then: The project cannot meet the mission success criteria.	The project is addressing the risk by establishing a Deployment Phase team jointly led by JPL and ISRO experts in the near future. The team will address, study and mitigate the risk by extensive analysis and testing before payload integration and test.

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 APERATURE 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	Dec 2019
Performance	SRB	Dec 2019	System Integration Review (SIR)	TBD	Oct 2021
Performance	SRB	Oct 2021	Operational Readiness Review (ORR)	TBD	N/A

LANDSAT 9

Formulation	Development	Operations

FY 2020 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	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	80.3	175.8	162.3	**108.9**	92.9	8.0	0.0	0.0	0.0	628.2
Operations/Close-out	0.0	0.0	0.0	**0.0**	1.3	2.8	2.9	3.0	6.1	16.1
2019 MPAR LCC Estimate	**315.1**	**175.8**	**162.3**	**108.9**	**94.2**	**10.8**	**2.9**	**3.0**	**6.1**	**879.0**
Total Budget	**315.1**	**175.8**	**162.3**	**108.9**	**94.2**	**10.8**	**2.9**	**3.0**	**6.1**	**879.0**
Change from FY 2019				**-53.4**						
Percentage change from FY 2019				**-32.9%**						

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

The Landsat 9 mission is a partnership between NASA and the U.S. Geological Survey. Landsat 9 will continue the Landsat program’s critical role in monitoring, understanding and managing the land resources needed to sustain human life.

PROJECT PURPOSE

Landsat 9 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.

The Landsat 9 mission 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-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 46-year Landsat record and will evolve through investment in, and introduction of, new sensor and system technologies.

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

LANDSAT 9

Formulation	Development	Operations

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 2020

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 2018

The Landsat 9 project completed its Key Decision Point-C (KDP-C) review, its mission-level Critical Design Review (CDR) and entered into the final design and fabrication activities phase.

WORK IN PROGRESS IN FY 2019

The Landsat 9 project plans to complete its System Integration Review (SIR), complete final design and fabrication, and prepare for its FY 2020 KDP-D review.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

NASA will conduct the Landsat 9 KDP-D review and enter into the spacecraft assembly and observatory integration and test phase of development. The Landsat 9 project will complete the integration and testing of Landsat 9 and its Operational Readiness Review (ORR) in preparation for shipment to the launch site.

LANDSAT 9

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

The November 2021 launch estimate reflects the agency baseline commitment made at the Key Decision Point-C review in December 2017. Currently, NASA is on track to launch Landsat-9 in December 2020.

Milestone	Confirmation Baseline Date	FY 2020 PB Request
KDP-C	Dec 2017	Dec 2017
Critical Design Review	Apr 2018	Apr 2018
System Integration Review	Aug 2019	Aug 2019
KDP-D	Dec 2019	Dec 2019
Operational Readiness Review	Sept 2020	Sept 2020
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 (mths)
2018	634.2	>70%	2019	628.2	-1%	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 (*j*oint *c*onfidence *l*evel); all other CLs (*c*onfidence *l*evels) 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:	**634.2**	**628.2**	**-6.0**
Aircraft/Spacecraft	98.1	101.8	3.7
Payloads	107.6	109.7	2.1
Systems I&T	0	0.8	0.8

LANDSAT 9

Formulation	Development	Operations

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
Launch Vehicle	154.4	154.4	0.0
Ground Systems	17.2	17.9	0.7
Science/Technology	9.2	9.2	0.0
Other Direct Project Costs	247.7	234.4	-13.3

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 Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): 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	
Spacecraft	Provide a platform with performance commensurate with OLI-2 and TIRS-2 requirements.	Provider: Northrop Grumman Innovation Systems Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): 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	

LANDSAT 9

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
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	
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	

Project Risks

Risk Statement	Mitigation
If: Schedule conflicts between Landsat 9 and other projects that have a higher national priority for test facilities or other resources at the two major supply contractors arise Then: This could cause an adverse effect on the Landsat 9 mission schedule.	The Landsat 9 project management team is proactively working with the other project managers and senior contractor personnel to mitigate schedule conflicts as they arise.

Acquisition Strategy

The acquisition strategy for Landsat 9 is the same strategy used for Landsat 8, formerly known as the Landsat Data Continuity Mission. NASA selected Ball to provide the OLI-2 instrument through a sole source procurement. NASA selected Northrop Grumman Innovation Systems (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.

LANDSAT 9

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
OLI-2	Ball	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	Systems Requirement Review (SRR)	Successful	Sept 2017
Performance	SRB	Sept 2017	Preliminary Design Review (PDR)	Successful	Apr 2018
Performance	SRB	Apr 2018	Critical Design Review (CDR)	Successful	Aug 2019
Performance	SRB	Aug 2019	System Integration Review (SIR)	TBD	Sept 2020
Performance	SRB	Sept 2020	Operational readiness Review (ORR)	TBD	N/A

SENTINEL-6

Formulation	Development	Operations

FY 2020 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	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	77.5	53.4	70.4	**64.5**	20.1	9.4	32.0	49.0	89.6	465.9
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.3	5.5	3.3	3.9	25.5	38.4
2019 MPAR LCC Estimate	**92.9**	**53.4**	**70.4**	**64.5**	**20.4**	**14.9**	**35.3**	**52.9**	**115.1**	**519.8**
Total Budget	**92.9**	**53.4**	**70.4**	**64.5**	**20.4**	**14.9**	**35.3**	**52.9**	**115.1**	**519.8**
Change from FY 2019				**-5.9**						
Percentage change from FY 2019				**-8.4%**						

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 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. 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-6A and Sentinel-6B, that will launch approximately five years apart (2021 for Sentinel-6A 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 humidity profiles by measuring bending angles of Global Navigation Satellite System (GNSS)

SENTINEL-6

Formulation	Development	Operations

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 2020

None

PROJECT PARAMETERS

NASA will provide the launch vehicle and launch services for each of the Sentinel-6 spacecraft, two sets of three instruments consisting of the NASA altimetry payload that includes Advanced Microwave Radiometer-Climate Quality (AMR-C), the GNSS-Radio Occultation (GNSS-RO) receiver, and a Laser Reflector Array (LRA). Additionally, NASA will provide services required to perform the NASA payload integration and test, mission operations support for the NASA-developed instruments, and technical support to the United States ground system team, as well as, an operational science data processor for the AMR-C to EUMETSAT to integrate into the overall mission science data processing chain. Moreover, NASA will provide near-real time and offline data processing for GNSS-RO data in addition to mission data product archiving and distribution. Sentinel-6A and Sentinel-6B observatories have a five-and-a-half year prime mission.

ACHIEVEMENTS IN FY 2018

NASA selected the launch vehicle for Sentinel-6 and awarded a contract to SpaceX for a Falcon 9 Full Thrust launch service. The project completed its Critical Design Review (CDR) and initiated the build of the NASA payload instruments.

WORK IN PROGRESS IN FY 2019

The Sentinel-6 project will complete the development and testing of the Sentinel-6 NASA instrument payload. The project will ship the instrument payload to the ESA spacecraft integrator, Airbus, and complete the System Integration Review (SIR).

KEY ACHIEVEMENTS PLANNED FOR FY 2020

The Sentinel-6 project will complete the Sentinel-6A Operational Readiness Review (ORR) and begin its launch campaign following completion of observatory-level integration and testing at Airbus. 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

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2020 PB Request
Key Decision Point (KDP-C)	Apr 2017	Apr 2017
CDR	Oct 2017	Oct 2017
Sentinel-6A US Payload delivery to ESA	Mar 2020	Mar 2020
Sentinel-6B US Payload delivery to ESA	Oct 2020	Oct 2020
Launch (Sentinel-6A)	Nov 2021	Nov 2021
Start Phase E (Sentinel-6A)	Feb 2022	Feb 2022
End Prime Mission (Sentinel-6A)	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

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)
2017	465.9	>70%	2019	465.9	0	LRD of Sentinel-6A	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 (*j*oint *c*onfidence *l*evel); all other CLs (*c*onfidence *l*evels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

SENTINEL-6

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:	**465.9**	**465.9**	**0**
Aircraft/Spacecraft	0	0	0
Payloads	65.8	85.2	19.4
Systems I&T	8.8	12.8	4.0
Launch Vehicle	280.7	248.7	-32.0
Ground Systems	9.7	9.0	-0.7
Science/Technology	4.4	4.2	-0.2
Other Direct Project Costs	96.5	106.0	9.5

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 between the 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

SENTINEL-6

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
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

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.	Project is following processes for eliminating foreign object debris in mechanical assemblies; ensuring large torque margins; conducting a robust test program; building an engineering model and performing a full life test; and using on-orbit torque/drag monitoring to park the SCS in science position and discontinue routine internal calibrations, if required.

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.

SENTINEL-6

Formulation	Development	Operations

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
Performance	SRB	Oct 2017	Critical Design Reviews (CDR)	Successful	Apr 2019
Performance	SRB	Apr 2019	Project System Integration Review (P-SIR)	TBD	Aug 2021
Performance	SRB	Aug 2021	Sentinel-6A ORR	TBD	Aug 2026
Performance	SRB	Aug 2026	Sentinel-6B ORR	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Earth Systematic Missions (ESM) Research	16.8	--	**24.1**	24.9	23.9	27.0	30.5
Ocean Surface Topography Science Team (OSTST)	5.7	--	**5.8**	5.8	5.9	6.0	6.2
Earth Observations Systems (EOS) Research	10.5	--	**11.0**	10.7	10.7	10.7	10.7
Sage III	5.0	--	**4.8**	4.6	4.6	4.7	4.8
Radiation Budget Instrument (RBI)	27.5	--	**0.0**	0.0	0.0	0.0	0.0
Sustainable Land Imaging	9.2	--	**34.0**	64.9	140.0	100.8	129.2
Earth from ISS	2.8	--	**1.6**	1.6	1.7	0.0	0.0
Plankton,Aerosols,Clouds,ocean Ecosystem (PACE)	110.0	--	**0.0**	0.0	0.0	0.0	0.0
Total Solar Irradiance Sensor-2 (TSIS-2)	2.1	--	**12.0**	14.0	15.0	5.0	5.0
Earth Radiation Budget Science	13.7	--	**13.8**	14.0	14.3	14.7	15.1
Ozone Mapping and Profiler Suite (OMPS)	12.2	--	**7.0**	7.4	5.9	3.7	2.5
Total Solar Irradiance Sensor-1 (TSIS-1)	4.9	--	**4.7**	4.9	4.7	4.8	4.9
CLARREO Pathfinder	17.0	--	**0.0**	0.0	0.0	0.0	0.0
Decadal Survey Missions	10.9	--	**20.4**	93.3	87.3	66.6	26.0
Earth Science Program Management	33.3	--	**39.0**	39.2	39.8	40.5	41.3
Precipitation Science Team	6.9	--	**6.3**	6.4	6.5	6.6	6.8
Ocean Winds Science Team	3.3	--	**3.0**	3.0	3.1	3.2	3.3
Land Cover Science Project Office	1.2	--	**1.3**	1.3	1.3	1.4	1.4
Ocean Salinity Science Team	7.6	--	**7.4**	7.5	7.6	7.8	8.0
Soil Moisture Active and Passive (SMAP)	13.6	--	**10.2**	10.4	10.6	10.8	11.0
Quick Scatterometer	2.8	--	**0.0**	0.0	0.0	0.0	0.0
Deep Space Climate Observatory	1.7	--	**1.7**	1.7	1.7	1.7	1.7
Global Precipitation Measurement (GPM)	20.4	--	**20.7**	20.9	21.4	21.5	22.1
Landsat 8	2.5	--	**0.0**	0.0	0.0	0.0	0.0
Ocean Surface Topography Mission (OSTM)	2.1	--	**2.3**	2.0	0.0	0.0	0.0
Suomi National Polar-Orbiting Partnership (Suomi NPP)	3.6	--	**3.6**	3.7	3.8	3.9	4.0
Terra	29.2	--	**28.2**	27.9	28.5	17.2	9.0
Aqua	33.2	--	**30.9**	30.3	31.0	19.8	11.7
Aura	27.9	--	**21.9**	22.4	22.8	12.4	9.0
SORCE	3.8	--	**3.2**	0.0	0.0	0.0	0.0
Ice, Cloud, and land Elevation Satellite (ICESat-2)	49.9	--	**19.6**	20.5	21.5	17.3	17.7
GRACE Follow-On	5.7	--	**11.2**	11.6	11.1	11.2	11.5
Total Budget	**497.2**	--	**349.7**	**454.8**	**524.7**	**419.4**	**393.2**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as *adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.*

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 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

Research demonstrated the capability of NASA’s spaceborne Soil Moisture Active Passive (SMAP) radiometer to give accurate estimates of the intensity and radii of hurricane-force winds. The researchers showed how to derive the signal of the wind-induced emissions at L-band frequencies and provided verification of derived wind speeds versus ground truth observations from buoys and aircraft measurements. Precipitation had little impact on SMAP wind speeds, even at high rain rates. The scientists presented examples of SMAP wind speed retrievals for notably intense tropical cyclones that occurred during the 2015 and early 2016 seasons, and compared these with wind fields observed by other space-based missions including the European Space Agency Advanced Scatterometer, the U.S. Navy’s multichannel polarimetric radiometer, WindSat, and NASA’s Rapid Scatterometer (RapidScat). In these storms and at the satellite footprint scales of 20–50 km, the SMAP radiometer was the only instrument able to observe wind speeds of 55–70 meters per second for all of them.

A recent study described a framework to assimilate Global Precipitation Measurement Microwave Imager (GMI) all-sky (including cloud and precipitation affected) radiance data using a hybrid 4D-Ensemble Variational analysis algorithm that became part of NASA’s Global Modelling and Assimilation Office operational forecast system in 2018. Assimilating satellite observations from microwave imagers such as GMI in cloudy and precipitating regions provides critical constraints on atmospheric parameters in dynamically sensitive regions and makes significant impacts on weather forecast accuracy. The Joint Center for Satellite Data Assimilation is currently testing how GMI data improve track forecasting for tropical cyclones, and the Navel Research Lab Automated Tropical Cyclone Forecasting System (https://www.nrlmry.navy.mil/TC.html) records over 1,000 GMI overpasses annually of cyclones. Forecasters around the globe use these data to monitor tropical cyclone structure.

Researchers developed a loss function that uses SMAP soil moisture to describe the movement of water through the top soil. Though SMAP senses only the top 5 cm of soil, the loss function highlights the role of this thin layer in multiple earth system processes and the study team has applied it to delineate areas of the continental United States based on the relative roles of drainage and evaporation. Results showed decay time scales gradually increase with increasing wetness, from approximately 3 days in hyper-arid regions to seven days in more humid areas. These are typically faster than previous analysis of soil moisture time scales, in part due to the focus on the thin upper layer as opposed to the larger root-zone soil moisture used in most previous studies. The results presented help early identification of departure from normal conditions for a region and possible initiation of a flash drought (or the end of a drought).

Rivers provide the link between the oceans and the terrestrial water and bio-geochemical cycles. Several studies analyzed salinity observations from SMAP and SMOS, together with land measurements, to trace large riverine waters over great distances. These studies reconstructed the complete lifecycle of hydrological events, from rainfall to river discharge on land, and then to river plume formation, mixing, and advection in the ocean. In addition to tracing the origin and fate signatures of freshwater, researchers use satellite salinity measurements to gauge the influence of rivers on regional climate and oceanic productivity as well as the impacts of the river-influenced warming on the upper ocean during the Atlantic hurricane season.

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

In celebration of the 25th anniversary of the launch of the first altimetric satellite Topopgrahy Experiment (TOPEX)/Poseidon, OSTST focused on activities related to benefits in coastal areas and water surfaces. Research demonstrated the cornerstone status of satellite altimetry in many areas: understanding of global and regional sea level rise and acceleration; large-scale ocean variability and climate; changes in the geoid (a model of global mean sea level); ocean tides, including nuisance tides and associated coastal flooding; and changes in the hydrological cycle and crysopheric processes, such as changes in ice sheets, glaciers, and ice caps.

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.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

A recent study showed that methane emissions from fires, identified using measurement of pollution in the Troposphere and Tropospheric Emission Spectrometer carbon monoxide and methane measurements, have been decreasing since the early 2000s due to a global decrease in tropical fires. The magnitude of this trend is nearly twice as much as expected from prior estimates. The decrease helps to explain overall methane trends and the previously conflicting increases seen from fossil fuel and wetland sources for methane.

Analyses of the long-term record of ozone profile observations from the Aura Microwave Limb Sounder and other sensors shows a statistically significant increase in the amount of ozone in the upper stratosphere (~35–50 km) since about the year 2000. In other regions, however, the magnitude and even the direction of the trend in ozone remain unclear. A recent study confirmed the recovery of ozone in the upper stratosphere but presented evidence of a continuing decline in lower stratospheric global (60N-60S) ozone. These studies are required for the conclusive verification that stratospheric ozone destruction is lessening as expected in response to international controls on anthropogenic ozone-depleting substances enacted under the Montreal Protocol.

Recent studies demonstrated that Atmospheric Infrared Sounder (AIRS) humidity products have the capacity to detect meteorological drought up to two months earlier than other drought indicators. Researchers now use these AIRS products in the production of the U.S. Drought Monitor (USDM) for a probationary period. If they demonstrate its utility, they will become part of the regular operational suite of indicators used in the generation of the USDM. AIRS data has shown great value in confirming volcanic eruptions in remote areas and tracking long-lived ash clouds. These NASA data provide the FAA and the aviation community sulfur dioxide detection for volcanic plumes. National Oceanic and Atmospheric Administration (NOAA) also uses it in volcanic ash detection for the Rapid Update Cycle Rapid Refresh Model. A fully automated rapid response system for sulfur dioxide (SO_2) detection has been developed and publicly debuted in summer 2018. The system triggers on detection of SO_2 and dust in the AIRS near real-time data product and provides imagery of SO_2, dust and clouds.

Parts of North America are vulnerable to increasing tree mortality from drought, pests, and pathogens. A study assessed the potential for data from several satellite sensors (Landsat, Moderate Resolution Imaging Spectroradiometer (MODIS), and the Advanced Very-High Resolution Radiometer) to detect early warning signals of tree mortality in forest inventories across Alaska and central-western Canada. Results indicated potential to use satellite data for early warning signals of tree mortality 2-24 years before death. Relationships are broadly consistent across inventories, species, and sensors, although coarse imagery in the heterogeneous aspen parkland is of limited utility. The results provide a tool to identify vulnerable landscapes and inform preventative land management.

Multi/hyperspectral optical remote sensing approaches, such as MODIS and ESA's Medium Resolution Imaging Spectrometer sensors, enable the broad scale assessment of water quality through the detection and tracking of water properties. Recent studies include the development of a new approach to track harmful algal blooms in Lake Erie. Another study explored several different empirical methods of atmospheric correction, which enable extraction and separation of mixed environmental signals from aquatic data sets. They developed an innovative calibration approach that employs a floating panel composed of 16 convex mirrors deployed on the water surface, providing an in-scene lake surface reference for image reflectance factor calibration.

OTHER MISSIONS AND DATA ANALYSIS

SUSTAINABLE LAND IMAGING

The Sustainable Land Imaging (SLI) program enables the development of a multi-decade, spaceborne system that will provide U.S. users with high quality, global, land-imaging measurements. These measurements will be compatible with the existing 45-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 requirements, 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 (through ROSES) instrument and subsystem developments 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 in FY 2019.

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 2018, NASA and USGS chartered a second Sustainable Land Imaging Architecture Study Team (AST 2019). The team will execute a study for the design and implementation approach for the second phase of a sustainable and evolvable spaceborne system to provide global, continuous Landsat-quality multispectral and thermal infrared measurements for approximately a fifteen-year period beginning in the FY 2026 timeframe. The AST 2019 study will use the AST 2014 study results and other NASA and USGS SLI studies as an initial starting point. The AST 2019 will provide architecture options that NASA and DOI/USGS will utilize to provide a recommendation for an SLI architecture beyond Landsat 9 to the Executive Office of the President (EOP) by the end of FY 2019.

The six ongoing investigations under the SLI-T element continue to make progress. Two of the three Advanced Technology Demonstrations (ATD) instrument will begin aircraft flight demonstrations in mid-FY 2019. The third concept will begin flight demonstrations later in FY 2019. The three ATD instrument teams will explore the possibility of meeting the new reference mission architecture document expected from the AST team during FY 2019.

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 measurements of total solar irradiance and spectral solar irradiance provided by TSIS-1. 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 will begin in FY 2019.

Recent Achievements

The TSIS-2 project completed two mission formulation studies evaluating various mission configurations and access to space alternatives. A third study is currently in progress to evaluate the implementation of TSIS-2 using flight spare parts from TSIS-1.

EARTH RADIATION BUDGET SCIENCE

The Earth Radiation Budget Science 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 as well as ancillary measurements to produce data products, which are integrated and self-consistent over the entire suite of radiation budget instruments. In addition to the five currently operating Clouds and the Earth's Radiant Energy System (CERES) instruments measuring broadband radiative fluxes from the Terra, Aqua, Suomi National Polar-orbiting Partnership (Suomi NPP) and NOAA-20 platforms, the data products utilize coincident imager measurements from Terra, Aqua, Suomi NPP, NOAA-20 and operational geostationary satellite observations. In total, 15 instruments on nine spacecraft 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.

Recent Achievements

In 2018, the CERES team supported early validation of the CERES FM6 instrument, which launched on the NOAA-20 satellite in November 2017. They also performed inter-comparison campaigns between Terra, Aqua, Suomi NPP, NOAA-20 and additional campaigns with the Geostationary Earth Radiation Budget instruments. They generated sensor gain and spectral response function correction coefficients for the Edition 4 forward processing, and performed validation studies and anomaly trends to evaluate the CERES data products. The CERES team completed and successfully implemented the modification of data product production code to utilize an updated version of the MODIS cloud data. To improve efficiency, the CERES team implemented an updated and streamlined software testing and delivery process that realizes significant workforce savings in the data production area. The team also made significant enhancements to the software system for running production jobs that improves maintainability and further improves data production monitoring capabilities.

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

NASA delivered the OMPS-Limb profiler to the JPSS-2 mission in September 2018, within budget and on schedule.

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 a set of space-based observation capabilities that included all currently planned Earth Science missions, termed the "program of record," and additional observation capabilities including the following "designated observable" (DO) scientific areas: Aerosols, Clouds, Convection, and Precipitation, Mass Change, Surface Biology and Geology, 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-center DO studies to encompass all five scientific areas listed above. The DO studies aim to identify and evaluate observing system architectures and approaches with the objectives of increasing capability and resilience and reducing costs. The studies will consider NASA, international, and interagency contributions, as well as commercial spaceborne assets and data products.

OTHER MISSIONS AND DATA ANALYSIS

EARTH SCIENCE PROGRAM MANAGEMENT

The Earth Science Program Management budget supports critical flight project management functions executed by the ESM program office at NASA Goddard Space Flight Center (GSFC), the Earth System Science Pathfinder Program Office at NASA Langley Research Center (LaRC) and the Earth Science Flight Project Office at the Jet Propulsion Laboratory (JPL).

This budget also 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;
- 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 (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.

Recent Achievements

Sixty members of the current Precipitation Measurement Missions (PMM) Science Team continue to perform algorithm development, application activities, and scientific investigations. They have their annual science team meeting in October. This is the third and last year of the current science team. NASA will select a new team for the next three-year cycle.

July 2018 marked the official start of the assimilation of GPM Microwave Imager brightness temperatures under all-sky conditions in the real-time Global Modeling and Assimilation Office Forward Processing system. All-sky assimilation is particularly difficult because it must be performed in a manner consistent with not only the data assimilation procedures but also the Goddard Earth Observing System model physics and dynamics.

PMM Scientists discovered specific circumstances where large ice particles like hail severely impacted satellite-based radar estimates of heavy rain when the hail occurred in sub-freezing portions of clouds. Researchers discovered that deep convective storms producing large ice at high altitudes cause radiometer temperature signals that dipped below the "good" data threshold in GPM radiometer algorithms. NASA will adjust the threshold to account for these intense storm situations so as not to eliminate good data in these situations.

New GPM product versions were developed, validated, and transitioned for application to TRMM data so researchers can process a consistent 18-year rainfall dataset spanning the TRMM and GPM eras.

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

This year marked the end of NASA's successful QuikSCAT mission, establishing one of the longest climate data records by a single spaceborne instrument and providing crucial ocean vector winds data. The data enabled discoveries of new mechanisms of air-sea interaction, improved forecasting of tropical hurricanes and cyclones, and allowed us to monitor ongoing changes of the Earth's systems, including sea ice, land and snow cover, urban extent, carbon biomass, and ocean productivity. The long duration of the QuikSCAT mission also enabled the development of the first global climatologies of winds over the ocean at high spatial resolution. In addition to continuing improvements to the surface ocean winds products, scientists are exploring conceptually novel approaches to measure winds from space involving a concurrent observation of ocean winds and currents from space 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

Last year, the LCPSO continued to focus on the integration of moderate resolution imagery from the Landsat and the European Sentinel-2 satellites. This effort included delivering a new version of the Harmonized Landsat/Sentinel-2 (HLS) dataset, which provides a seamless record of surface reflectance derived from both sensors. Integration of Landsat and Sentinel-2 data provides more frequent observations that better support a range of land management applications. The LCPSO continues to support the Committee on Earth Observation Satellites initiatives within NASA, including the Land Surface Imaging Virtual Constellation and the Working Group on Calibration/Validation. A key focus has been working with the USGS to create Analysis Ready Data products from the Landsat archive, consisting of gridded surface reflectance and surface temperature fields that are easy to use for end users. LCPSO and USGS collaborated on identifying optimal algorithms for retrieving surface temperature from the Landsat 8 data record.

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 the ocean salinity with unprecedented coverage, accuracy, and resolution, boosting oceanographic research and scientific applications. New salinity maps improve our ability to study large-scale ocean processes, including tropical instability waves and Rossby waves; predict various climate phenomena such as El Niño–Southern Oscillation; and gain insights into recent amplification of the Earth's hydrological cycle that produce flood and drought events. New satellite salinity maps are becoming key in monitoring ocean carbon cycle, enabling the development of the first space-based ocean acidification products. Recent studies also demonstrate the use of satellite salinity as a new resource to monitor hurricanes and ocean's response to tropical storms.

Operating Missions

ICE, CLOUD, AND LAND ELEVATION SATELLITE (ICESAT-2)

The ICESat-2 mission will measure vegetation canopy heights, allowing estimates of biomass and carbon in above-ground vegetation in conjunction with related missions, and allow measurements of solid earth properties. ICESat-2 will continue to provide an important record of multi-year elevation data needed to determine ice sheet mass balance and cloud property information. It will also provide topography and vegetation data around the globe in addition to the polar-specific coverage over the Greenland and Antarctic ice sheets.

The ICESat-2 observatory is comprised of one instrument, the Advanced Topographic Laser Altimeter System (ATLAS). The design of ATLAS allows measurement of ice-sheet topography and associated temporal changes, and sea-ice freeboard, which is the difference between the height of the surface of sea ice and surrounding water.

Recent Achievements

NASA launched ICESat-2 on September 15, 2018, aboard the last Delta-II rocket. The telescope door on ATLAS opened two weeks later, and its laser began firing the following day. The satellite reached its mission orbit on October 13, and the project entered its prime operations phase in December 2018.

OTHER MISSIONS AND DATA ANALYSIS

GRACE FOLLOW-ON

The Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) mission will provide continuity of high-resolution global models of Earth's gravity field, including how it varies over time, as in the original GRACE mission (launched in 2002). The GRACE-FO mission will allow scientists to gain new insights into the dynamic processes in Earth's interior, currents in the oceans, and variations in the extent of ice coverage. Data from the mission, combined with other existing sources of data, will greatly improve scientific understanding of glaciers and hydrology. GRACE-FO data is vital to ensuring there is a minimal gap in gravitational field measurements following the decommissioning of the original GRACE mission. GRACE-FO is a partnership with the German Research Centre for Geosciences.

Recent Achievements

NASA launched the two GRACE-FO satellites on May 22, 2018, aboard a SpaceX Falcon 9 rocket. Both accelerometers were powered-up on May 28, and ranging between the satellites with the microwave instruments commenced on May 29. The laser ranging interferometers, which are technology demonstration instruments, switched on in June. On July 19, the GRACE-FO-1 satellite experienced an anomaly with the instrument processing unit within the Microwave Instrument. After conducting a thorough review of the anomaly, the flight operations team switched to the redundant side of the unit, and resumed collection of science data on October 22, 2018.

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.

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.

Recent Achievements

In 2018, SMAP significantly improved the quality of its data products; in particular, data acquired in the evening has reached the same level of quality as data acquired in the morning, thus allowing global monitoring of soil moisture every 1.5 days. Several national agencies are evaluating SMAP data. For example, the project delivered SMAP surface soil moisture data and changes in this data over time across the U.S., to the multi-agency National Drought Mitigation Center at the University of Nebraska-Lincoln. There, scientists use the information from SMAP and 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 determinations. SMAP has produced soil moisture products with a much-reduced turnaround time to enable usage by the U.S. Air Force's 557th Weather Wing, which provides services to a number of defense-related applications. SMAP soil moisture data is 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 also uses the SMAP data for operational assessments.

OTHER MISSIONS AND DATA ANALYSIS

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 2018, GPM improved, validated, and transitioned rainfall retrieval algorithms to enable the generation of a consistent 21-year rainfall dataset spanning the TRMM mission (1998-2015) and the GPM mission (2014-present). Completion of these sensor-level algorithms allows for the reprocessing of merged multi-satellite products – called IMERG, GPM's most downloaded product – across the TRMM and GPM eras. Furthermore, the GPM ground-validation group expanded IMERG validation efforts with a focus placed on evaluation of extreme events, including several recent U.S. hurricanes. Data from the GPM Olympic Mountains Ground Validation Experiment field campaign has advanced knowledge of precipitation evolution as storms transition from the ocean to land and of precipitation enhancement over steep topography. In addition, GPM has efficiently leveraged field measurements in collaboration with scientists in Finland and Canada to provide new ground-validation “benchmark” radar-based snowfall datasets for direct validation of satellite products. The ground-validation team also participated in the International Collaborative Experiment – PyeongChang Olympics and Paralympics 2018 (ICE-POP 2018) experiment for validation studies of heavy mountain snow over the Korean Peninsula. GPM continued to cultivate several collaborations and partnerships with government and non-government organizations, and private groups, to facilitate the use of the data within their environments, including the Army Geospatial Center, the Pacific Disaster Center, the World Resources Institute, the World Bank, and reinsurance groups.

OCEAN SURFACE TOPOGRAPHY MISSION (OSTM)

OSTM (also known as Jason-2), launched in June 2008, measures sea surface height, and enables scientists to track changes in ocean currents, assess climate variability, and make improved maps of the sea floor. This mission is 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 now use to better understand gravity over the ocean, and make improved maps of the sea floor. OSTM is a joint mission with NOAA, CNES, and EUMETSAT.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

The orbit configuration adopted in 2017 significantly improved the resolution for observations of ocean currents and climate variability, and improved the forecasting of ocean currents, marine wind and wave conditions, and hurricane intensity used by various domestic agencies. A new "geodetic" orbit phase repeats only once per year and has very closely-spaced ground tracks. The spacecraft successfully completed its first geodetic cycle in this new orbit in 2018. A second cycle, with even denser data spacing, is now being used by scientists and naval operations to improve the marine geoid and to make significantly improved maps of the sea floor, and to chart small to mid-sized seamounts (underwater mountains), tens of thousands of which had been previously been uncharted. The first OSTM geodetic cycle has already yielded significant improvements in the marine gravity field and the completion of the second geodetic cycle in mid-2019 remains the top scientific priority for OSTM in its continuing mission. These improvements to bathymetry (measurement of water depth) and mean sea surface models 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. 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. The 2017 Earth Science senior review endorsed the Suomi NPP mission for continued operations through 2020, and preliminarily, through 2023.

Recent Achievements

In 2018, Suomi NPP continued to meet its two primary goals: (1) providing satellite observations to NOAA for NOAA products and services, primarily weather forecasts, and (2) providing satellite observations to continue the Earth Science data products created using data from the NASA Earth Observing System (EOS) satellites. The science team responsible for creating these EOS continuity products was recompeted and NASA selected 68 of 230 proposals received for funding, supporting the development of new Earth system data products and research. NASA provided wildfire location and intensity data from the Visible Infrared Imaging Radiometer Suite to the U.S. Forest Service during the very active 2018 fire season. NASA's Black Marble High Definition products continued to support hurricane recovery efforts during the 2018 season. Research revealed that the Ozone Mapping Profiler Suite instrument measured the smallest ozone hole in nearly twenty years in 2017, attributable to anomalously warm weather during the 2017 Antarctic spring.

OTHER MISSIONS AND DATA ANALYSIS

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 Spaceborne 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

On October 6, 2018, Terra completed its 100,000th orbit around Earth. Data from Terra, in combination with Aura, revealed that clean air programs have continued to improve fine particle pollution, declines in carbon monoxide emissions are slowing down, and efforts to reduce nitrogen oxide emissions have not been as successful as expected. Terra's long lifetime, vantage point from space, and its robust suite of sensors combined to provide a spatial assessment that would not be available using only ground-based measurements. Furthermore, Terra's unique observations allowed tracking of fire intensity, smoke plume heights, and spatial extent of wildfire activity and pollution during the 2018 Western U.S. fire season; evaluation of the impact of Hawaii's Kilauea eruption; and better understanding of the tracks and impacts Hurricanes Florence and Michael.

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 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

All Aqua data are readily available to users worldwide. Scientists have used the data in thousands of scientific publications, as well as numerous practical applications. In 2018, researchers used AIRS data to obtain high-resolution measurements of the vertical structure of temperature and humidity within the eyes of hurricanes, measurements that should lead to improved predictions of hurricanes and other major storms. The weekly U.S. Drought Monitor now officially uses AIRS near-surface temperature and humidity observations operationally. MODIS data have been critical to a wide variety of applications, including: (1) revealing, unexpectedly, that global burned area has declined by approximately 25 percent over the past 18 years, (2) demonstrating that ocean biological productivity has varied in concert with the El Niño and Southern Oscillation (ENSO), and (3) helping to pinpoint current and future communities that are the most vulnerable to the detrimental effects of heat waves and extreme heat in urban areas. Furthermore, in conjunction with data from Suomi NPP, MODIS data have also shown that the global distribution of aerosol particles produced by human activities, natural dust storms, and fires is relatively stable, with large seasonal changes between North Africa and Asia that affect human health and visibility in the United States.

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.

Recent Achievements

The annual number of health studies that use Aura data continued to increase in 2018. Researchers are taking advantage of the long 14-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, such as by industry to demonstrate their efforts to reduce their pollutant emissions. In 2018, Aura’s long data record contributed to several international assessments of trends in atmospheric ozone, such as to monitor and interpret trends in stratospheric ozone, which protects all life on Earth from UV radiation, and to assess whether the stratospheric “ozone hole” over Antarctica may be recovering because of efforts to reduce the use of artificial ozone-destroying chemicals. Researchers also used Aura data to assess trends, and the causes of trends, in ozone in the lower atmosphere, where it acts as a climate gas and an air pollutant.

SOLAR RADIATION AND CLIMATE EXPERIMENT (SORCE)

SORCE, launched in January 2003, measures the total and spectral solar irradiance incident at the top of the Earth’s atmosphere. SORCE measurements of incoming X-ray, ultraviolet, visible, near infrared, and total solar radiation help researchers to understand natural variability in atmospheric ozone and ultraviolet-B radiation, thus leading to enhanced climate prediction models. These measurements are also critical to studies of the Sun, its effect on the Earth system, and its influence on humankind.

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SORCE is currently in extended operations. The 2017 Earth Science senior review endorsed the SORCE mission for continued operations through 2019, and possibly 2020, to ensure an overlap with the TSIS-1 mission.

Recent Achievements

Collecting accurate Total Solar Irradiance (TSI) and Solar Spectral Irradiance (SSI) data spanning multiple years helps scientists understand how much solar radiation is deposited in the atmosphere and at the surface and thus how much energy is available to influence weather, climate, the cryosphere, atmosphere dynamics, and ocean currents. In 2018, the SORCE mission extended the uninterrupted TSI record to 39 years. The project established a new 16-year SSI record for the near ultraviolet, visible, and near infrared wavelength ranges that together comprise almost 96 percent of the incoming Sun's total energy. Important in these solar records is the amount by which the TSI and SSI increase and decrease over an 11-year period, known as the solar activity cycle. Global energy-balance estimates and climate studies use the SORCE TSI.

STRATOSPHERIC AEROSOL AND GAS EXPERIMENT III (SAGE-III)

Stratospheric Aerosol and Gas Experiment III (SAGE-III), launched in February 2017, operates on the International Space Station (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

The second operational year for the SAGE-III mission demonstrated an improvement in operational efficiency for payload commanding and science data collection. The unique orbit of the International Space Station allowed SAGE-III to observe the global impact of the intense mid-August 2017 Canadian wildfires on the stratospheric aerosol content. The SAGE-III team has completed a new version (5.1) of the science data products, providing improvements in ozone and aerosol concentrations in the upper troposphere, and including flags that detail ISS blockages that impact science collection. They also produced the first release of the stratospheric water vapor product. Researchers released both products publicly in 2018. The competitively selected SAGE-III/ISS Science Team held its first meeting in October 2018, 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.

OTHER MISSIONS AND DATA ANALYSIS

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 achievement of sub-millisecond timing and sub-pixel geolocation in early 2018 completed its full compliance with Level-1 science requirements and led to the public release of provisional data to the broader science community. The LIS Science team is currently working toward public release of fully validated data in 2019. Initial science analyses of the annual and seasonal global flash rates show results similar to the prior climatology obtained from the LIS instrument on the Tropical Rainfall Measuring Mission satellite, but now extended to climatically important higher latitudes. Efforts are currently underway to provide near-real-time (two-minute) observations, successfully produced since mission start, to selected users to complement operational forecast and aviation applications in data sparse regions such as over the ocean.

TOTAL SOLAR IRRADIANCE SENSOR-1 (TSIS-1)

The TSIS-1 mission will provide 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. Currently, the data from an earlier NASA-managed TIM instrument, flying on the aging SORCE spacecraft, launched in 2003, provides TSI data as part of an unbroken 39-year data record.

Recent Achievements

In January 2018, TSIS-1 made the first-light measurement of solar irradiance from the ISS, and transitioned to normal operation in March 2018. Both TSIS-1 and SORCE instruments tracked daily TSI variations consistently to within 0.004 percent. New SSI data from TSIS-1 established an accurate reference solar spectrum in the 200-2400 nm wavelength bands that helps scientists calibrate sensors on other national and international satellites for global climate and environmental studies. Measuring the incoming solar energy at different wavelength bands provides critical elements for understanding how that energy is absorbed by the Earth's atmosphere and surface.

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

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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 include: color images of the full sunlit disk of the Earth; maps of ozone, clouds, aerosols, and vegetation; and measurements of sulfur dioxide from volcanic eruptions.

DSCOVR completed its prime mission in 2018, and is currently in extended operations. The 2017 Earth Science senior review endorsed the DSCOVR mission for continued operations through 2020.

Recent Achievements

In 2018, the DSCOVR EPIC and NISTAR data production team successfully reprocessed all of the DSCOVR Earth science data, significantly improving the accuracy of all data products. EPIC vegetation data captured for the first time the daily variation of green leaf area, a key measure of photosynthesis, the process in which carbon dioxide converts into oxygen. EPIC sulfur dioxide measurements of volcanic eruption plumes demonstrated the mission’s ability to track volcanic clouds as they spread out at high altitudes and are carried away by winds, impacting air travel. A new data product showing the ultraviolet (UV) radiation levels on the surface of the Earth revealed that dangerous levels of UV radiation are more prevalent in certain areas of the world (e.g., in Chile). The near-real-time true color images of the Earth generated by EPIC remained highly popular with the public, especially during major storms.

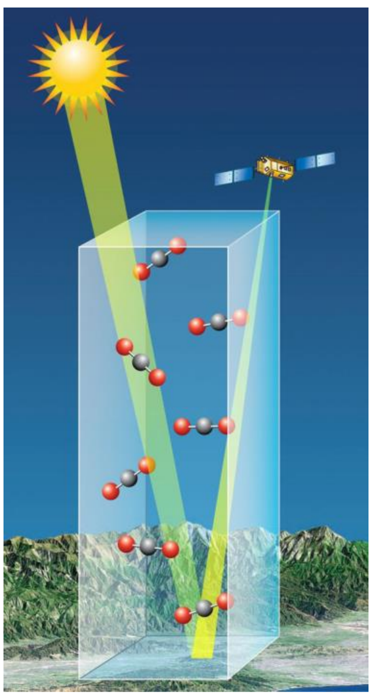
EARTH SYSTEM SCIENCE PATHFINDER

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Venture Class Missions	179.2	--	**199.2**	183.2	188.1	197.5	183.4
Other Missions and Data Analysis	62.8	--	**76.1**	71.9	64.9	67.7	64.9
Total Budget	**242.0**	**--**	**275.4**	**255.1**	**253.0**	**265.2**	**248.3**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



The OCO-3 instrument on the International Space Station will help to determine CO2 concentration levels.

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 2020

In response to the 2017 Decadal Survey recommendations, NASA initiated a new Earth Venture element called Earth Venture Continuity (EVC). This element will focus on specific instruments for continuity of measurements. NASA released the first Announcement of Opportunity for EVC-1 in December 2018.

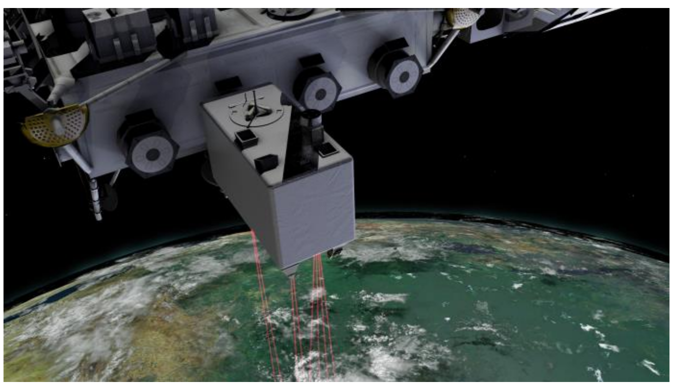
VENTURE CLASS MISSIONS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	179.2	--	199.2	183.2	188.1	197.5	183.4

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



The Global Ecosystem Dynamics Investigation: high resolution laser ranging of the Earth's forests and topography from the ISS.

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 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 FY 2018 dollars.

The cadence of solicitations for EVI and EVC investigations will alternate every 18 months, releasing each approximately every 3 years. The cadence of EVS and EVM solicitation is independent of other Earth Venture solicitations.

EXPLANATION OF MAJOR CHANGES IN FY 2020

In September 2018, NASA selected five investigations for Earth Venture Suborbital-3. NASA initiated the Earth Venture Continuity component, in response to a recommendation from the 2017 Decadal Survey. NASA released the Earth Venture Continuity-1 (EVC-1) Announcement of Opportunity in December 2018.

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, releasing each approximately every three years.

CYCLONE GLOBAL NAVIGATION SATELLITE SYSTEM (CYGNSS) (EVM-1, SELECTED IN 2012)

CYGNSS performs accurate measurements of ocean surface winds throughout the life cycle of tropical storms and hurricanes, leading to better weather forecasting. CYGNSS data is enabling 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 provides information to the hurricane forecast community, potentially enabling better modeling to predict the strength of hurricanes as they develop.

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, while the reflected signals are indicative of ocean surface roughness. Scientists use both measurements to derive the critical measurement of wind speed. CYGNSS completed development and launched in December 2016. NASA has approved CYGNSS for operation through April 2019.

Recent Achievements

The numerical prediction models added CYGNSS measurements of surface winds in the inner core of hurricanes to study their impact on forecast skill. The initial results are favorable, with improvements noted in the forecasting of storm track, intensity, and structure. The studies used archival data from the 2017 Atlantic hurricane season and the results will determine decisions regarding possible operational use of CYGNSS measurements by the National Hurricane Center and Joint Typhoon Warning Center. CYGNSS measurements over land proved to be an unexpectedly rich source of information about soil moisture and the extent of flood inundation after major storm landfall events, such as Hurricanes Harvey and Irma.

Planned Future Achievements

The first broad public release of well-calibrated CYGNSS data occurred in FY 2018. Refinements to the calibration continue and updated data releases will continue into FY 2019. The initial results of hurricane forecast impact studies will expand to revisiting the archival 2017 storms and adding the new 2018 storms. The relevant operational government agencies, National Hurricane Center and Joint Typhoon Warning Center, will get updates on the study results. New science investigations are underway addressing the use of CYGNSS measurements over land. These include soil moisture and hydrology studies, which have the potential to supplement measurements made by the NASA Soil Moisture Active Passive (SMAP) mission, by adding observations at intermediate times between the SMAP overpasses. This is possible due to the faster sampling characteristics of a constellation of small satellites such as CYGNSS.

As the CYGNSS ocean wind and land moisture algorithms and data products mature, the possibility to develop coupled algorithms materializes to make use of both products simultaneously. One natural application of this capability is the modeling and forecasting of storm surge over land due to hurricanes moving over land. Studies conducted preliminary simulations to verify that such a coupled ocean/land algorithm can improve storm surge forecasts. By 2020, it should be possible to begin development and testing of such coupled algorithms. Furthermore, by 2020, there should be sufficient empirical demonstrations of the potential benefits to operational hurricane forecasting of using CYGNSS measurements. At that point, the CYGNSS project science team will support the operational agencies in their trial uses of the data.

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, such as ozone and 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.

NASA will procure the commercial host spacecraft service through the United States Air Force Space and Missile Systems Center Hosted Payload Solutions contract. In discussions with potential hosts, all identified concerns about the cost impact a late delivery by NASA would have on their spacecraft. In order to avoid the adverse pricing such risk would entail, the TEMPO project will delay the release of the RFP for hosting until after the completion of the instrument, with a projected launch date of no earlier than 2021.

Recent Achievements

The TEMPO instrument completed development and testing successfully. The project continues to make progress on the data processing and instrument operations center software development. NASA released a Request for Proposals (RFP) for hosting services, but did not receive any bids. Based on discussions with the pool of potential hosts, NASA plans to release the RFP again in FY 2019.

Planned Future Achievements

TEMPO plans to conduct a System Acceptance Review (SAR) in FY 2019. Upon successful completion of this review, NASA will place the instrument into storage. The project plans to complete Version 1.0 of the science data processing software and Version 2.0 of the instrument operations center software. Additionally, NASA plans to release the hosting services RFP with the intent to award a contract. In FY 2020, TEMPO will begin preparations for integration to the host. The project plans to complete the science data processing and instrument operations center software.

ECOSYSTEM SPACEBORNE THERMAL RADIOMETER EXPERIMENT ON SPACE STATION (ECOSTRESS) (EVI-2, SELECTED IN 2014)

ECOSTRESS will fill a key gap in our observing capability and advance core NASA and societal objectives. Specifically, ECOSTRESS will enable NASA to address the following science objectives:

1) Identify critical thresholds of water use and water stress in key climate sensitive biomes; 2) Detect the timing, location, and predictive factors leading to plant water uptake decline and/or cessation over the daily cycle; and 3) Measure agricultural water consumption over the contiguous United States to improve drought estimation accuracy.

ECOSTRESS will observe changes in global vegetation from the ISS. The sensors will give scientists new ways to see how changes in climate or land use change affect forests and ecosystems. ECOSTRESS will use 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 will 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 completed the ECOSTRESS payload development, launched, and installed the instrument on the International Space Station. The project began collecting data.

Planned Future Achievements

ECOSTRESS continues to operate and plans to finish prime operations by the end of FY 2019.

VENTURE CLASS MISSIONS

GLOBAL ECOSYSTEM DYNAMICS INVESTIGATION (GEDI) LIDAR (EVI-2, SELECTED IN 2014)

GEDI will use a laser-based system to study a range of climates, including the observation of the forest canopy structure over the tropics, and the tundra in high northern latitudes. These data will help scientists better understand the changes in natural carbon storage within the carbon cycle from both human-influenced activities and natural climate variations. The lidar instrument will be the first to systematically probe the depths of forests from space. The unique 3D view of Earth's forests will facilitate an understanding about their role in the carbon cycle. The plan is to host the instrument aboard the International Space Station. GEDI will conduct its prime mission for 24 months.

Recent Achievements

NASA successfully launched the GEDI mission on December 5, 2018 from Kennedy Space Center. GEDI completed in-orbit checkout and calibration and has now begun its two year prime mission phase.

Planned Future Achievements

GEDI will begin generation of its Level-4 data products, based on the first twelve months of data collected, and use it to estimate aboveground biomass density. (Level-4 data reflects aboveground biomass and makes biomass maps using statistics.) The GEDI team will also continue calibration and validation, through ground-based measurements and an airborne campaign using NASA's Land, Vegetation, and Ice Sensor instrument.

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.

EARTH VENTURE SUBORBITAL-2 (EVS-2; SELECTED IN 2014)

EVS-2 investigations include:

- Atmospheric Tomography Mission (ATom) explores the impact of human-produced air pollution on certain gases that trap heat. Airborne instruments will look at how various air pollutants affect atmospheric chemistry (including methane and ozone).
- North Atlantic Aerosols and Marine Ecosystems Study (NAAMES) seeks to improve predictions of how ocean ecosystems would change with temperature increases. The mission will study the annual life cycle of phytoplankton, and the impact small airborne particles (composed of material derived from marine organisms) have on climate in the North Atlantic.
- Atmospheric Carbon and Transport-America (ACT-America) quantifies the sources of regional carbon dioxide, methane and other gases, and documents how weather systems transport these gases in the atmosphere.
- Observations of Aerosols above Clouds and their Interactions (ORACLES) investigates how smoke particles from massive biomass burning in Africa influences cloud cover over the Atlantic.

Particles from this seasonal burning interact with permanent stratocumulus “climate radiators,” which are critical to the regional and global climate system.

- Oceans Melting Greenland (OMG) project studies the role of warmer, saltier Atlantic Ocean subsurface waters in Greenland glacier melting. The study will help pave the way for improved estimates of future sea level rise by observing changes in glacier melting where ice contacts seawater.
- The Coral Reef Airborne Laboratory (CORAL) investigation analyzes the status of coral reefs and predict their future. It will provide the most extensive picture to date of the condition of a large portion of the world’s coral reefs.

Recent Achievements

EVS-2 completed seven deployments during FY 2018, with another deployment extending into FY 2019. ACT-America and ATom each completed two deployments. Both of ACT-America's 6-week deployments encompassed three sites in eastern and central U.S. using the Wallops Flight Facility (WFF) C-130 and Langley Research Center B-200 aircraft. ATom's 6-week deployments were global transits using the AFRC DC-8 aircraft. NAAMES completed their final deployment to the North Atlantic/St John's Newfoundland, using the University-National Oceanographic Laboratory System ship RV-Atlantis. OMG completed a deployment to Iceland/Greenland/Norway using the GLISTIN-A instrument on board the Johnson Space Center G-III, and completed a second deployment to Greenland utilizing Airborne Expendable Conductivity Temperature Depth Probes from the AirTec Basler-BT67. ORACLES initiated its final deployment to São Tomé and Príncipe, Africa with the WFF P-3B with the full deployment extending into FY 2019. CORAL is in post-deployment phase, and received a no-cost schedule extension in FY2018, extending its end date to September 30, 2019.

Planned Future Achievements

In FY 2019, CORAL will complete its Key Decision Point-F (KDP-F) review and close out. ACT-America and OMG will continue with data collection. All investigations will continue with data analysis and publication. In FY 2020, all remaining investigations will hold KDP-F reviews and close out.

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 Preliminary Design Review (PDR) and Key Decision Point-C (KDP-C) and began final design and fabrication. NASA selected the General Atomics as the host for the instrument.

Planned Future Achievements

MAIA plans to conduct its Critical Design Review (CDR), as well as a series of meetings and reviews with the instrument host. In FY 2020, MAIA plans to complete its instrument development and testing. NASA will place the instrument in storage. Meetings and reviews with the host will continue.

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. The measurements will provide 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.

TROPICS six CubeSats 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, or 10x10x10 cubic centimeters).

Recent Achievements

TROPICS completed its Preliminary Design Review (PDR) and Key Decision Point-C (KDP-C) for delivery to storage.

Planned Future Achievements

In FY 2019, TROPICS plans to conduct its System Integration Review (SIR) and Pre-environmental Review (PER) of the CubeSats. In FY 2020, NASA plans to deliver the TROPICS instrument to storage after completion of the space vehicle testing, and NASA will assess potential 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 GeoCarb project conducted a successful Key Decision Point-B in October 2018 and is now conducting preliminary design and technology completion activities.

Planned Future Achievements

In FY 2019, GeoCarb continues to work toward a successful confirmation review (KDP-C) and plans to begin final design and fabrication and proceed to its Critical Design Review. In FY 2020, GeoCarb will continue instrument development.

EARTH VENTURE SUBORBITAL-3 (EVS-3; SELECTED IN 2018)

Five investigations will start in 2020 to look into a range of pressing research questions such as what drives 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 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.

• SubMesoscale 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

NASA selected five investigations in FY 2018 from the EVS-3 solicitation.

Planned Future Achievements

All investigations will continue preliminary design and technology completion activities and prepare for their investigation confirmation reviews in FY 2019. All investigations will begin deployment phase in FY 2020.

EARTH SURFACE MINERAL DUST SOURCE INVESTIGATION (EMIT) (EVI-4; SELECTED IN 2018)

EMIT will use a sensor mounted to the exterior of the International Space Station 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. The EMIT team brings together a broad expertise covering mineral measurements, soil science, remote-sensing of surface properties, and Earth system modeling. EMIT's modeling component will use the data collected to advance our 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 concept and technology development and working toward a System Requirements Review/Mission Definition Review (SRR/MDR) in FY 2019.

Planned Future Achievements

EMIT is planning an SRR/MDR, followed by Key Decision Point-B. In addition, the project is planning its PDR inlate FY 2019. EMIT plans to conduct its KDP-C in early FY 2020 and CDR 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. The PREFIRE team brings together expertise in remote sensing, Earth system modeling, and Artic Ice.

Recent Achievements

The PREFIRE project is currently completing concept and technology development and working toward an SRR/MDR in FY 2019.

Planned Future Achievements

PREFIRE is planning an SRR/MDR in the second quarter of FY 2019. PREFIRE will not have a KDP-B per the SMD guidelines for Class D projects. The project is planning its PDR in FY 2019, followed by KDP-C in early FY 2020.

EARTH VENTURE CONTINUITY-1 (EVC-1)

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.

Planned Future Achievements

NASA released a solicitation for EVC-1 in December 2018, to address radiation budget measurement continuity. NASA will select the first EVC-1 investigation and initiate project formulation in FY 2020.

VENTURE CLASS MISSIONS

Program Schedule

Date	Significant Event
FY 2018	EVI-5 (instrument) solicitation released
FY 2019	EVC-1 (Radiation Budget Measurement) solicitation released
FY 2018	ECOSTRESS Instrument delivery to ISS
FY 2019	ECOSTRESS prime operating mission ends
FY 2019	GEDI Instrument Delivery to ISS
FY 2019	GEDI launch readiness
FY 2019	EVM-3 (mission) solicitation released
FY 2019	TEMPO delivery to storage
FY 2020	TROPICS Instrument Delivery to storage
FY 2020	EVI-6 (instrument) solicitation released
FY 2021	MAIA Instrument Delivery host spacecraft
FY 2021	TEMPO launch readiness
FY 2022	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 2023	EVI-7 (instrument) 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-2: ATom	Provider: Harvard College Lead Center: ARC Performing Center(s): LaRC, ARC, GSFC, AFRC, JPL Cost Share Partner(s): NOAA

VENTURE CLASS MISSIONS

Program Element	Provider
EVS-2: NAAMES	Provider: Oregon State University Lead Center: LaRC Performing Center(s): LaRC, GSFC, ARC Cost Share Partner(s): N/A
EVS-2: ACT-America	Provider: Pennsylvania State University Lead Center: LaRC Performing Center(s): LaRC, GSFC, JPL Cost Share Partner(s): N/A
EVS-2: ORACLES	Provider: ARC Lead Center: ARC Performing Center(s): ARC, LaRC, GSFC, AFRC, JPL Cost Share Partner(s): University of Namibia
EVS-2: OMG	Provider: JPL Lead Center: JPL Performing Center(s): JPL, GSFC, AFRC, JSC Cost Share Partner(s): Danish National Space Institute, Stockholm University
EVS-2: CORAL	Provider: Bermuda Institute of Ocean Sciences Lead Center: JPL Performing Center(s): JPL, AFRC Cost Share Partner(s): N/A
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
EVS-3: DCOTSS	Provider: Texas A&M University Lead Center: LaRC Performing Center(s): AFRC, ARC, GSFC Cost Share Partner(s): N/A

VENTURE CLASS MISSIONS

Program Element	Provider
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

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 each every 18 months. NASA will award all Venture Class funds through full and open competition.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
CYGNSS: project management, development, integration and mission operations	Southwest Research Institute	San Antonio, TX
TEMPO: development of instrument (ultraviolet-visible spectrometer)	Ball Aerospace & Technologies Corp.	Boulder, CO
GeoCarb: project management, development, integration and mission operations	University of Oklahoma	Norman, OK

VENTURE CLASS MISSIONS

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Oct 2018	GEDI ORR	Successful	N/A
Performance	SRB	May 2018	TROPICS PDR	Successful	FY 2018 Q2
Performance	SRB	May 2018	ECOSTRESS ORR	Successful	N/A
Performance	SRB	Apr 2018	MAIA PDR	Successful	FY 2019 Q2
Performance	SRB	FY 2019 Q4	GeoCarb CDR	TBD	FY 2023 Q2
Performance	SRB	FY 2019 Q2	MAIA CDR	TBD	N/A
Performance	SRB	FY 2019 Q2	GEDI ORR	TBD	N/A
Performance	SRB	FY 2019 Q2	EMIT SRR/MDR	TBD	FY 2019 Q4
Performance	IRT	FY 2019 Q2	PREFIRE SRR/MDR	TBD	FY 2019 Q4
Performance	SRB	FY 2019 Q4	TROPICS ORR	TBD	N/A
Performance	SRB	FY 2019 Q4	EMIT PDR	TBD	FY 2020 Q4
Performance	SRB	FY 2019 Q4	PREFIRE PDR	TBD	FY 2020 Q3
Performance	IRT	FY 2020 Q3	PREFIRE CDR	TBD	FY 2022 Q1
Performance	SRB	FY 2020 Q4	EMIT CDR	TBD	FY 2022 Q1
Performance	SRB	FY 2022 Q1	EMIT ORR	TBD	N/A
Performance	SRB	FY 2022 Q1	PREFIRE ORR	TBD	N/A
Performance	SRB	FY 2023 Q2	GeoCarb ORR	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
ESSP Missions Research	11.8	--	**16.5**	18.5	20.7	26.3	29.3
Orbiting Carbon Observatory-3	9.7	--	**7.4**	7.2	5.8	2.8	0.0
Small Satellite Constellation Initiative	1.0	--	**25.0**	25.0	25.0	25.0	25.0
OCO-2	15.8	--	**11.0**	9.9	10.1	10.4	10.7
GRACE	5.4	--	**0.0**	0.0	0.0	0.0	0.0
CloudSat	12.9	--	**9.6**	5.1	0.0	0.0	0.0
Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO)	6.2	--	**6.6**	6.2	3.3	3.3	0.0
Total Budget	**62.8**	**--**	**76.1**	**71.9**	**64.9**	**67.7**	**64.9**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 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 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

The A-Train is a convoy of satellites that occupy the same orbital path called the Afternoon Constellation. Researchers used A-Train data extensively with models, and the data contributed substantially to studies of the important and complex aerosol and cloud radiative interactions. Using Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation satellite (CALIPSO) data, researchers found that these interactions strongly depend on the relative altitude of clouds and smoke layers in the southeast Atlantic. A related study reported that from June to October, low-level clouds in the southeast Atlantic often underlie seasonal aerosol layers transported from the African continent. Two seasons of observations

OTHER MISSIONS AND DATA ANALYSIS

from NASA's Cloud-Aerosol Transport System on the International Space Station revealed that the bottom of the above-cloud aerosols layer is much lower than previously estimated based on CALIPSO observations. This research advances understanding of recently observed global changes and improve capabilities to predict the future climate.

A recent study investigated influences of sea ice cover on arctic clouds using Cloud-Aerosol Lidar with Orthogonal Polarization profile data from CALIPSO. Researchers used eight years of data, and partitioned cloud observations into those over sea ice and those over open water. Liquid water clouds controls the surface radiation budget in the Arctic and may influence the formation and melting of sea ice in fall and summer, respectively. Summer is the only season with no observed cloud response to sea ice cover variability, implying no effect during the season of peak arctic sea ice loss. In other seasons, however, there are more clouds over open water than over sea ice.

Although NASA did not design the Orbiting Carbon Observatory-2 (OCO-2) satellite to monitor power plant emissions, a recent study shows in some cases, carbon dioxide observations from OCO-2 can be used to quantify daily carbon dioxide emissions from individual middle- to large-sized coal power plants by fitting the data to plume model simulations. Satellite emission estimates for U.S. power plants are within 1–17 percent of reported daily emission values, enabling application of the approach to international sites that lack detailed emission information.

Researchers combined OCO-2 data with other satellite data sets including precipitation and temperature and showed that while land generally releases carbon to the atmosphere during El Niño years, the processes governing that release varies by ecosystem. Specifically, it showed that compared to the 2011 El Niño period, on a global basis, tropical regions released more carbon during the 2015-2016 El Niño. Significant increases in fire activity during El Niño years compared to La Niña years drives these differences. The heat and drought of the 2015-2016 El Niño had distinctly different impacts on Africa, South America, and Southeast Asia, each with different implications for these forests’ ability to function as a carbon sink. Tropical South America, including the Amazon rainforest, experienced the driest conditions in 30 years.

In an important publication , NASA scientists and collaborators analyzed 14 years of GRACE data collected between 2002-2016 by quantifying 34 trends in terrestrial water storage (TWS), categorized their drivers as natural interannual variability, unsustainable groundwater consumption, or climate change, and found that freshwater availability is changing worldwide. Researchers found that the largest TWS trends occur in Antarctica, Greenland, the gulf coast of Alaska, and the Canadian archipelago, where the warming climate continues to drive rapid ice sheet and glacier ablation. Excluding those four ice-covered regions, freshwater accumulates in far northern North America and Eurasia and in the wet tropics, while the greatest non-frozen freshwater losses have occurred at mid-latitudes. Their investigation found that several of these trends had been lacking thorough investigation and attribution, including massive changes in northwestern China and the Okavango delta. Others are consistent with climate model predictions. Their observation-based assessment of how the world’s water landscape is responding to human impacts and climate variations provides a blueprint for evaluating and predicting emerging threats to water and food security.

SMALL SATELLITE CONSTELLATIONS INITIATIVE

The Small Satellite Constellations Initiative focuses on increasing the use and utility of commercial constellations of small satellites for Earth system science research. NASA designed the initiative to select private sector data vendors that will provide Earth science data products that are directly related or lead to Essential Climate Variables. This will provide a cost-effective means to augment and/or complement the suite of Earth observations acquired by NASA and other US government agencies, as well as those by international partners made available to NASA and its stakeholders. The initiative emphasizes data acquired by small satellites constellations, affording the means of complementing NASA acquired data with additional data sources.

During the first year, NASA will conduct a pilot program to capitalize on the increasing availability of commercial, low-cost, miniaturized small satellites and instruments to investigate the science capabilities of small satellite constellations to augment data produced by current NASA assets. During the pilot NASA intends to provide the purchased data sets to a broad set of separately selected NASA-funded researchers who will examine and analyze the data set(s) to help determine the utility of the constellation-based products for advancing NASA's science and applications development goals. Selected data providers will afford NASA and its stakeholders an efficient increase in capabilities by building on synergies with NASA assets. If the data proves of value, NASA will establish longer-term contracts for the regular purchase of data products. In addition, after the pilot, NASA will provide on-ramps for other potential private sector small satellite constellation data product providers.

Recent Achievements

NASA selected three data providers in September 2018 for the first year pilot: Spire, Planet, and DigitalGlobe.

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 International Space Station (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. After launch and docking with the ISS, NASA will host the instrument on the ISS Japanese Experiment Module - Exposed Facility.

Recent Achievements

In 2018, OCO-3 completed payload integration and testing. Currently, the project is preparing for launch to the ISS on SpaceX-17, post launch assessment review, and initial operations.

Operating Missions

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.

The OCO-2 instrument has collected almost one million soundings globally each day since September 2014, completed its prime mission in October 2016, and is now in its first extended mission. The 2017 Earth Science Senior Review endorsed the OCO-2 mission for continued operations through 2020, and preliminarily, through 2023.

Recent Achievements

In 2018, the release of Version 9 estimates of column-averaged carbon dioxide led to improved accuracy in areas of rapidly changing topography and increased coverage in dark forested areas, particularly in the tropics and boreal regions. OCO-2 continued to work closely with several research teams to coordinate the collection of coincident OCO-2 satellite observations with detailed ground-based measurements. Several of these coordinated observations measured the patterns of carbon dioxide distributions in the urban environment of Los Angeles, from space and on the ground, to understand the role of industrial activity, movement of air by winds, and the seasonal role of plants in the urban environment. The mission’s additional capability to detect photosynthesis from space through plant fluorescence has prompted collaborations with many researchers, including the U.S. Department of Agriculture, to connect this new measurement to plant health and crop productivity.

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 improves 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 2018, following an anomaly with one of its reaction wheels, which control its orientation, CloudSat successfully transitioned to a new operational orbit below the A-Train to ensure the safety of the other constellation members. The new orbit does not significantly alter CloudSat's science capabilities, and the data record continues to reveal new and unique information about cloud and precipitation processes around the Earth. CloudSat continued to produce data products that global weather centers routinely use to improve cloud and precipitation processes that impact weather forecast skill. Researchers also use CloudSat data to evaluate the accuracy of operational algorithms for weather satellites, and in particular, the use of vertical-profiling capability of CloudSat refined algorithms for estimating cloud base heights from geostationary weather satellites that are useful in aviation. The project 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.

OTHER MISSIONS AND DATA ANALYSIS

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

Following the departure of CloudSat from the A-Train in February 2018, the CALIPSO team evaluated the best way to maximize the science derived from the mission, leading to a decision to follow CloudSat into its new orbit. Following the establishment of formation-flying of CALIPSO and CloudSat in the new orbit, 15 km below the A-Train in October 2018, the CALIPSO team also wrote and released a set of journal papers describing the new Version 4 algorithms in a special issue of Atmospheric Measurement Techniques. Furthermore, release of the two new data products included the three-dimensional distribution of clouds around the globe; the other enables studies on sulfuric acid aerosols in the stratosphere. The mission also supported NASA field campaigns investigating phytoplankton ecosystems in the North Atlantic Ocean and impacts of smoke particles on clouds off the coast of southwest Africa.

EARTH SCIENCE DATA SYSTEMS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	204.4	--	214.4	229.0	239.3	250.1	267.7

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

NASA's Worldview application provides the capability to interactively browse over 800 global, full-resolution satellite imagery layers and then download the underlying data. This is an image of Hurricane Florence as it approaches the east coast of the U.S. on September 12, 2018, taken by the Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi National Polar-Orbiting Partnership (S-NPP) satellite.

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 nation.

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 as well as 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–such as 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.

EARTH SCIENCE DATA SYSTEMS

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.

NASA's Earth Science data is available to the public at https://earthdata.nasa.gov.

EXPLANATION OF MAJOR CHANGES IN FY 2020

NASA changed the name of the Multi-Mission Operations program to the Earth Science Data Systems (ESDS) program. NASA also renamed two projects within this program: Earth Science Data and Information Systems (ESDIS) project (previously the Multi-Mission Operations project), and the Data System Evolution (DSE) project (previously the Earth Observing System Data and Information System (EOSDIS) project). These new names are representative of current program and project functions and reflect names already in use at NASA centers.

ACHIEVEMENTS IN FY 2018

The EOSDIS archives grew to over 27 petabytes in FY 2018. EOSDIS distributed over 1.6 billion data products to four million users around the world. EOSDIS provided data stewardship to over 11,000 unique data products from more than 100 instruments, ensuring NASA's irreplaceable observational data are available for scientists today and in the future.

EOSDIS supported the launch and early operations of the ICESat-2 (Ice, Cloud, and land Elevation Satellite-2) mission, with increased capacity and new capabilities at the National Snow and Ice Data Center, one of the twelve science discipline-focused Distributed Active Archive Centers (DAACs). Additionally, data from several new instruments and missions were added to DAAC archives, including the TROPOspheric Monitoring Instrument on the European Space Agency (ESA) Sentinel-5P satellite, Joint Polar Satellite System-1 (JPSS-1/NOAA-20), ESA's Sentinel-3B, and the Gravity Recovery and Climate Experiment Follow-On (GRACE-FO), as well as two new instruments on the International Space Station: Total and Spectral solar Irradiance Sensor-1 (TSIS-1) and ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS). The program is preparing for the upcoming deployment of the Orbiting Climate Observatory (OCO-3) to the International Space Station, and is currently supporting the recently launched Global Ecosystem Dynamics Investigation (GEDI).

The program completed an evaluation of the relative cost, technical performance, and security implications of utilizing a commercial cloud environment. Based on the findings of that evaluation, the program has implemented "Cumulus," an open source, cloud-based framework for the ingest, archive, management and distribution of data from a cloud environment. The program deployed Cumulus for testing with the SWOT Science Data System and DAAC at JPL. The team integrated it with the NASA Compliant General Application Platform (NGAP). NGAP provides underlying capabilities for all applications in order to meet NASA cloud security requirements, and it received its initial authorization to operate in July 2018.

The Global Image Browse Service and NASA Worldview continued to gain popularity, with over 15,000 daily users. The public used the imagery from this platform in hundreds of news articles, blog posts, research articles, and other media. In FY 2018, the capability to directly compare imagery from different dates (e.g., “before” and “after”), or across different instruments, was released to the public. There are currently over 800 imagery products available, many updated daily.

Several Making Earth System Data Records for Use in Research Environments (MEaSUREs) activities, initiated after the ROSES 2012 competition, were in their final year. The following are selected highlights:

--An activity produced Earth System Data Records (ESDRs) for the longest length possible (for most cases about 20 years, the length of the altimetry record) of key measures of surface water storages and fluxes. In particular, the project produced pre-SWOT data records of reservoir and lake storage change for as many of the largest global reservoirs and lakes as possible. In addition, they produced pre-SWOT data records of large river heights, slopes, widths, and storage change for as many of the world's largest rivers as possible.

--An activity led by NASA scientists provided precipitation products to enhance the Global Precipitation Climatology Project data set, which blends outdoor rain gauges (including independent historical gauge records) and rainfall estimates culled from satellite algorithms. The team provided updated monthly satellite rain products for the period 1992-2015.

--The Ice Velocity Mapping of the Antarctic Ice Sheet activity continued the production and distribution of ESDRs of ice velocity in Antarctica. The latest version of the ice velocity map covers 99.6 percent of the surface area with measured velocity values (up from 95.1 percent in the last published version). While Greenland is now well covered (regular coastal acquisitions and multiple repeat acquisitions in the interior), the same cannot yet be claimed for Antarctica. Due to the size of the ice sheet, a single sensor cannot achieve complete coverage. The team utilized the Sentinel-1 and Landsat-8 missions changing the way data are available for ice sheet monitoring.

--Finally, the successful development and routine production of the ESDR of Earth's surface mass variations from GRACE and geodetic satellites became part of the standard GRACE-FO mission product suite. In particular, mass concentration blocks (mascons) are essentially another form of gravity field maps. Using mascons rather than the standard spherical harmonic approach, which has been the standard for the first decade of GRACE observations, offers several key advantages, including regional analyses and improved geophysical mass change investigations.

WORK IN PROGRESS IN FY 2019

The program is capitalizing on the benefits of operating in a cloud environment by developing a cloud-based architecture for delivering a variety of data transformation services (e.g., subsetting, reformatting, and regridding) for data from several missions/instruments. These services improve the usability of data for all users. EOSDIS will support critical ground system tests for SWOT in late FY 2019 using the cloud-based capabilities of Cumulus. Work will continue with several other flight projects, instrument teams, and science teams to prepare for upcoming missions such as Geostationary Carbon Observatory, Polar Radiant Energy in the Far-InfraRed Experiment, and Earth Surface Mineral Dust Source Investigation.

In FY 2019, EOSDIS will begin ingesting, processing, and distributing data from the Joint Polar Satellite System-1 (JPSS-1) (now NOAA-20) mission, launched in November 2017, for the specific needs of

NASA science. These data products provide continuity with data from previous earth observing system platforms and the Suomi National Polar-orbiting Partnership mission, extending the 18-year record of critical Earth science measurements.

NASA selected new MEaSUREs activities after the ROSES 2017 solicitation and they will begin their first year of work. MEaSUREs will reach a number of milestones throughout FY 2019, including establishment of the DAAC, data system user group involvement and other project-specific tasks.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

The program will expand its capabilities to support data from new missions, including 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 DAACs, 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 team 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.

EARTH SCIENCE DATA SYSTEMS

- 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 team developed core systems to reduce duplication and improve user access to EOSDIS data.
- Common Metadata Repository (CMR) is a high-performance, high quality, continuously evolving metadata system that catalogs all data and service metadata records for EOSDIS and is the authoritative management system for all EOSDIS metadata.
- Global Imagery Browse Services (GIBS) provides visual representations of NASA Earth science data at full resolution in a free, open, and interoperable manner. Through responsive and highly available web services, it enables interactive exploration of data to support a wide range of applications including scientific research, applied sciences, natural hazard monitoring, and outreach. GIBS provides much of the LANCE near real-time imagery, as well as present day and historical imagery.
- NASA-compliant General Application Platform is a cloud-based platform that provides a scalable, flexible application platform solution that offers the cost benefits of hardware consolidation with the safety and security of application sandboxing and resource management.
- Earth Observing System Networks: Effective access to EOSDIS depends on the end-to-end network connectivity between users and geographically distributed DAACs. An EOSDIS internal and external logical network provides connectivity. These two logical networks consist of a variety of physical networks including wide area and local area networks.
- The NASA Earthdata website (https://earthdata.nasa.gov) integrates information from across EOSDIS. Earthdata is the entry point for EOSDIS data, articles, documentation, and collaboration. It also leverages NASA's CMR to provide comprehensive search capabilities. Earthdata offers new and experienced users an organized view of EOSDIS resources and latest events.
- Earthdata Code Collaborative is a platform for the development, testing, and discovery of Earthdata-related applications and services. It provides a full suite of development tools to EOSDIS' geographically distributed projects, embodying current best practices for software requirement gathering, development, testing, and operations.
- The NASA Sentinel Gateway obtains data from a dedicated interface to the European Commission's Copernicus Programme Sentinel 1, 3 and 5P satellite ground system. The Sentinel Gateway transfers data from the Sentinel 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.

- 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.
- IMPACT at NASA's Marshall Space Flight Center (MSFC) works with other government agencies to increase the use of NASA Earth observations. This team assesses, independently evaluates and makes recommendations to improve EOSDIS services and processes; manages archiving of airborne science observations; and develops proof of concept data system capabilities. IMPACT also works closely with the Satellite Needs Assessment Working Group (SNWG) to design and implement a systematic plan to assist other agencies in incorporating NASA Earth observation data into their workflows.

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.

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

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

EARTH SCIENCE DATA SYSTEMS

Program Element	Provider
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
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

EARTH SCIENCE DATA SYSTEMS

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
NSIDS	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 (CSI) score for NASA EOSDIS over the last eleven years is 77. It also identifies the key areas that NASA can leverage across the DAACs to continuously improve its service to its customers.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	American Customer Satisfaction Index	2018	Survey current EOSDIS users to assess satisfaction with current services	Customer Satisfaction Index: 79	2019, annually thereafter

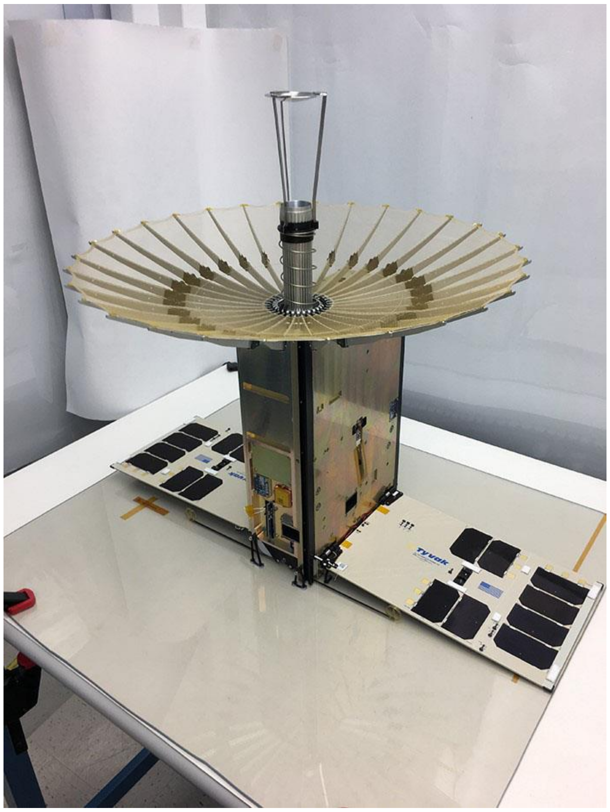
EARTH SCIENCE TECHNOLOGY

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	60.4	--	69.6	79.2	82.8	84.6	86.4

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



Developed at the Jet Propulsion Laboratory, the RainCube (Radar in a CubeSat) is a technology validation mission to enable Ka-band precipitation radar technologies on a low-cost, quick-turnaround platform. The International Space Station (ISS) deployed the 6-unit CubeSat on July 13, 2018. On August 27, 2018, NASA turned on the RainCube radar and successfully acquired the vertical range profiling measurements of precipitation and land surface at a nadir-pointing configuration. Since then, RainCube has taken data of several large storms, including Typhoon Trami off the coast of

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 2020

NASA created the Decadal Incubation project in response to the recommendation of the 2017 Earth Science Decadal Survey.

ACHIEVEMENTS IN FY 2018

The ESTP worked on 136 active projects in FY 2018. For projects eligible to do so, 40 percent advanced at least one Technology Readiness Level during FY 2018. Over 100 students from 31 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, NASA infused the Super Cloud Library (SCL), a data analysis and visualization tool for cloud-resolving models, into the data analytics and storage system at the NASA Center for Climate Simulation. Cloud resolving models are numerical simulations of convective clouds or storms that help scientists explore cloud phenomena and aid in the development of improved weather models. The SCL has demonstrated 20 times speed improvements over previous manual processes.

The program awarded 12 proposals through a competitive solicitation under the Advanced Component Technology (ACT) program element. The new awards have commenced and are already making contributions toward new observing instruments. The program awarded four new proposals under the In-Space Validation of Earth Science Technologies (InVEST) program element. These projects will test and validate new technologies on orbit using the CubeSat satellite platform.

NASA launched three InVEST projects in May 2018 to the International Space Station, and subsequently deployed in July 2018. By September 2018, all three were taking their first measurements and sending data to the ground.

WORK IN PROGRESS IN FY 2019

Based on the 2017 Earth Science Decadal Survey, the program plans to issue solicitations in FY 2019 for the Advanced Information Systems Technology (AIST) program element and the Instrument Incubator Program (IIP) element. Both will focus on the decadal survey recommended observables.

The program also plans technology demonstration launches in FY 2019, which began with the launch of the Compact Spectral Irradiance Monitor CubeSat on December 3, 2018. The HyperAngular Rainbow Polarimeter CubeSat will launch no earlier than April 2019.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

In FY 2020, the program anticipates the selection of awards under the IIP FY 2019 solicitation, and releasing a solicitation for the Advanced Component Technologies (ACT) program element. ESTP also anticipates the competitive selection of two study teams for each targeted observable in the new Decadal Incubation project. These teams will perform investigations to define the needs and capabilities of their relevant target observable area, in either Planetary Boundary Layer (PBL) 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. In addition, the program expects to launch the Compact Infrared Radiometer in space no earlier than October 2019.

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 instrument 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, and access, visualize, communicate, and understand science data. Currently, AIST activities focus on four areas needed to support future Earth science measurements:

- Concept Development of Improved Sensor Measurements, which includes tools to help assess various types of measurements and how to make them, including technologies that aid in the design and analysis of quantitative observations;
- Data Acquisition and Management, which refers to the collection and management of high-volume and/or high-rate data and supports the building and operation of infrastructures that are necessary for sensor data acquisition;
- Data Product Generation, which is the creation of interdisciplinary products that aggregate observational data, thus improving the scientific value of the data at reduced costs; and
- Exploitation of Data for Earth Science and Applications, which focuses on the transformation of data products into actionable information and includes modeling and visualization tools, as well as collaborative environments. In general, projects aim to advance the discovery, access, and use of sensor data and model output within the Earth Science community.

Program Schedule

Date	Significant Event
Q1 FY 2019	ROSES-2018 selection no earlier than six months of receipt of proposals
Q2 FY 2019	ROSES-2019 solicitation
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

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.

MAJOR CONTRACTS/AWARDS

None.

EARTH SCIENCE TECHNOLOGY

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)	03/2018	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	2019
Performance	NASA Advisory Council Earth Science Advisory Committee	09/2019	Review for success in infusion of new technologies	TBD	2019

APPLIED SCIENCES

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**53.2**	**--**	**53.3**	**53.9**	**56.3**	**57.0**	**58.5**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

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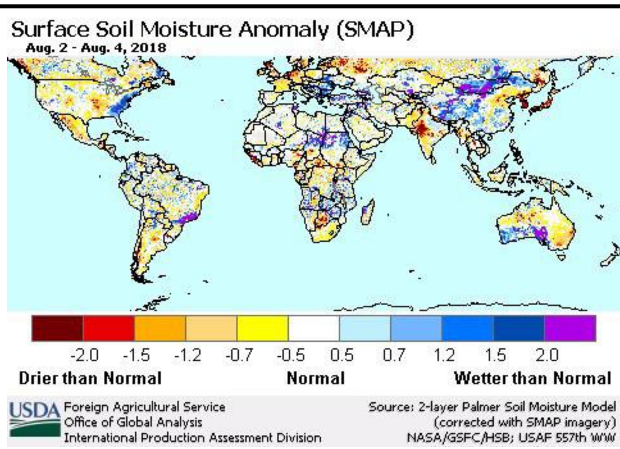

The USDA Foreign Agriculture Service integrated SMAP-based soil moisture products into their crop forecasting system in 2018. This image shows variances in surface soil moisture from normal. Soil moisture is an essential indicator of potential crop yield, and the information can improve yield estimates, providing U.S. farmers and markets with better information on global competitors particularly from regions lacking gauge data. The image from the USDA Crop Explorer website includes soil moisture information provided by NASA. It is also available in Google Earth Engine.

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 nation 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:

- Use of NASA soil moisture data by the U.S. Department of Agriculture (USDA) to support its monthly global crop production estimates;
- Use of wildfire detection data and progression predictions by the U.S. Forest Service to improve determination of fire boundaries and 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;

- 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 for 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.

EXPLANATION OF MAJOR CHANGES IN FY 2020

None.

ACHIEVEMENTS IN FY 2018

A few of the accomplishments from FY 2018:

- The New York State Department of Health lowered the temperature for alerting citizens of an upcoming heat wave from 100 degrees to 95 degrees to help prevent heat-related illnesses. This decision stemmed from a project with the Department of Health using heat metrics from the North American Land Data Assimilation System.
- The Delaware Division of Fish and Wildlife used ocean color and sea surface temperature data from the Aqua and Suomi National Polar-orbiting Partnership satellites to assess sturgeon occurrence risk and make decisions on permits and commercial fishing.
- The Bureau of Land Management and Forest Service employed the NASA-sponsored RECOVER system on over 40 wildfire events in FY 2018, using NASA satellite data to shorten recovery time.
- The Department of Agriculture's CropExplorer made NASA soil moisture data available operationally and uses soil moisture in its monthly global crop production estimates.

NASA supported the response to scores of national and international disasters, including the Indonesian tsunami, Hurricane Florence, a dam break in Laos, and multiple U.S. wildfires. For example, NASA provided support to Federal Emergency Management Agency (FEMA), California National Guard, and

California governor's Office of Emergency Services during the 2018 California wildfires; NASA produced burn severity and fire intensity, natural and false color images of fires for burn scar detection. NASA enabled the use of data from multiple Earth observing satellites to measure surface deformation, support sulfur dioxide monitoring for air quality issues, and track lava flow from fissures during the 2018 Kilauea eruption in Hawaii.

The DEVELOP program element, an endeavor for young professionals to work with user organizations to apply Earth science data, included 330 participants working on 67 projects and serving efforts in 41 U.S. states. The Applied Remote Sensing Training program element conducted 14 virtual and in-person trainings, with a record number of advanced trainings. The trainings reached over 2,147 people from all 50 U.S. states and 108 countries representing 1,083 organizations worldwide.

The SERVIR program element (managed jointly with the U.S. Agency for International Development) launched a service-planning toolkit, which strengthens methods to design and implement sustainable services. SERVIR and the Mekong River Commission co-developed a service that advises government ministries in lower Mekong countries on drought status, water availability, and other critical irrigation decisions. SERVIR and the Afghanistan Ministry of Agriculture, Irrigation and Livestock co-developed an agriculture information portal with timely, actionable, province-level information on crop statistics, crop calendars, and commodity market prices to support decision making by the government, farmers, and other stakeholders.

The Applied Sciences Program increased engagement with users in upcoming satellites through its early adopters and targeted application efforts. ICESat-2 developed a community of 25 early adopters who will use the data in health, hazard response, energy production, and arctic shipping applications. The TEMPO mission held an early adopter workshop where its stakeholders identified ways of implementing mission data products for new health effects assessments of ozone and total oxidants, as well as updating state and tribal implementation plans. MAIA announced an early adopter effort and identified 12 target cities for its public health investigations.

WORK IN PROGRESS IN FY 2019

The program will initiate new applications tasks related to disasters, health and air quality, and water resources management. Applied Sciences will initiate tasks from a joint solicitation with the research and analysis program focused on enabling innovative uses of Earth observations for pursuing sustainable development. The Health and Air Quality Applied Sciences Team (HAQAST) will initiate four additional Tiger Team tasks for efficient, nimble response to priority stakeholder uses of Earth observations.

The program will have initial results from the Harvest applications consortium for food security and agriculture as well as from projects related to nine specific elements in the Group on Earth Observations (GEO) Work Programme.

Together with USAID, NASA will announce a new hub serving Amazonia and South America for the SERVIR program. Sixteen program elements in the second SERVIR applied sciences team will deliver results on projects done in partnership with regional hubs in Eastern Africa, Western Africa, Lower Mekong River, and Himalayan-Hindu Kush; the program elements address food security, weather and climate, disasters, and water management. SERVIR will hold its SERVIR annual global exchange event to share applications experiences and examples across its four international hubs. DEVELOP will again sponsor three terms for applications projects. Applied Remote Sensing Training (ARSET) will continue its introductory and advanced level webinars, in-person trainings, and train-the-trainer series; it expects to reach people in all 50 states and over 100 countries.

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. The program will conduct a peer review evaluation of its consortium on socioeconomic impact assessments led by the organization Resources for the Future; the evaluation will assess progress toward the original solicitation's objectives.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

Eight program elements in the Water Resources applications area will produce results related to uses of Earth observations to address water security, threats to water quality, and imbalances between agricultural water supplies and agricultural water requirements.

The Health and Air Quality applications area will deliver results from HAQAST and tiger team activities focused on uses of Earth observations in health and air quality. The health and air quality area will also select members of the next HAQAST team. The 32 tasks supporting the U.S. contributions to the GEO Work Programme will deliver initial results.

The SERVIR Amazonia hub will have its first full year of activities and operation. The third SERVIR applied sciences team will commence with projects done in partnership with the regional hubs and addressing applications of Earth observations for food security, weather and climate, disasters, and water management.

Program Elements

CAPACITY BUILDING

The Capacity Building project enhances U.S. and developing countries' capacity, including 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 it 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 projects, 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 ten-week interdisciplinary projects 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 and throughout 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. In this project, Applied Sciences 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 projects, 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.

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 projects, 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.

- 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.
- 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.

- 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.
- 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.

In addition to these activities, the Applications project supports the following initiatives:

- Food Security 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: NASA 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 US national approach to GEO and the Work Programme, increasing opportunities for these organizations.
- Western Water Applications Office: NASA's 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
Q2 FY 2019	ROSES-2019 solicitation release
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

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.
Capacity Building	Provider: Various Lead Center: LaRC, MSFC, GSFC Performing Center(s): ARC, GSFC, JPL, MSFC, LaRC Cost Share Partner(s): USGS, Groundwork USA, Mobile, Alabama, US Department of Agriculture, University of Georgia, NOAA, Arizona State University, Boston University, USAID, EPS, NOAA, NWS

APPLIED SCIENCES

Program Element	Provider
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
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)

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	June 2018	Review strategy and implementation; Review applications in Earth Science Decadal Survey	Provided recommendations on HAQAST and applications in support of 2017 Decadal Survey implementation	May 2019; semi-annual
Relevance	Applied Sciences Advisory Committee	May 2019	Review strategy and implementation.	TBD	Nov 2019; semi-annual
Relevance	Applied Sciences Advisory Committee	Nov 2019	Review strategy and implementation.	TBD	May 2020; semi-annual

PLANETARY SCIENCE

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Planetary Science Research	279.5	--	**266.2**	272.6	268.6	270.2	301.9
Planetary Defense	76.0	--	**150.0**	150.0	150.0	99.5	100.0
Lunar Discovery and Exploration	22.0	--	**210.0**	327.0	417.0	441.0	458.0
Discovery	258.3	--	**502.7**	393.4	364.4	371.6	371.6
New Frontiers	88.1	--	**190.4**	261.2	341.9	387.3	291.7
Mars Exploration	678.0	--	**546.5**	472.2	481.7	506.1	590.1
Outer Planets and Ocean Worlds	676.2	--	**608.4**	549.6	463.7	224.2	68.8
Radioisotope Power	139.8	--	**147.9**	151.3	142.1	102.5	168.8
Total Budget	**2217.9**	**--**	**2622.1**	**2577.3**	**2629.4**	**2402.4**	**2350.9**

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Planetary Science

PLANETARY SCIENCE

PLANETARY SCIENCE RESEARCH

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Planetary Science Research and Analysis	197.9	--	**183.8**	188.0	181.9	180.9	204.7
Other Missions and Data Analysis	81.6	--	**82.4**	84.7	86.7	89.3	97.2
Total Budget	**279.5**	**--**	**266.2**	**272.6**	**268.6**	**270.2**	**301.9**

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101955 Bennu is a carbonaceous asteroid in the Apollo group discovered on September 11, 1999. It is a potentially hazardous object listed on the Sentry Risk Table with the second-highest cumulative rating. It has a cumulative 1-in-2,700 chance of impacting Earth between 2175–2199. It is the planned target of the OSIRIS-REx mission, which intends to return samples to Earth in 2023 for further study.

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 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 2020

NASA moved the Advanced Multi-Mission Operations System (AMMOS) project to the Planetary Science Research program from the program formerly known as Technology. The move allows AMMOS to better integrate with the research and operations functions, such as the Planetary Data System, that it supports.

ACHIEVEMENTS IN FY 2018

The Juno spacecraft has made observations of Jupiter's polar regions that have never been possible before. This is due to its close, polar orbit; these observations have revealed that the familiar zones and belts that characterize Jupiter's weather system at lower latitudes give way to pervasive cyclonic activity at the poles. Eight circumpolar cyclones surround a single polar cyclone in the north; five circumpolar cyclones encircle a single polar cyclone in the south. The manner in which the cyclones persist without merging and the process by which they evolve to their current configuration are unknown. Progress in understanding these newly discovered weather systems will inform understanding of planetary weather systems across the Solar System.

The Cassini mission found that immense northern storms on Saturn can disturb atmospheric patterns at the planet's equator. This effect, also seen in Earth's atmosphere, suggests the two planets are more alike than previously thought. Despite their considerable differences, the atmospheres of Earth, Jupiter, and Saturn all display a remarkably similar phenomenon in their equatorial regions: vertical, cyclical, downwards-moving patterns of alternating temperatures and wind systems that repeat over a period of multiple years. These patterns appear to be a defining characteristic of the middle layers of a planetary atmosphere.

Data from NASA's Cassini spacecraft reveal complex organic molecules originating from Saturn's icy moon Enceladus, strengthening the idea that this ocean world hosts conditions suitable for life. Research results show much larger, heavier molecules than ever before. Powerful hydrothermal vents mix up material from the moon's water-filled, porous core with water from the moon's massive subsurface ocean – and released into space, in the form of water vapor and ice grains. Scientists continue to examine the makeup of the ejected ice, and recently identified fragments of large, complex organic molecules. Previously, Cassini had detected relatively common organic molecules at Enceladus that were much smaller. Complex molecules comprising hundreds of atoms are rare beyond Earth. The presence of the large complex molecules, along with liquid water and hydrothermal activity, bolsters the hypothesis that the ocean of Enceladus may be a habitable environment for life.

The Lunar Reconnaissance Orbiter (LRO) made unique measurements using the Mini-RF instrument of the lunar crater Cabeus located near the lunar south pole and the site of the Lunar CRater Observation and Sensing Satellite (LCROSS) impact. The measurements suggest that near surface ice may be present. Using the Arecibo telescope as a signal source, Mini-RF measured reflected radar beams off several lunar targets. Results from the LCROSS impact experiment, as well as from the Lunar Exploration Neutron Detector (LEND) instrument on the LRO, show that Cabeus contains H2O. The interior of Cabeus crater has a distinctive response at different bistatic angles (angle subtended between the transmitter, target and receiver in a bistatic radar), suggesting that water ice may be buried in the upper ~meter of the surface. Additional Mini-RF measurements of Cabeus crater and other sites will identify other locations of buried ice using Goldstone antennas and Arecibo.

PLANETARY SCIENCE RESEARCH

Reconsiderations of interpretations of many of the original data that lead to the Late Heavy Bombardment theory, have led to questioning this previously unassailable theory, and an increased scientific interest in the potential of new returned samples from the moon. The Late Heavy Bombardment (LHB) is a theory that the Earth, and the entire inner Solar System, suffered through an intense spike in asteroid bombardment roughly 4 billion years ago. The theory grew from studies of the Moon's crater record and the hundreds of kilograms of lunar material returned to Earth by the Apollo astronauts. Previous dating showed a significant number of impacts occurred during a 50-million-year window. Later dating of lunar meteorites and the introduction of the Nice model further strengthened this theory. The theory suggested that instability and migration of the large planets of the outer Solar System might have sent a barrage of comets and asteroids raining down on the inner Solar System long after the planets had originally formed. Observations of the moon indicate that the collected samples may not be as diverse as originally thought. Sampling a smaller number of impacts multiple times, considering the methods for dating, indicate that they may not yield ages that are as accurate as originally hoped. Advanced simulations indicate that the rearrangement promised by the Nice model may have occurred much earlier in the Solar System's history than originally predicted.

These significant findings suggest that the LHB may have occurred over a much longer time than originally theorized. This reconsideration would align better with observations of the earliest evidence of life on this planet, fossilized, complex communities from 3.5 billion years ago. The renewed focus on lunar exploration raises the possibility that new samples may help clarify this puzzle in the near future.

Researchers proposed disequilibria in planetary atmospheres, as a generalized method for detecting life on exoplanets through remote spectroscopy. Among Solar System planets with substantial atmospheres, the modern Earth has the largest chemical disequilibrium due to the presence of life. However, how this disequilibrium changed over the billions of years of life and Earth, and during increasing oxygen levels, is largely unknown. Scientists calculated the disequilibrium of gases between the atmosphere and ocean during the Precambrian period. They report that: (i) the disequilibrium increased through time in step with the rise of oxygen; (ii) both the Proterozoic and Phanerozoic periods may have had remotely detectable biogenic disequilibria due to the coexistence of O2, N2, and liquid water; and (iii) abiogenic (not produced by living organisms) disequilibrium in the Archean period caused by the coexistence of N2, CH4, CO2, and liquid water, which, for an exoplanet twin, may be remotely detectable.

Based on these results, the researchers identified a new combination of gases that would provide evidence of life on an exoplanet: methane and carbon dioxide found together, but only in the absence of carbon monoxide. Future telescopes like the James Webb Space Telescope will observe the atmospheres of distant planets to seek evidence of life. Earth has several gases in its atmosphere that reveal the presence of life, primarily oxygen and ozone. The new study finds that for the early Earth, the combination of abundant methane and carbon dioxide would provide an alternative sign of life.

WORK IN PROGRESS IN FY 2019

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.

PLANETARY SCIENCE RESEARCH

KEY ACHIEVEMENTS PLANNED FOR FY 2020

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 March 2019.

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), 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.

PLANETARY SCIENCE RESEARCH

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	Planetary Science Advisory Committee (PAC)	2018	Review to assess progress against strategic objectives of Planetary Science.	Recommendation was to maintain a strong program consistent with the decadal survey.	2019

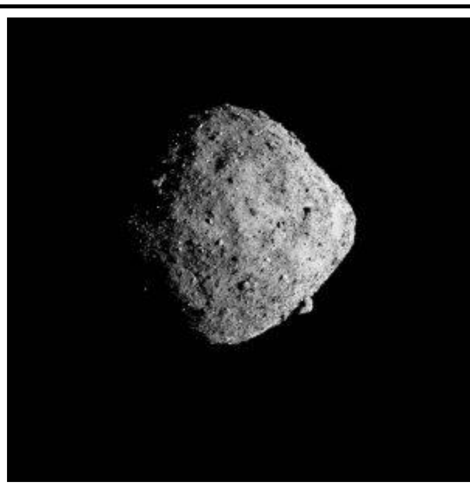
OTHER MISSIONS AND DATA ANALYSIS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Advanced Multi-Mission Operation System	39.9	--	**40.0**	40.7	41.6	42.4	42.5
Planetary Science Directed R&T	3.4	--	**6.5**	7.8	8.6	10.1	17.5
Planetary Data System	16.8	--	**17.1**	17.2	17.3	17.4	17.5
Astromaterial Curation	9.5	--	**12.0**	12.1	12.3	12.4	12.7
Science Data & Computing	2.5	--	**2.7**	2.8	2.8	2.9	2.9
Rosetta	5.4	--	**0.0**	0.0	0.0	0.0	0.0
Robotics Alliance	4.1	--	**4.1**	4.1	4.1	4.1	4.1
Total Budget	**81.6**	**--**	**82.4**	**84.7**	**86.7**	**89.3**	**97.2**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



This image was captured by OSIRIS-REx's MapCam imager on December 12, 2018 as the spacecraft flew over Bennu's equatorial region during the mission's Preliminary Survey of the asteroid. The image was taken from a distance of about 8 miles (13 km) while the spacecraft was traveling toward the asteroid.

Other Missions and Data Analysis includes supporting mission functions such as Planetary Data Systems, Science Data and Computing, and Astromaterial Curation, as well as the NASA portion of the European Space Agency (ESA) Rosetta mission.

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. In addition, AMMOS will pursue complementary collaborations with the Agency's crosscutting Space Technology program. 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.

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 2020.

PLANETARY DATA SYSTEM (PDS)

The PDS is an online data archive. Scientists with expertise in planetary science disciplines designed the PDS, and they curate its data. The PDS 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 archives include imaging experiments, magnetic and gravity field measurements, orbit data, and various spectroscopic observations. All 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 has received data from 16 planetary missions in 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 200 terabytes to a total holding of approximately 1.4 petabytes.

ASTROMATERIAL CURATION

The Astromaterials Acquisition and Curation Office at JSC curates all extraterrestrial material under NASA control. Curation is an integral part of all 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) preparation and allocation of samples for research; (7) and 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 and coupons for several past, present, and future sample return missions (e.g., Apollo, Genesis, Stardust, OSIRIS-Rex, Mars 2020). Planning and research 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 (MMX), and comets (CAESAR). NASA plans to receive Hayabusa2 and MMX samples under international agreements with 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.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

In the past year, the Curation Office completed the designs for new advanced-curation and advanced-cleaning facilities, and competed and awarded the contracts to construct these labs along with the OSIRIS-Rex and Hayabusa2 curation labs. JSC has also purchased a state-of-the-art scanning Raman system for non-destructive characterization of astromaterials, to use in concert with the existing X-ray CT scanner for astromaterials. The Curation Office has made significant strides in advanced curation activities relating to: (1) developing techniques for automated small particle manipulation, especially of samples in complex substrate materials; (2) efforts to merge data products from multiple high-resolution 3D imaging techniques to better characterize samples; (3) the measurement and characterization of the biological load and diversity in multiple sample curation labs; and (4) the digitization of 45+ years of sample processing records.

The curation office has also made significant preparations for opening previously sealed Apollo samples, including working to add the ability to process samples in a He-purged environment and under cold conditions (-20° C). All of this is in addition to maintaining eight current collections housed in 22 clean rooms, from which we have allocated > 1400 samples to the > 400 registered Principle Investigators (PIs) from 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 being 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 is currently working to convert many of the original data sets, which exist in analog form in their original media, to digital data sets accessible on-line by researchers. The PDS Lunar Data Node restores old Apollo data, packaging the data, and overseeing their archive with PDS. This involves reading the data, converting it to standard digital formats, and collecting and making sense of the data formats and documentation so the researchers can easily access and use the data. Currently we have completed archive of 18 data sets with PDS, completed packaging of 12 data sets in PDS compliant format, now awaiting review or lien resolution circa December 2018, and have restored and are in the process of packaging 24 data sets, which should undergo review in the summer/fall of 2019. In addition, the team has restored and archived 17 raw binary data collections from the Apollo ARCSAV tapes.

ROSETTA

Rosetta is an ESA-led comet rendezvous mission, with NASA participation, in its operations phase. It launched in March 2004, and has enabled scientists to look at some of the most primitive material from the formation of the solar system 4.6 billion years ago. Rosetta is studying the nature and origin of comets, the relationship between cometary and interstellar material, and the implications of comets with regard to the origin of the solar system. The Rosetta spacecraft is the first to undertake long-term exploration of a comet at close quarters. It comprises a large orbiter designed to operate for a decade at large distances from the Sun, and a small lander. Each of these elements carries a large number of scientific experiments and examinations designed to complete the most detailed study of a comet ever attempted. Rosetta arrived at comet 67P/Churyumov–Gerasimenko in FY 2014. The operational phase of the mission ended with the controlled descent of the spacecraft onto the comet at the end of FY 2016. The team will complete data analysis and archive efforts in 2019.

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 Robotics Alliance Project 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 2018 RAP sponsored 270 FIRST Robotics Competition teams (approximately 7,000 students), 50 VEX robotics teams (approximately 500 students), and sponsored and/or supported 18 FIRST Robotics Competition events (affecting approximately 48,000 students).

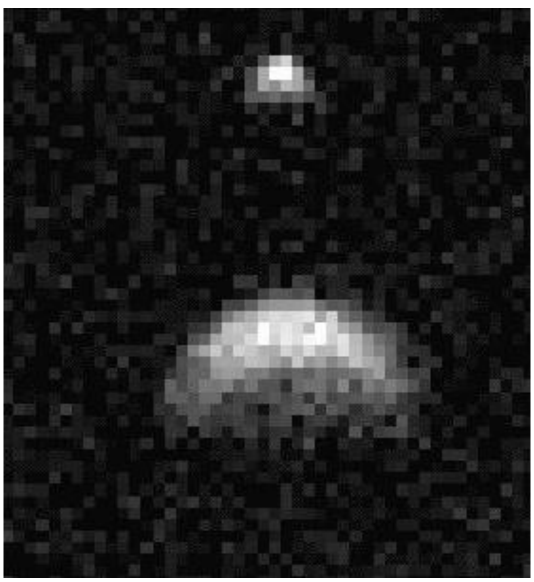
PLANETARY DEFENSE

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
DART	41.0	98.0	**72.4**	66.4	9.1	4.5	0.0
Other Missions and Data Analysis	35.0	--	**77.6**	83.6	140.9	95.0	100.0
Total Budget	**76.0**	**--**	**150.0**	**150.0**	**150.0**	**99.5**	**100.0**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



Asteroid 2018 EB, discovered by NEOWISE on April 4, 2018, is in a potentially hazardous orbit just outside of and inclined to Earth's orbit, which afforded the opportunity to observe it again 6 months after discovery. Radar imagery from Arecibo (above) and Goldstone revealed that 2018 EB is, in fact, a binary asteroid. It approached Earth at 15.4 times the Earth-Moon distance on October 7, 2018.

The focus of planetary defense missions is to detect and provide subsequent 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 US government response to any detected impact threat. In the event that deflection or disruption is not possible due to too short of 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, should a PHO be on an impact course or actually impact

Earth. The PDCO participates in implementing the U.S. National Near-Earth Object Strategy and Action Plan.

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 of Earth, 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 2020

None.

DOUBLE ASTEROID REDIRECTION TEST

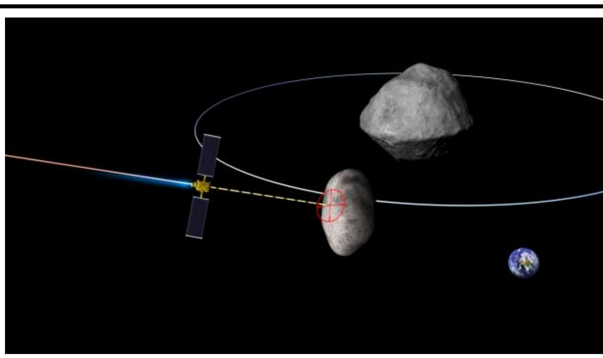
Formulation	Development	Operations

FY 2020 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	BTC	Total
Formulation	22.5	--	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	40.6
Development/Implementation	0.0	--	98.0	**72.4**	65.0	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	15.0
2019 MPAR LCC Estimate	**22.5**	**--**	**98.0**	**72.4**	**66.4**	**9.1**	**4.5**	**0.0**	**0.0**	**313.9**
Total Budget	**22.5**	**--**	**98.0**	**72.4**	**66.4**	**9.1**	**4.5**	**0.0**	**0.0**	**313.9**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



Artists depiction (not to scale) of the DART spacecraft approaching impact with the moonlet of the double asteroid Didymos at a time when 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 double asteroid Didymos. The Didymos system consists of the primary asteroid, Didymos A that is about 780 meters (1/2 mile) and a "moonlet," Didymos B is about 163 meters (535 feet). The DART spacecraft will demonstrate the kinetic impact deflection method by deliberately crashing into the moonlet at a speed of approximately six kilometers per second (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 this demonstration possible without 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 and NASA will use it to improve our readiness to respond to an actual asteroid impact threat.

DOUBLE ASTEROID REDIRECTION TEST

Formulation	Development	Operations

NASA's DART spacecraft has a launch readiness date of February 2022. The targeted impact date with the Didymos system moonlet is October 2022, when the Didymos system is within 11 million kilometers of Earth, enabling observations of the change the orbital period of the moonlet by ground-based telescopes and planetary radar.

EXPLANATION OF MAJOR CHANGES IN FY 2020

None.

PROJECT PARAMETERS

NASA plans to launch DART in 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. The DART spacecraft will utilize the NASA Evolutionary Xenon Thruster – Commercial (NEXT-C) solar electric propulsion system as its primary in-space propulsion system. The next-generation NEXT-C system, based on the Dawn spacecraft propulsion system, provides DART with significant flexibility in the mission timeline, including significantly widening the viable launch period (compared to most planetary missions), as well as decreasing the cost of the launch service. 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.

ACHIEVEMENTS IN FY 2018

The DART asteroid deflection technology demonstration passed its mission confirmation review Key Decision Point (KDP-C) gate review, completing formulation Phase B, preliminary design and technology completion, and beginning implementation Phase C, final design and fabrication.

WORK IN PROGRESS IN FY 2019

DART will continue final design and fabrication activities, pass its critical design review and mission operations review, and prepare for the KDP-D gate review in FY 2020.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

DART will complete its final design and fabrication activities. Based on technical progress and results of the Critical Design Review (CDR) and mission operations review conducted in FY 2019, at the KDP-D gate review NASA will approve DART to start spacecraft assembly, integration, and test in preparation for launch.

DOUBLE ASTEROID REDIRECTION TEST

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2020 PB Request
Formulation Authorization	March 2016 (Rev B)	March 2016 (Rev B)
MCR	May 2015	May 2015
SRR/MDR	September 2016	September 2016
KDP-B	March 2017	March 2017
PDR	April 2018	April 2018
KDP-C	August 2018	August 2018
CDR	June 2019	June 2019
KDP-D	April 2020	April 2020
ORR/FOR	March 2021	March 2021
MRR/FRR	May 2021	May 2021
Launch Readiness	February 2022	February 2022
KDP-E	March 2022	March 2022
Asteroid Impact/End of Flight Operations	October 2022	October 2022
End of Ground Observations and Data Analysis	September 2023	September 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 (mths)
2019	258.3	70%	2019	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 (*j*oint *c*onfidence *l*evel); all other CLs (*c*onfidence *l*evels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

DOUBLE ASTEROID REDIRECTION TEST

Formulation	Development	Operations

Development Cost Details

This is the first report of development cost for this mission. The NEXT-C electric propulsion 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	73.9	2.2
Payloads	5.3	5.4	0.1
Systems I&T	16.5	16.5	0.0
Launch Vehicle	41.0	41.0	0
Ground Systems	5.7	5.8	0.1
Science/Technology	3.2	3.3	0.1
Other Direct Project Costs	114.9	112.4	-2.4

Project Management & Commitments

The John Hopkins University/Applied Physics Laboratory 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	No
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	No

DOUBLE ASTEROID REDIRECTION TEST

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
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	No
Launch Vehicle	Launch vehicle and all launch services	Provider: TBD Lead Center: TBD Performing Center(s): N/A Cost Share Partner(s):N/A	

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 (size, shape, and albedo of each body, orbit characteristics, etc.), 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. The acquisition of host launch capability with DART as a secondary payload is to be determined. 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

DOUBLE ASTEROID REDIRECTION TEST

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Institutional Review Team (IRT)	September 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)	February 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, project ready to proceed to Phase B	PDR
Performance	Standing Review Board (SRB)	April 2018	Preliminary Design Review (PDR) to assess readiness for final design and fabrication (Phase C)	Successful, project ready to proceed to Phase C	CDR
Performance	Standing Review Board (SRB)	June 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)		ORR

DOUBLE ASTEROID REDIRECTION TEST

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board (SRB)	March 2021	Operational Readiness Review (ORR) to assess readiness for system launch, checkout, (completion of Phase D), operations, and sustainment (Phase E)		

OTHER MISSIONS AND DATA ANALYSIS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Near Earth Object Observations (NEOO)	35.0	--	**77.6**	83.6	140.9	95.0	100.0
Total Budget	**35.0**	**--**	**77.6**	**83.6**	**140.9**	**95.0**	**100.0**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

Mission Planning and Other Projects

NEAR-EARTH OBJECT OBSERVATIONS (NEOO)

The NEOO project, using ground and space-based assets, looks 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, with smaller objects being two orders of magnitude more numerous than larger objects.

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 January 2010 National Academies study on the NEO hazard, 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) newly commissioned Space Surveillance Telescope;
- Support the operation of the two small telescope wide field survey system 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, and acquire two more for southern hemisphere sites;
- Support the continued and enhanced operation of planetary radar capabilities at the National Science Foundation’s Arecibo (now under University of Central Florida management) and NASA’s Goldstone facilities; and
- Investigate both ground and space-based concepts for increasing capacity to detect, track, and characterize NEOs of all sizes.

OTHER MISSIONS AND DATA ANALYSIS

Since NASA's search started in 1998, the project has found over 96 percent of these objects that are 1 kilometer and larger, and about 34 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 crewed exploration, and possible eventual candidates for asteroid mining operations.

For more information on NEOO: 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 University of Hawai'i Institute for Astronomy operates the IRTF for NASA under contract. 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: http://irtfweb.ifa.hawaii.edu/

The NEOWISE mission uses the Wide-field Infrared Survey Explorer (WISE) spacecraft, a 40 cm (16 in) diameter infrared telescope in Earth-orbit that continues an all-sky astronomical survey with its two detectors, which remain in non-cryogenic operations. The Jet Propulsion Laboratory (JPL) operates the NEOWISE mission. 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: https://www.nasa.gov/mission_pages/neowise/mission/index.html

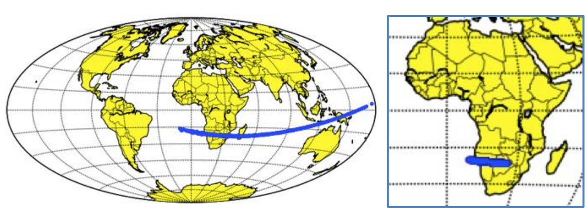
NASA continues to invest in instrument development for a potential space-based infrared telescope mission optimized for NEO search and characterization. The instrument development follows the extended Phase A study of the NEOCam mission concept originally proposed to the Discovery Program. Instrument development is expected to proceed to Phase B in FY 2019.

Recent Achievements

Asteroid search teams funded by the NEO Observations project found, in FY 2018, another six asteroids larger than one km in size with orbits that come close to Earth's vicinity. Asteroid search teams also found 2,022 asteroids less than one km in size. Observers found one additional Earth-approaching comets. This brought the total known population of NEOs to 18,869 as of September 30, 2018. The high-precision orbit predictions computed by the Center for Near-Earth Object Studies at JPL show that none of these objects is likely to strike the Earth in the next century.

However, as of Oct. 24, 2018, 1940 near-Earth asteroids (of which 155 are larger than one km in diameter), with 100 found in FY 2018, are in orbits that could become a hazard in the more distant future and warrant continued monitoring.

A small asteroid (less than three meters in size) was discovered prior to impacting Earth on June 2, 2018 and it was only the third time in the 20-year history of the NEOO Program that a larger than one meter sized object was discovered in time to calculate an impact solution prior to an impact. The Minor Planet Center and JPL's Center for NEO Studies (CNEOS) warned the Planetary Defense Coordination Office of



the potential impact. CNEOS calculated an initial impact corridor (left map) and considerably narrowed it (right map) once additional observations became available, in particular those from the ATLAS (Asteroid Terrestrial-impact Last Alert System) site on Mauna Loa. The asteroid impacted over Botswana and the resultant energy imparted to Earth's atmosphere was just shy of 1 kiloton equivalent TNT. Comprehensive Test Ban Treaty Organization infrasound sensors also detected the bolide. Citizens and surveillance cameras also observed it. Recovered from the ground were over 20 meteorites from the impact. This real-world event allowed us to exercise planetary defense capabilities and it gave some confidence that our impact prediction models are adequate to inform response to the potential impact of a larger object.

Researchers studied other 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 2018, 71 asteroids passed Earth within the distance from the Earth to the Moon: Five small asteroids (less than 20 meters in size) passed within the distance of the geosynchronous satellites. All but one were discovered in the days either just prior to or just following close-approach. The other, 2010 WC, was one of the larger close-approach asteroids and had an uncertain orbit, but new observations helped the Center for Near-Earth Object Studies to constrain the orbit and rule out any impact threat into the next century.

The Center for Near-Earth Object Studies celebrated 20 years of tracking NEOs with a web feature detailing the development of its capability to take NEO observations and apply trajectory calculation to map the known NEO population, warn of possible impacts by unconfirmed discoveries, and determine long-term impact probabilities for the next 100 years. It also issued a release in response to incorrect news stories on the possibility of asteroid Bennu impacting the Earth, noting that the earliest possible year in which the asteroid could hit our planet is 2175, and the chance of the impact happening in that year is 1 in 24,000. Bennu is the target of the OSIRIS-REx sample return mission.

NASA released the 2017 Report of the Near-Earth Object Science Definition Team (NEO SDT), Update to Determine the Feasibility of Enhancing the Search and Characterization of NEOs, early in FY 2018. The NEO SDT was composed of experts from around the community who conducted a comprehensive update of a 2003 report. It confirmed that NASA is making good progress with regard to detection of objects that pose the greatest risk if they were to collide with Earth, but noted there are still more than twice the number undetected. Asteroids 140 meters and larger were still found to pose the greatest risk to Earth on a regional scale. Discovered and catalogues are about 34 percent of the predicted population of those asteroids. See https://www.nasa.gov/planetarydefense/supporting_documents.

NEOWISE is on its twelfth full sky survey. Over 10 million sky images have been downlinked, processed for moving object detection, and archived. NEOWISE discovered 21 near-Earth asteroids in FY 2018. The NEOWISE project has completed reprocessing all primary mission data to extend the search for asteroids and comets to fainter limits and to take advantage of improved calibrations now available. Submitted to the Minor Planet Center, these detections await ingesting. The project has also delivered a preliminary catalog of physical properties for known minor planets to NASA's Planetary Data System (PDS). NASA is pursuing one final extension to July 2019, and then the mission will be complete. Updates to PDS will occur at the end of the mission with the reprocessing results and other updated results.

NEOCam completed its System Requirements Review/Mission Design Review in February 2018 as part of its extended Phase A study. The focus of the revised mission concept is exclusively on planetary defense asteroid and comet survey requirements, and advance technology development needs for the project, particularly in the development of the infrared focal plane detector.

WORK IN PROGRESS FY 2019

The Pan-STARRS 2 telescope is now ready to begin NEO survey operations following commissioning of its Giga-Pixel Camera 2. Researchers expect to increase the discovery productivity of the project by about 50 percent once both Pan-STARRS telescopes are in routine operations.

The NEOWISE spacecraft, whose orbit has been precessing away from the ideal sun synchronous orbit alignment since its year of prime operations in 2010, will likely reach a point in Summer 2019 where the Sun's light will reach too far down into the telescope and the heat will effectively blind the infra-red detectors, terminating the useful life of the spacecraft. Precessing means a change in the orientation of the primary axis of the orbit. NEOWISE has no orbital maintenance thrust capability, therefore, it cannot compensate for this natural precession.

NASA is working toward a formalized space-based infrared instrument for NEO search and characterization development project in FY 2019, with KDP-B planned for May 2019.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

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 development for a potential future space-based infrared capability that would support NEO survey goals.

LUNAR DISCOVERY AND EXPLORATION

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Other Missions and Data Analysis	22.0	--	**210.0**	327.0	417.0	441.0	458.0
Total Budget	**22.0**	**--**	**210.0**	**327.0**	**417.0**	**441.0**	**458.0**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

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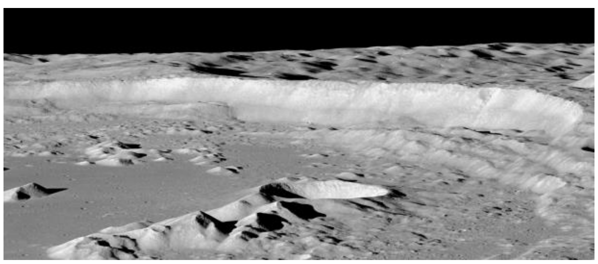

The Moon, our nearest neighbor, a location rich in scientific interest and potential resources.

NASA's Exploration Campaign will be an innovative and sustainable program of 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 program will accomplish this 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 Science is a key component of the Exploration Campaign. It includes activities such as: 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 will prioritize capabilities that support lunar resource analysis and prospecting to inform future human space flight objectives.

Instruments, experiments, or other payloads on the lunar surface will address the variety of exploration, science, technology demonstration, and utilization objectives identified by NASA. In partnership with United States industry and the scientific community, the program will develop lunar surface payloads (and supporting orbital payloads), along with cost-effective ways to deliver and provide services for these payloads. These payloads and services will 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 (see https://www.nasa.gov/exploration/library/skg.html).

NASA expects to fly NASA payloads or instruments 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. This approach offers NASA the potential to address critical strategic objectives related to exploration, science, and technology demonstration using commercially provided domestic space services and hardware.

In parallel with the development of commercial partnerships to provide lunar surface payload delivery and support services, LDEP will develop the exploration, science, and technology payloads to support this on-going investment. 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 2020

None.

ACHIEVEMENTS IN FY 2018

NASA released the Lunar Surface Cargo Transportation Services Request for Information (RFI) soliciting information to determine the extent of interest and availability of domestic vendor sources capable of providing commercial launch and landing services on commercial missions to the lunar surface for NASA payloads. NASA subsequently released the Commercial Lunar Payload Services Request for Proposal (RFP) to procure commercial lunar landing services.

NASA continued operations of LRO. LRO continues to provide a treasure trove of lunar data that directly support the advancement of lunar science and the planning of future lunar missions by helping to characterize and to conduct detailed surveys of potential landing sites for commercial missions. Early in FY 2018 the scientific journal, Icarus published Part III of the three-part Special Issue on the scientific results from LRO.

NASA released a call for smallsats in support of planetary science investigations. The expectation is that some proposals will include investigations of the Moon, and if selected, this program would fund them.

WORK IN PROGRESS IN FY 2019

In FY 2019, NASA awarded Commercial Lunar Payload Services (CLPS) contracts for the purchase of commercial transportation and services to deliver NASA scientific, exploration, and technology payloads to the surface of the Moon.

NASA selected twelve NASA-provided science and technology demonstration payloads to fly on the first CLPS missions. Additional payloads will be selected in the spring from the Lunar Surface Instrument and Technology Payload call through the Research Opportunities in Space and Earth Science (ROSES) process. Robotic payload proposals will be selected that advance NASA's exploration, scientific, and technology goals.

LUNAR DISCOVERY AND EXPLORATION

NASA will work 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 will continue operations of 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.

NASA will conduct studies to develop rover capabilities for future resource investigations and utilization. NASA will assess options for commercial landers that could transport a rover to the lunar surface.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

In FY 2020 NASA will continue to work with the selected CLPS contractors to launch and land NASA scientific, exploration, and technology payloads on the surface of the Moon.

NASA will competitively select additional robotic lunar surface payloads that advance NASA and United States industry's exploration, scientific, and technology goals to include resource utilization. These payloads will fly on the CLPS-provided launch and landing services to the lunar surface.

NASA will continue operations of LRO in support of scientific research and future science and exploration mission planning. NASA will continue to offer LRO landing site characterization capabilities to international and commercial partners upon request.

NASA will determine an acquisition approach for a rover capability that would utilize a commercially developed lander and implement the approach.

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	Request for proposal for robotic surface payloads
FY 2020	Request for proposal for the DALI program
FY 2020	Determine and implement acquisition approach for rover and commercial lander.

Program Management & Commitments

Program Element	Provider
Lunar Reconnaissance Orbiter	Provider: Lead Center: GSFC Performing Center(s): GSFC, APL, JPL Cost Share Partner(s):
Commercial Lunar Payload Services	Provider: Various Lead Center: JSC Performing Center(s): TBD Cost Share Partner(s): TBD

Acquisition Strategy

LDEP acquisition strategy established flexible contract mechanisms, such as indefinite delivery, infinite quantity (IDIQ) contracts, that enable the flexible and rapid procurement of commercial transportation and services to deliver NASA scientific, exploration, and technology development payloads to the surface of the Moon, including potential supporting services (orbital assets) and sample return.

In parallel, NASA will use its established solicitation mechanism, 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 extent possible, NASA will leverage commercial efforts.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Commercial Lunar Payload Services	Astrobotic Technology	Pittsburg, PA
Commercial Lunar Payload Services	Deep Space Systems	Littleton, CO

LUNAR DISCOVERY AND EXPLORATION

Element	Vendor	Location (of work performance)
Commercial Lunar Payload Services	Firefly Aerospace	Cedar Park, TX
Commercial Lunar Payload Services	Intuitive Machines	Houston, TX
Commercial Lunar Payload Services	Lockheed Martin	Bethesda, MD
Commercial Lunar Payload Services	Masten Space Systems	Mojave, CA
Commercial Lunar Payload Services	Moon Express	Cape Canaveral, FL
Commercial Lunar Payload Services	Orbit Beyond	Edison, NJ
Commercial Lunar Payload Services	The Charles Stark Draper Laboratory	Cambridge, MA

OTHER MISSIONS AND DATA ANALYSIS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Lunar Future	0.0	--	**57.5**	174.5	264.5	248.5	265.5
Lunar Reconnaissance Orbiter (LRO)	20.0	--	**22.0**	22.0	22.0	22.0	22.0
Lunar Instruments	2.0	--	**50.0**	50.0	50.0	50.0	50.0
Commercial Lunar Payload Services	0.0	--	**80.0**	80.0	80.0	120.0	120.0
Lunar International Mission Collaboration	0.0	--	**0.5**	0.5	0.5	0.5	0.5
Total Budget	**22.0**	**--**	**210.0**	**327.0**	**417.0**	**441.0**	**458.0**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

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Mission Planning and Other Projects

LUNAR FUTURE

Lunar Future Missions will support public-private partnerships and innovative approaches to achieving human and science exploration goals, including the return of humans to the moon. It will also support activities such as the establishment of commercial contracts for transportation services, the development of small rovers delivered via commercial landers, and the building and launching of instruments that serve lunar science and exploration needs. Example missions include deploying nodes for the Lunar Geophysical Network, a priority identified by the National Academy of Sciences; in situ investigation of potential lunar resources, a priority identified in the Exploration Strategic Knowledge Gaps; and the demonstration of technologies to enable long-term robotic missions on the lunar surface despite the power and thermal challenges imposed by the lunar night.

NASA is also planning future missions to better understand the nature of lunar volatiles, a priority for the science and exploration communities, as well as industry. These missions will follow in the footsteps of a number of lunar missions such as the Lunar CRater Observation and Sensing Satellite (LCROSS), LRO, and Chandrayaan, addressing the Global Exploration Roadmap (GER) ISRU recommendation of prospecting for the lunar resources, demonstrating an In-Situ Resource Utilization (ISRU) capability. NASA is working with commercial industry to develop mobile science instrument packages to look for and sample water-ice (volatile) deposits for potential follow-on resource utilization investigations.

COMMERCIAL LUNAR PAYLOAD SERVICES

With the strategic goal of supporting affordable commercial operations to and on the Moon that support NASA and the needs of an emerging private sector market, CLPS will open competition to United States commercial providers of space transportation services, consistent with the National Space Transportation

OTHER MISSIONS AND DATA ANALYSIS

Policy and Commercial Space Act. CLPS will produce 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 the awards for the (CLPS) contract. This is a 10-year IDIQ contract for landed lunar payload delivery services. NASA awarded tasks to commercial services companies that will provide opportunities for NASA to fly science instruments and technology development units to the surface of the Moon, along with other customers as well. See the list of commercial service company awardees in the Major Contract/Awards table of the Lunar Discovery and Exploration Program section.

LUNAR INSTRUMENTS

NASA will develop instruments and technology payloads to manifest on both CLPS and international lunar lander missions.

Recent Achievements

NASA announced awards for lunar surface instruments and technology payloads to fly on the early CLPS missions. Funding for future instrument development through the Development and Advancement of Lunar Instrumentation (DALI) research call will continue in FY 2020.

NASA is providing the laser retro-reflector assembly (LRA) on the first Israeli lunar lander built by Space IL. The Weizmann Institute developed the instrument with NASA to measure the magnetic field on and above the landing site. The LRA will provide a location marker for any lunar orbiting spacecraft, or future landers, which has a laser to obtain geolocation data relative to the SpaceIL lander. NASA plans to install a similar LRA on the India Space Research Organization (ISRO) Chandrayann-2 lunar lander launching in 2019.

LUNAR INTERNATIONAL MISSION COLLABORATION

Under the Lunar International Mission Collaboration project (LIMC), NASA funds instruments and scientific investigators and will provide navigation and data relay services in exchange for participation.

Recent Accomplishments

NASA signed an agreement with the Israel Space Agency (ISA) on October 3, 2018, to cooperatively utilize the Israeli nonprofit SpaceIL's commercial lunar mission, expected to land on the Moon in 2019. The agreement exemplifies the innovative approach that NASA and its international partners are taking to team up with commercial partners to advance important science and exploration objectives on and around the Moon.

NASA will contribute a laser retroreflector array to aid with ground tracking, and Deep Space Network support to aid in mission communication. ISA and SpaceIL will share data with NASA from the SpaceIL lunar magnetometer installed aboard the spacecraft. NASA will publicize the data through NASA's Planetary Data System. In addition, NASA's Lunar Reconnaissance Orbiter will attempt to take scientific measurements of the SpaceIL lander as it lands on the Moon.

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.

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 with each of the instruments probing different depths, from coatings on the surface to volatiles mixed within the first few feet (about one meter) below 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 such as water ice, where these volatiles come from, how they move about on the lunar surface, and where they end up. LRO also has 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 of the surface.

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 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 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Lucy	81.4	170.5	**218.5**	153.4	56.0	16.5	18.6
Psyche	42.0	--	**213.2**	181.9	156.4	33.7	24.0
Other Missions and Data Analysis	134.9	--	**71.0**	58.1	152.0	321.4	329.0
Total Budget	**258.3**	**--**	**502.7**	**393.4**	**364.4**	**371.6**	**371.6**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

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NASA InSight spacecraft flipped open the lens cover on its Instrument Context Camera (ICC) on Nov. 30, 2018, and captured this view of Mars. Located below the deck of the InSight lander, the ICC has a fisheye view, creating a curved horizon. Some clumps of dust are still visible on the camera's lens. One of the spacecraft's footpads can be seen in the lower right corner. The seismometer's tether box is in the upper left corner.

NASA's Discovery program supports innovative, relatively low-cost, 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); one mission in formulation: Psyche; and one flight mission in development: Lucy. The program has also developed and delivered the Strofio instrument as a part of ESA's BepiColombo mission to Mercury. NASA and JAXA are engaged in joint studies for NASA's participation in the MMX mission to the moons of Mars, planned for launch in 2024. NASA has competitively selected MEGANE, a neutron and gamma ray spectrograph, for flight on the MMX spacecraft.

DISCOVERY

EXPLANATION OF MAJOR CHANGES IN FY 2020

The Budget provides 10 million dollars per year for a competitive Planetary SmallSats project.

ACHIEVEMENTS IN FY 2018

InSight launched successfully in May 2018.

Lucy completed its PDR in September 2018.

WORK IN PROGRESS IN FY 2019

InSight arrived at Mars in November 2018.

Lucy transitioned from formulation into integration in November 2018.

Psyche will hold its PDR in March 2019 and transition into implementation in May 2019.

NASA will release an Announcement of Opportunity for the Discovery Program.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

Lucy and Psyche will both hold CDRs.

Program Schedule

Date	Significant Event
2019	Discovery 15 AO
2021	Lucy Launch
2022	Psyche Launch
2023	Discovery 16 AO

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 one every 36 months, with a goal of one every 24 months, commensurate with the availability of adequate funding. This budget provides for a mission every 30 months.

Acquisition Strategy

NASA competitively selects new Discovery missions, releasing announcements of opportunity 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	SRB	Aug 2016	Review implementation of Program	Passed	2021

LUCY

Formulation	Development	Operations

FY 2020 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	BTC	Total
Formulation	57.5	37.2	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	94.7
Development/Implementation	0.0	44.2	170.5	**218.5**	153.4	32.6	0.0	0.0	0.0	619.2
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	23.4	16.5	18.6	208.7	267.2
2019 MPAR LCC Estimate	**57.5**	**81.4**	**170.5**	**218.5**	**153.4**	**56.0**	**16.5**	**18.6**	**208.7**	**981.1**
Total Budget	**57.5**	**81.4**	**170.5**	**218.5**	**153.4**	**56.0**	**16.5**	**18.6**	**208.7**	**981.1**
Change from FY 2019				**48.0**						
Percentage change from FY 2019				**28.2%**						

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

Lucy will for the first time investigate Trojan asteroids, which are of particular scientific interest because they are leftovers of giant planet formation and thus 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 embodies the goal 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 bodies, including one binary system (two asteroids in orbit around each other), in stable orbits near the L4 and L5 Lagrange points with Jupiter, known as the Jupiter Trojans. Scientists believe Trojans are primitive, volatile, and organic rich bodies that are gravitationally shepherded by Jupiter. Lucy is the first mission to visit the Jupiter Trojan asteroids, and NASA plans to launch it by November of 2021.

LUCY

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2020

None.

PROJECT PARAMETERS

NASA selected the Lucy mission in December 2016 from the Discovery Program's most recent AO. Lucy, with a launch date of 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 instrument payload includes a panchromatic and color visible imager (L'Ralph), a high-resolution visible imager (L'LORRI), and a thermal infrared spectrometer (L'TES). In addition, Lucy will perform Doppler mass determinations using its radio subsystem.

Lucy will have a heliocentric trajectory and performs all its flybys in a period of 11.6 years. Lucy will fly by and extensively study several different taxonomic classes of Jupiter Trojans. A fortuitous orbital alignment that is unlikely to recur in the near future enables this comprehensive Trojans tour

ACHIEVEMENTS IN FY 2018

Lucy completed its preliminary design review (PDR) and other project development and risk reduction activities throughout FY 2018.

WORK IN PROGRESS IN FY 2019

Lucy will proceed with project implementation and enter its final design and fabrication phase of the mission (KDP-C) and other risk reduction activities throughout FY 2019.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

Lucy will complete its critical design review (CDR) in October 2019 and continue project implementation. It will proceed to its system assembly, integration and test phase review (KDP-D) in August of 2020.

LUCY

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2020 PB Request
KDP-C	Nov 2018	Nov 2018
CDR	Oct 2019	Oct 2019
SIR	July 2020	July 2020
KDP-D	Aug 2020	Aug 2020
ORR/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 (mths)
2019	622.2	70%	2019	619.2	0	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 (*j*oint *c*onfidence *l*evel); all other CLs reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

LUCY

Formulation	Development	Operations

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:	**622.2**	**619.2**	**-3.00**
Aircraft/Spacecraft	161.3	161.3	0
Payloads	43.2	43.2	0
Systems I&T	30.7	30.7	0
Launch Vehicle	161.2.	158.2	0
Ground Systems	17.2	17.2	0
Science/Technology	14.3	14.3	0
Other Direct Project Costs	194.3	194.3	0

LUCY

Formulation	Development	Operations

Project Management & Commitments

NASA selected the Lucy project through the competitive Discovery 2014 AO. The principal investigator for Lucy is from GSFC. GSFC will manage 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): None Cost Share Partner(s): None	None
Panchromatic visible imager and IR spectrometer (L'Ralph=MVIC+ LEISA)	Provides color and near IR images to discriminate between and map compositional units.	Provider: SwRI/GSFC Lead Center: GSFC Performing Center(s): None Cost Share Partner(s): None	None
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): None Cost Share Partner(s): None	None
Thermal Emission Spectrometer (L'TES)	Provides, thermal inertia maps of the Trojans elemental composition.	Provider: ASU Lead Center: GSFC Performing Center(s): None Cost Share Partner(s): None	None

LUCY

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Radio Science	Utilizes the X-band radio telecommunications system to measure the Trojans mass	Provider: GSFC Lead Center: GSFC Performing Center(s): None Cost Share Partner(s): None	None
Launch Vehicle	Launch vehicle and related launch services	Provider: ULA Lead Center: KSC Performing Center(s): None Cost Share Partner(s): None	None

Project Risks

Risk Statement	Mitigation
If: the current design for LV loads based on heritage designs cannot be used because the LV selected exceeds the current design loads, Then: the project may have to redesign for LV selection or delay delivery of instruments	The project submitted spacecraft-compatible loads to the launch vehicle request for proposal, reducing the risk of needing a spacecraft redesign.

Acquisition Strategy

NASA competitively selected the mission through an AO. The major elements of the mission and spacecraft are as proposed for the AO.

LUCY

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

NASA selected Lucy through the Discovery Program AO released on November 5, 2014. The Planetary Missions Program Office in Huntsville, Alabama provides programmatic oversight of the mission. The major contracts are under development

Element	Vendor	Location (of work performance)
Spacecraft	Lockheed Martin	Denver CO
PI, Co-Is, Science data center	Southwest Research Institute (SWRI)	Boulder Co
Project management, systems engineering, SMA, spacecraft design, build and test, navigation, operations, ground data system, L'Ralph instrument	NASA GSFC	Greenbelt MD

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Sep 2018	PDR	Successful	Oct 2019
Performance	SRB	Oct 2019	CDR	TBD	July 2020
Performance	SRB	Jul 2020	System Integration Review (SIR)	TBD	Jul 2021
Performance	SRB	Jul 2021	Operations Readiness Review (ORR)	TBD	

PSYCHE

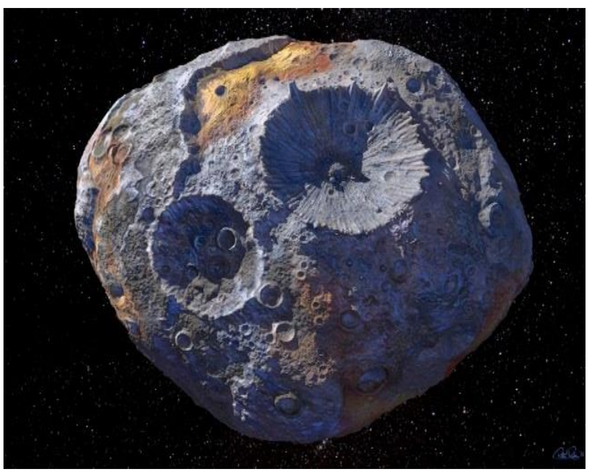
Formulation	Development	Operations

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**42.0**	**--**	**213.2**	**181.9**	**156.4**	**33.7**	**24.0**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



Only the 16th minor planet to be discovered, hence its formal designation, 16 Psyche. At 16 Psyche, scientists will explore, for the first time ever, a world made of metal, rather than of rock or ice. It appears to be the exposed nickel-iron core of a protoplanet, one of the building blocks of the Sun's planetary system.

The Psyche mission will explore one of the most intriguing targets in the main asteroid belt—a giant metal asteroid, known as 16 Psyche, approximately three times farther away from the Sun than the Earth. This asteroid measures about 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 wonder whether Psyche could be an 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 2020

None.

PROJECT PRELIMINARY PARAMETERS

NASA plans to launch the mission in August 2022 for arrival at 16 Psyche in January 2026. 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. Psyche will spend 21 months orbiting 16 Psyche in four different orbital periods. The mission will seek to aid in our understanding of iron cores. It will provide insight into terrestrial planets,

PSYCHE

Formulation	Development	Operations

including Earth, by directly examining what 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 2018

Psyche continued activities to reduce mission risk and refine cost and schedule estimates.

WORK IN PROGRESS IN FY 2019

Psyche will continue with project formulation and risk reduction activities throughout FY 2019. Psyche will hold its PDR in March 2019 and plans to proceed to its final design and fabrication review (KDP-C) in May 2019.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

Psyche will continue its final design and fabrication efforts. Psyche will hold its CDR in April 2020.

ESTIMATED PROJECT SCHEDULE

All dates are preliminary.

Milestone	Formulation Authorization Document	FY 2020 PB Request
PDR	Mar 2019	Mar 2019
KDP-C	May 2019	May 2019
CDR	Apr 2020	Apr 2020
KDP-D	Jan 2021	Jan 2021
ORR	May 2022	May 2022
Launch	Aug 2022	Aug 2022

PSYCHE

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 a non-advocate review and/or preliminary design review.

KDP-B Date	Estimated Life Cycle Cost Range ($M)	Key Milestone	Key Milestone Estimated Date Range
Jan 4, 2017	907 - 957	Launch	Aug 2022

Project Management & Commitments

The Principal Investigator and Deputy Principal Investigator are both from ASU and lead the management of the mission. JPL serves as the development Center for the Psyche mission, working for the Principal Investigator. JPL 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 Formulation Agreement
Solar electric propulsion chassis	Spacecraft bus and propulsion system	Provider: Space Systems Loral Lead Center: JPL Performing Center(s): None Cost Share Partner(s): None	None
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): None Cost Share Partner(s): None	None
Magnetometer	Detects and measures the remnant magnetic field of 16 Psyche.	Provider: UCLA Lead Center: JPL Performing Center(s): None Cost Share Partner(s): None	None
Gamma Ray and Neutron Spectrometer	Detects, measures, and maps 16 Psyche's elemental composition.	Provider: APL Lead Center: JPL Performing Center(s): None Cost Share Partner(s): None	None

PSYCHE

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
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): None Cost Share Partner(s): None	None
Launch Vehicle	Launch Vehicle and launch services	Provider: TBD Lead Center: KSC Performing Center(s): None Cost Share Partner(s): None	
Deep Space Optical Communications (DSOC)	Demonstrates DSOC technology's capabilities.	Provider: JPL Lead Center: JPL Performing Center(s): None Cost Share Partner(s): NASA Human Exploration and Operations Mission Directorate (HEOMD)/Space Technology Mission Directorate (STMD)	None

Project Risks

There are no major risks at this time.

Acquisition Strategy

NASA competitively selected the mission through an Announcement of Opportunity (AO). The major elements of the mission and spacecraft are as proposed for the AO.

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, Alabama provides programmatic oversight of the mission.

Element	Vendor	Location (of work performance)
Spacecraft	Space Systems Loral	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

All dates are preliminary.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Mar 2019	PDR	TBD	April 2020
Performance	SRB	April 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 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
InSight	74.3	--	**11.8**	9.0	9.0	9.0	0.0
Strofio	0.6	--	**0.8**	0.6	0.7	0.6	0.7
International Mission Contributions (IMC)	2.2	--	**2.4**	2.2	2.0	2.0	2.0
Planetary Missions Program Office	11.4	--	**15.5**	14.6	16.4	16.5	16.5
Discovery Future	28.0	--	**15.1**	7.7	103.1	273.6	290.1
Discovery Research	6.7	--	**9.0**	9.0	9.0	9.0	9.0
Dawn	11.1	--	**0.0**	0.0	0.0	0.0	0.0
Planetary SmallSats	0.0	--	**10.0**	10.0	10.0	10.0	10.0
Mars-moon Exploration with Gamma rays and NEutrons (MEGANE)	0.7	--	**6.4**	5.0	1.8	0.7	0.7
Total Budget	**134.9**	**--**	**71.0**	**58.1**	**152.0**	**321.4**	**329.0**

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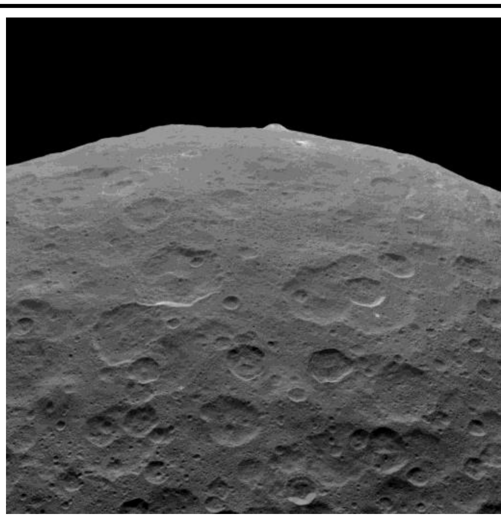

This photo of Ceres and one of its key landmarks, Ahuna Mons, was one of the last views Dawn transmitted before it depleted its remaining hydrazine and completed its mission.

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 SERENA suite of instruments flown onboard the European Space Agency BepiColombo spacecraft, launched on October 20, 2018. Strofio will determine the chemical composition of Mercury’s surface, providing a powerful tool to study the planet’s geologic history.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

The Strofio instrument is on board the BepiColombo spacecraft, which successfully launched October 2018, for a 9-year voyage to Mercury.

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 the planetary science programs of other space agencies to find opportunities to participate in each other's missions. 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 in FY 2020 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 Venus for at least the next five years. Hayabusa2 has arrived at the Ryugu asteroid and has deployed successfully Japanese and European rovers. JAXA will attempt to touchdown and collect samples at the beginning of FY 2019 for its return to Earth in December 2020

PLANETARY MISSIONS PROGRAM OFFICE

The Planetary Missions Program Office (PMPO) at the MSFC manages all Planetary Science flight projects that are not part of the Mars Exploration Program. This currently includes the competed Discovery and New Frontiers missions, and the JUpiter ICy moons Explorer (JUICE) and Europa projects. 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 LaRC to support the mission selection process including the development of Announcement of Opportunities (AOs) and the formation and operations of independent panel reviews 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 plans to release the next Discovery AO in 2019 with mission selection in 2021.

PLANETARY SMALLSATS

On August 8, 2015, NASA announced the selection of two CubeSat missions under the Small Innovative Missions for Planetary Exploration (SIMPLEx) Program. The Lunar polar Hydrogen Mapper (LunaH-Map) CubeSat will launch on the Space Launch System Exploration Mission-1. LunaH-Map will enter a polar orbit around the Moon with a low altitude perilune centered on the lunar South Pole to produce maps of near-surface hydrogen. The CubeSat Particle Aggregation and Collision Experiment (Q-PACE) CubeSat is an Earth-orbiting mission to study low-velocity collisions between cm-scale and smaller particles in the microgravity environment, gathering fundamental experimental data to understanding how planets form. In addition to the two mission opportunities, NASA selected three proposals for further technology development, the Mars Orbiter (MMO), the Hydrogen Albedo Lunar Orbiter (HALO), and the Diminutive Asteroid Visitor using Ion Drive (DAVID).

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, that is intended to be a NASA contribution to JAXA's MMX (Martian Moons eXploration) mission. Planned for launch in 2024, MMX will operate in close proximity to the Martian moons Phobos and Deimos for approximately 3 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, in order to constrain theories for the origin of the moons, and will make maps of the near-surface materials on Phobos to enable the study of surface processes and support MMX sample site selection.

Recent Achievements

Selected in 2017 through a Stand-ALone Mission of Opportunities-3 (SALMON-3) announcement, MEGANE is currently in Phase A.

DISCOVERY RESEARCH

Discovery Research funds analysis of archived data from Discovery missions, and supports participating scientists for the Dawn and InSight missions. Discovery Research gives the research community access to samples and data and allows research to continue for many years after mission completion. Scientists in the U.S. planetary science community submit research proposals that NASA selects 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 (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 these data sets, going beyond the work conducted by the original mission teams.

Recent Achievements

Research supported by the DDAP program has revealed the locations of water ice deposits on the planet Mercury. Even though Mercury is the closest planet to the Sun, there are places at its poles that never receive sunlight and are very cold—cold enough to hold water. Researchers used images from NASA's MESSENGER mission and new observations from the Arecibo radar observatory to map numerous locations of water ice near Mercury's south pole. The investigators mapped how much sunlight Mercury's south pole receives over one complete rotation of the planet and identified locations that are always in shadow. The permanently shadowed locations match the radar-reflective features seen in the Arecibo images, as expected for water ice. Perplexingly, about half of the permanently shadowed locations at both the north and south poles lack water ice. The authors conclude that this finding is most consistent with Mercury's water coming from a large, recent impact of a comet on the planet.

OTHER MISSIONS AND DATA ANALYSIS

Operating Missions

DAWN

Dawn is completing its exploration of the two largest and most massive bodies in the main asteroid belt between Mars and Jupiter. This mission would have been impossible without ion propulsion, building on the experience from NASA's Deep Space 1. By closely orbiting asteroid Vesta and the dwarf planet Ceres with the same set of instruments, Dawn has the unique capability to compare and contrast these bodies, enabling scientists to answer questions about the formation and evolution of the solar system. Their surfaces preserve clues to the solar system's first 10 million years, along with alterations since that time, allowing Dawn to investigate both the origin and the current state of the main asteroid belt. DAWN launched in September 2007, and orbited Vesta July 2011 to September 2012 providing data that indicates Vesta is more closely related to the terrestrial planets than to typical (and much smaller) asteroids. DAWN arrived at Ceres in March 2015. October 2018 marks the end of Dawn's second and final extended mission operations as the spacecraft has run out of hydrazine. DAWN has been a very successful mission.

Data from the Dawn mission revealed the rugged topography and complex textures on the surface of Ceres. Additional data, such as the chemical composition, interior structure, and geologic age, are helping scientists to understand the history of the only dwarf planet of the inner solar system and the planetary evolution processes that took place in the early solar system.

Recent Achievements

DAWN has shown Ceres to be a complex, geologically active world of rock, ice, and salts. Ice, which should not be stable on the surface, has been observed on the ground, and one crater wall even showed an increase in the area of ice during six months, perhaps as part of a seasonal cycle. DAWN identified a geologically young cryovolcano as well as more than 20 older ones. There is good reason to believe that a global ocean once covered Ceres. In 2016, Dawn completed its primary mission. NASA approved the mission to remain in orbit at Ceres for an extended mission, and in 2017 approved a second extended mission. Taking advantage of its ion propulsion system, Dawn ultimately maneuvered to its 10th orbit, a highly, elliptical orbit with a periapsis of only 35 km over the 940-km diameter body. This allowed the spacecraft to provide extremely high-resolution images, gamma-ray, neutron, and infrared spectra, and gravity measurements.

INSIGHT

InSight is a robotic lander designed to study the interior of the planet Mars. The mission launched on May 5, 2018 at 11:05 UTC and landed on the surface of Mars at Elysium Planitia on November 26, 2018. InSight will investigate fundamental issues of terrestrial planet formation and evolution with a study of the deep interior of Mars. This mission will help understand the evolutionary formation of rocky planets, including Earth, by investigating the crust and core of Mars. InSight will also investigate the dynamics of any Martian tectonic activity and meteorite impacts and compare this with like phenomena on Earth. The InSight lander is equipped with two science instruments that will conduct 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 Seismometer (SEIS) and the Heat Flow and Physical Properties

Package (HP3). SEIS will take 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 that burrows 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) will use the spacecraft communication system to provide precise measurements of planetary rotation. InSight will spend roughly two years (720 Earth days or 700 "sols" Martian days) investigating the deep interior of Mars.

Recent Achievements

NASA successfully completed spacecraft integration and tests in the early part of FY 2018, shipped the spacecraft to the launch site at Vandenberg Air Force Base in February 2018, and successfully launched to Mars on the first day of the launch window on May 05, 2018. The spacecraft landed on Mars on November 26, 2018 and is beginning science operations.

NEW FRONTIERS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Other Missions and Data Analysis	88.1	--	**190.4**	261.2	341.9	387.3	291.7
Total Budget	**88.1**	**--**	**190.4**	**261.2**	**341.9**	**387.3**	**291.7**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

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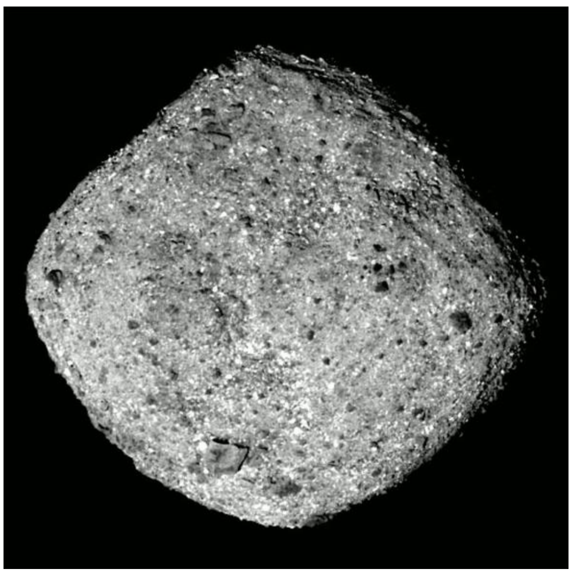


Credits: NASA/Goddard/University of Arizona

NASA's Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer (OSIRIS-REx) spacecraft completed its 1.2 billion-mile (2 billion-kilometer) journey to arrive at the asteroid Bennu on December 3, 2018. The spacecraft executed a maneuver that transitioned it from flying toward Bennu to operating around the asteroid. The OSIRIS-REx spacecraft took this image of Bennu from a distance of around 50 miles (80 km).

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, as described in the Planetary Decadal.

The program is currently comprised of three missions in operations: New Horizons, Juno, and OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer).

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 fly-by of MU69, 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 bring pristine samples from a carbon-rich asteroid (Bennu) to study and analyze on Earth. This 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, in close proximity to a large Near-Earth Object (NEO). This knowledge will provide significant insight for potential planetary defense strategies.

NEW FRONTIERS

Potential future missions identified by the National Academies include Venus in Situ Explorer, Saturn Probe, Trojan Tour and Rendezvous, the Comet Surface Sample Return, Lunar South Pole-Aitken Basin Sample Return, Io Observer, and Lunar Geophysical Network. NASA added, to the current New Frontiers 4 Announcement of Opportunity (AO), Ocean Worlds targets Enceladus and Titan.

EXPLANATION OF MAJOR CHANGES IN FY 2020

None.

ACHIEVEMENTS IN FY 2018

The New Horizons mission successfully completed a set of stellar occultation observations, and distant observation of MU69, which aided the trajectory development for its fly-by of a Kuiper Belt target on January 1, 2019, called MU69.

Juno successfully completed seven additional polar orbits of Jupiter in FY 2018 for a total of fourteen. Juno will be halfway through the prime mission objectives after sixteen orbits.

The OSIRIS-REx mission completed preparations for its rendezvous with Bennu. The approach phase started on August 17, 2018, with the first images of Bennu, followed in September 2018 by a search for dust near Bennu.

WORK IN PROGRESS IN FY 2019

The New Horizons mission developed the scientific observational sequences for its next Kuiper Belt target, called MU69. MU69 encounter phase is from mid-2018 through March 2019, data downlink from MU69 will last through 2021.

Juno is continuing science operations in orbit around Jupiter. The primary mission will end in 2021.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

NASA expects to select the New Frontiers 4 mission in spring of 2019.

The New Horizons mission plans to complete downlink of the data from its MU69 fly-by.

The Juno mission will continue science operations in orbit of Jupiter.

In FY 2020, OSIRIS-Rex will complete the reconnaissance overflights to confirm the safety and suitability of the primary and backup sample collection site. OSIRIS-Rex will conduct a series of progressively closer rehearsals in preparation for sample acquisition. In July 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 sample, and (after confirmation) stow 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 right to begin the Earth Return

NEW FRONTIERS

Cruise Mission Phase. The period between the planned sample stow and the latest possible asteroid departure provides considerable operational margin in case of unexpected challenges.

PROGRAM SCHEDULE

Date	Significant Event
December 2017	New Frontiers 4 Step 1 Selection
July 2019	New Frontiers 4 Step 2 Down-selection
2022	New Frontiers 5 AO release

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 announcements of opportunity when available funding allows.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
PIR	MSFC	2016	Program Implementation Review	completed	2021

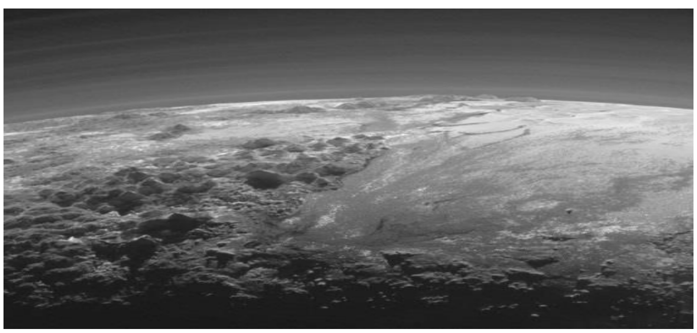
OTHER MISSIONS AND DATA ANALYSIS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
New Frontiers Future Missions	13.4	--	**83.8**	194.1	296.3	351.2	273.1
New Frontiers Research	2.1	--	**6.0**	7.0	9.4	9.5	9.5
Origins Spectral Interpretation Resource	42.8	--	**50.3**	21.6	17.2	26.6	9.1
New Horizons	12.0	--	**18.3**	9.5	0.0	0.0	0.0
Juno	17.8	--	**32.0**	29.0	19.0	0.0	0.0
Total Budget	**88.1**	**--**	**190.4**	**261.2**	**341.9**	**387.3**	**291.7**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



Just 15 minutes after its closest approach to Pluto on July 14, 2015, NASA's New Horizons spacecraft looked back toward the Sun and captured a near-sunset view of the rugged, icy mountains and flat ice plains extending to Pluto's horizon. Scientists think the mountains of Pluto are made of water ice, which is one of the few materials on Pluto that is strong enough at the extremely low temperatures to form the steep slopes of the huge mountains. The smooth expanse of the informally named Sputnik Planum (right) is flanked to the west (left) by rugged mountains up to 11,000 feet (3,500 meters) high, including the informally named Norgay Montes in the foreground and Hillary Montes on the skyline.

New Frontiers Other Missions and Data Analysis supports operating New Frontiers 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 released the fourth New Frontiers AO in early December 2016, and expects to select a new mission in July 2019.

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, the 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 allows the maximum science return from each of the missions. Scientists in the U.S. planetary science community submit research proposals that NASA selects through competitive peer review. NASA will select new research in 2020, using the New Horizons mission data returned from Pluto MU69 (Ultima Thule), Juno mission data returned from Jupiter, and OSIRIS-Rex mission data returned from asteroid Bennu. NASA will select new participating scientists for the Juno mission in 2019, whose work will extend to 2020 and beyond.

Recent Achievements

NASA selected 13 participating scientists for OSIRIS-Rex in 2018, whose work will continue during asteroid operations in 2019 through 2021.

Operating Missions

NEW HORIZONS

New Horizons is the first scientific investigation to obtain a close look at Pluto and its moons Charon, Nix, Hydra, Kerberos, and Styx (scientists discovered the last four moons after the spacecraft's launch in 2006). Scientists aim to find answers to basic questions about the surface properties, geology, interior makeup, and atmospheres on 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 on October 2016. The spacecraft is now venturing deeper into the Kuiper Belt, and as part of a NASA-approved extended mission, studying one of the small, and most primitive icy bodies in this region approximately two billion miles beyond Pluto’s orbit. The project completed the fly-by of Kuiper Belt Object 2014MU69, nicknamed Ultima Thule, in January 2019.

Recent Achievements

The New Horizons project developed the Kuiper Belt Extended Mission Integrated Master Schedule and established the baseline. The Student Dust Counter continues to collect unprecedented new data of an area of our Solar System little explore before. In addition, the mission has successfully conducted several Operation Readiness Reviews in rehearsal and preparation to the Ultima Thule flyby.

Some of the surprising findings from Pluto by New Horizons include:

- Charon’s enormous equatorial extensional tectonic belt hints at the freezing of a former water ice ocean inside Charon in the distant past. Other evidence found by New Horizons indicates Pluto could well have an internal water-ice ocean today.

OTHER MISSIONS AND DATA ANALYSIS

- All of Pluto's moons that can be age-dated by surface craters have the same, ancient age—adding weight to the theory that they formed together in a single collision between Pluto and another body in the Kuiper Belt long ago.
- Charon's dark, red polar cap is unprecedented in the solar system and may be the result of organic atmospheric gases that escaped Pluto and then accreted on Charon's North Pole.
- Pluto's vast 1,000-kilometer-wide heart-shaped nitrogen glacier (called Sputnik Planum) that New Horizons discovered is the largest known glacier in the solar system.
- Pluto shows evidence of vast changes in atmospheric pressure and, possibly, past presence of running or standing liquid volatiles on its surface and underneath its icy crust – something only seen elsewhere on Earth, Mars and Saturn's moon Titan in our solar system.
- The New Horizons project successfully completed stellar occultations on June and July 2017 to determine that MU69 is possibly a binary object 14 to 25 miles (22 to 40 kilometers) wide. The spacecraft completed the overflight of this new world MU69 on January 1, 2019. NASA held a public engagement competition to name MU69 and the name selected was Ultima Thule.

JUNO

Juno is conducting an in-depth study of Jupiter, the most massive planet in the solar system. Juno's instruments seek information from deep in Jupiter's atmosphere, enabling scientists to understand the fundamental processes of the formation and early evolution of the solar system. Juno launched on August 5, 2011 and entered Jupiter's orbit on July 4, 2016. 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 sixteen science flybys of Jupiter.

The planned magnetic field mapping is about half way complete and indicates possible multiple sources of the interior magnetic field. This defies expectations based on experience with other planets' dynamos including our own. Preliminary gravity and microwave results indicate a complicated interior structure and deep atmospheric variability. These results are likewise upending current planet formation theories. Observations of the aurora suggest that the mechanisms producing them are superficially similar to Earth's but differ in the details including the fact that volcanoes on Jupiter's moon Io are the primary source for the particles creating the aurora. Finally, Juno's camera continues to return popular images that both inspire and provide additional scientific insights regularly.

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 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 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 flew by the Earth on September 22, 2017. After over two years in space, OSIRIS-REx arrived at Bennu on December 3, 2018. The mission will study the asteroid for about one and a half years, globally mapping the surface from distances of about three miles to less than half a mile. The spacecraft cameras and instruments will photograph the asteroid and measure its surface topography, composition, and thermal emissions. Radio science will provide 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, and gently contact the surface, collecting a sample, before backing away. The spacecraft will remain near the asteroid for almost another two years before beginning its return to Earth. 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. JSC will make subsamples available for research to the worldwide science community.

Recent Achievements

OSIRIS-REx began imaging Bennu in August and arrived at Bennu on December 3, 2018. For the remainder of December, OSIRIS-REx performed a series of close flybys to improve our understanding of Bennu's size, shape, and gravity, information needed to finalize plans for orbiting the asteroid. On December 31, 2018, OSIRIS-REx entered an approximately 1.5 km radius (about 1.25 km from the surface), orbit around Bennu, with each orbit taking approximately 50 hours. In addition to continuing science observations, OSIRIS-REx demonstrated using landmarks on the surface of Bennu to determine the location of the spacecraft. This is a key part of the later navigation capability required to safely touch the surface and acquire a sample for return to Earth.

MARS EXPLORATION

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Mars Rover 2020	505.8	305.6	**278.0**	145.0	110.0	60.0	60.0
Other Missions and Data Analysis	172.2	--	**268.5**	327.2	371.7	446.1	530.1
Total Budget	**678.0**	**--**	**546.5**	**472.2**	**481.7**	**506.1**	**590.1**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

Every time we feel close to understanding Mars, new discoveries send us straight back to the drawing board to revise existing theories. We've discovered that today's Martian wasteland hints at a formerly volatile world where volcanoes once raged, meteors plowed deep craters, and flash floods rushed over the land, and yet we now know that early Mars could have supported microbial life. Mars continues to throw out new enticements with each landing or orbital pass made by our spacecraft.

The Mars Exploration Program seeks to understand when Mars was habitable, is Mars habitable today, or can it 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 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 2020

This budget, through funding in the Mars Future project, supports the development of the Mars Sample Return mission as early as 2026. This request consolidates funding from across NASA mission directorates for aeroscience testing capabilities into a single project within Safety, Security, and Mission Service's Shared Capability Asset Program. This includes the transfer of the Aeronautics Evaluation & Testing Capability Project (AETC). AETC will continue to provide the necessary support for both Aeronautics and other Agency large ground test needs.

In addition, recent technical issues with the Mars 2020 Planetary Instrument for X-ray Lithochemistry (PIXL) and Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals (SHERLOC) instruments and the Sample Caching System have resulted in mission cost growth. NASA will report these changes in the pending FY 2019 operating plan.

MARS ROVER 2020

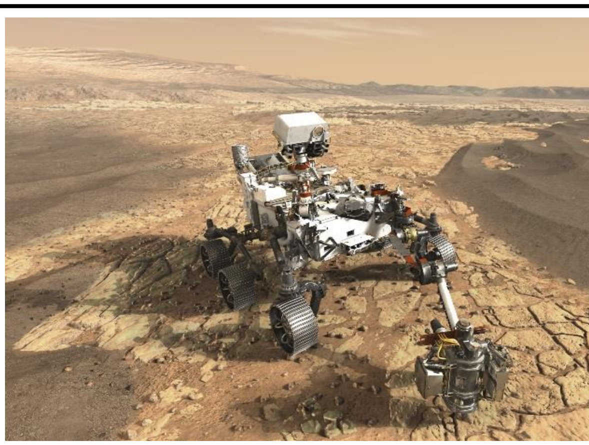
Formulation	Development	Operations

FY 2020 Budget

		Actual	Enacted	Request						
Budget Authority (in $ millions)	**Prior**	**FY 2018**	**FY 2019**	**FY 2020**	**FY 2021**	**FY 2022**	**FY 2023**	**FY 2024**	**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	648.1	536.6	311.7	**229.0**	0.0	0.0	0.0	0.0	0.0	1725.4
Operations/Close-out	0.0	0.0	0.0	**33.3**	148.9	111.9	43.3	0.0	0.0	337.4
2018 MPAR LCC Estimate	**1045.7**	**536.6**	**311.7**	**262.3**	**148.9**	**111.9**	**43.3**	**0.0**	**0.0**	**2460.4**
Total Budget	**983.1**	**505.8**	**305.6**	**278.0**	**145.0**	**110.0**	**60.0**	**60.0**	**0.0**	**2447.5**
Change from FY 2019				**-27.6**						
Percentage change from FY 2019				**-9.0%**						
Total NASA Budget	**1045.7**	**536.6**	**311.7**	**262.3**	**148.9**	**111.9**	**43.3**	**0.0**	**0.0**	**2460.4**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



Mars 2020 will re-use the basic engineering of NASA's Mars Science Laboratory to send a different rover to Mars, with new objectives and instruments, launching in 2020. The rover will carry seven instruments to conduct its science and exploration technology investigations including two contributed by international partners and one to demonstrate a critical technology for future human exploration.

PROJECT PURPOSE

NASA's Mars 2020 science rover is a mission, currently in development, that will advance the scientific priorities detailed in the National Research Council’s 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 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 Earth in the future, and test new technology to benefit future robotic and

MARS ROVER 2020

Formulation	Development	Operations

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 2020

Recent 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 have resulted in mission cost growth in the Mars 2020 project. NASA will report these changes in the pending FY 2019 operating plan.

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 2018

The Mars 2020 mission completed its System Integration Review (SIR) and formally entered Phase D of implementation and began Assembly, Test, and Launch Operations (ATLO).

WORK IN PROGRESS IN FY 2019

The Mars 2020 mission will be delivering the instrument payload to spacecraft ATLO.

MARS ROVER 2020

Formulation	Development	Operations

KEY ACHIEVEMENTS PLANNED FOR FY 2020

The Mars 2020 mission will complete its Operational Readiness Review (ORR) in preparation for launch in July 2020.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2020 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 (mths)
2017	SMD 1620.1 NASA 1676.9	70	2019	SMD 1655.6 NASA 1725.4	2.9	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 (*j*oint *c*onfidence *l*evel); all other CLs (*c*onfidence *l*evels) 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**	1725.4	48.5
Tech Development	88.4	201.3	112.9
Aircraft/Spacecraft	527.4	704.3	176.9
Payloads	155.4	215.9	60.5
Systems I&T	71.1	71.8	.7
Launch Vehicle	342.5	242.6	-99.9
Ground Systems	80.4	62.9	-17.5
Science/Technology	16.5	19.9	-3.4
Other Direct Project Costs	395.1	206.7	-188.4

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	None
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	None

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	None
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	None
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	None
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	None
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	None
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	None

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: SHERLOC has significant implementation issues (technical, schedule, or cost) due to the large number of new and challenging subassemblies (laser, laser power supply, scan mirror, etc.), Then: Direct development cost (instrument side) and project ripple effects (flight system thermal/mechanical/ATLO) and schedule impacts could result.	The project provided additional resources and institutional support to address key risk areas, including leadership & technical team augmentations for critical skills. The project aggressively mitigated subassembly level risks at the component and subassembly level and released some project-held schedule margin to allow SHERLOC to overcome key technical issues and reduce risk. SHERLOC passed its termination review and NASA has agreed to allow the instrument to continue.
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.	Risk updated to remove risks retired by MSL's flight itself and Mars 2020 plans that will correct some testing shortfalls. Previously 43 identified risks; reduced to 27. Reexamine 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) drives delays in development/test activities, or new actuators are late being delivered by the Motion Control Subsystem, or new or modified contamination control requirements require additional time to complete assembly/test, or additional re-design cycles of SCS hardware delays build/testing, Then: The delivery of the Sampling and Caching System (SCS) hardware to ATLO may be later than planned.	SCS is proceeding with fabrication, assembly, and test of both engineering and flight model hardware, utilizing multiple shifts and extended workweeks where appropriate. Project has been aggressively working the supplier chain with manufacturing teams and augmenting where necessary. Project is also assessing restructuring the test program to improve robustness and achieve more efficient schedule.

MARS ROVER 2020

Formulation	Development	Operations

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 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	Mars 2020 successfully met the criteria and the PMC decision authority approved the project to continue to the next phase.	Feb 2016
Performance	SRB	Feb 2016	PDR	Complete	Feb/Mar 2017
Performance	SRB	Feb/Mar 2017	CDR	Complete	Feb 2018
Performance	SRB	Feb 2018	SIR	Complete	May 2020
Performance	SRB	May 2020	ORR	TBD	

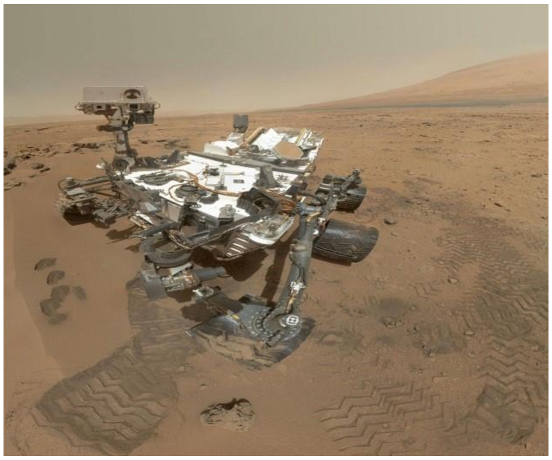
OTHER MISSIONS AND DATA ANALYSIS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Mars Organic Molecule Analyzer (MOMA)	12.9	--	**6.7**	6.9	4.0	4.0	3.0
Aeroscience Ground Test Capabilities	5.5	--	**0.0**	0.0	0.0	0.0	0.0
ExoMars	1.9	--	**2.2**	2.2	2.0	0.0	0.0
Mars Program Management	8.5	--	**19.5**	19.8	18.8	17.7	19.4
Mars Future Missions	1.7	--	**109.0**	179.0	279.0	358.0	442.3
Mars Mission Operations	1.7	--	**1.9**	1.9	1.9	1.9	1.9
Mars Research and Analysis (R&A)	10.0	--	**12.0**	15.0	15.0	15.0	15.0
Mars Technology	3.7	--	**4.0**	4.5	4.5	4.5	4.5
2011 Mars Science Lab (MSL)	51.4	--	**50.0**	50.0	0.0	0.0	0.0
Mars Reconnaissance Orbiter 2005 (MRO)	26.3	--	**28.0**	26.0	25.5	25.0	24.0
Mars Exploration Rover 2003	12.5	--	**0.0**	0.0	0.0	0.0	0.0
Mars Odyssey 2001	11.3	--	**11.7**	0.0	0.0	0.0	0.0
Mars Express	2.7	--	**3.0**	0.0	0.0	0.0	0.0
Mars Atmosphere & Volatile EvolutioN (MAVEN)	22.2	--	**20.5**	22.0	21.0	20.0	20.0
Total Budget	**172.2**	**--**	**268.5**	**327.2**	**371.7**	**446.1**	**530.1**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



Rigorous scientific questions will drive all of our future missions. The questions will continuously evolve as we make new discoveries. Brand new technologies will enable us to explore Mars in ways we never have before, resulting in higher-resolution images, precision landings, longer-ranging surface mobility, and the ability to cache samples.

Other Missions and Data Analysis includes the mission planning and other projects such as NASA's contribution 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 to the mission planning projects are the operating projects which include Mars Science Laboratory (MSL), Mars Reconnaissance Orbiter 2005 (MRO), Mars Exploration Rover 2003 (MER,) 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).

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) is the NASA-provided subsystem of MOMA, which 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.

AEROSCIENCE GROUND TEST CAPABILITIES

NASA established the Aeroscience Ground Test Capabilities project to help sustain the Agency's entry, descent, and landing test capabilities. This request consolidates funding from across NASA mission directorates for aeroscience testing capabilities into a single project within Safety, Security, and Mission Service's Shared Capability Asset Program. This includes the transfer of the Aeronautics Evaluation & Testing Capability Project (AETC). AETC will continue to provide the necessary support for both Aeronautics and other Agency large ground test needs.

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 TGO launched in March of 2016. For this mission, NASA contributed two Electra ultra-high frequency (UHF) telecommunication radios, identical to those used successfully on NASA's MRO and MAVEN. Electra radio acts as a communications relay and navigation aid for Mars landers and rovers. Electra's UHF radios support navigation, command, and data-return needs for landers and rovers. Furthermore, two instruments, the Stereo Surface Imaging Systems (CaSSIS) and the Nadir and Occultation for Mars Discovery (NOMAD) have significant contributions from US co-Investigators.

The ExoMars TGO spacecraft entered Mars orbit in late October of 2016 and completed its aerobraking towards achieving the science orbit in March of 2018 starting the science and relay operations phase.

RECENT ACHIEVEMENTS

The ExoMars TGO has returned the first images of the Red Planet from its new orbit. The spacecraft arrived in a near-circular 400 km altitude orbit in late March 2018 ahead of its primary goal; to seek out gases that may be linked to active geological or biological activity on Mars. The orbiter's CaSSIS instrument, took stunning images, which features part of an impact crater, during the instrument's test period. The team activated the camera on 20 March 2018 and tested it for the start of its main mission on 28 April. As a communication relay using the NASA provide Electra radios, ExoMars TGO proved its capability as a valuable asset for relay starting in mid-April 2018 in the first of a series of relay communications with NASA's Curiosity rover, highlighting the cooperation between NASA and ESA to maintain a strong communications infrastructure around Mars for current and future missions.

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 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 in order 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, which analyzes archived data collected on Mars missions; and
- Critical Data Products, which 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. One of these papers concludes that abiotic reduction of carbon dioxide into organic matter has occurred on Mars in the past and evidence of the process is preserved in several meteorites from Mars studied here on Earth. Abiotic: physical rather than biological; not derived from living organisms. Work funded through Mars research programs has also greatly contributed to informing the landing site selection process for the next Mars mission.

OTHER MISSIONS AND DATA ANALYSIS

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

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 mission. In developing concepts for a Mars Sample Return mission, NASA intends to leverage commercial and other partnerships.

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. Curiosity is twice as long and three times as heavy as the Mars Exploration Rover Opportunity. 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.

In addition, 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 12 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. Scientists can attribute mineral-filled veins in multiple locations with varying mineral assemblages (starting at the base and going up Mt. Sharp) to multiple generations of water at the surface, extending both the extent and to younger times that the environment could have supported microbial life. The rover instruments also found sedimentary rock strata similar to lacustrine basins on Earth in which the accumulation of water and sediment exceeds loss from evaporation causing the central lake to rise and shift toward the crater's center, found evidence of persistent subsurface habitable conditions, identified strata in the Vera Rubin Ridge that have been interpreted to indicate a series of lakes sustained by rivers and groundwater, and monitored three Mars years of local weather and radiation environments.

OTHER MISSIONS AND DATA ANALYSIS

MARS RECONNAISSANCE ORBITER 2005 (MRO)

MRO, currently in its fourth 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 helps identify 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 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 ice. MRO also carries a radar sounder to find subsurface water, an important consideration in selecting scientifically worthy landing sites for future exploration.

In addition, 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 an atmospheric sounder, the Mars Climate Sounder (MCS), shows how the Martian atmosphere transports dust and water ice. 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. In the final years of its fourth extended mission, 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 is characterizing landing sites for the Mars 2020 Rover and the 2020 ESA ExoMars Rover. It continues a survey of possible landing sites for potential human missions. 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 and Opportunity rovers to Earth. In FY 2019 MRO will continue to characterize activity during the great dust storm season on Mars.

Recent Achievements

In FY 2018 and early FY 2019, the Mars Reconnaissance Orbiter focused on the detection of modern surface changes and on extending surveys for the detection of aqueous minerals that indicate water-related environments (ground water, paleolakes, and possible ocean) on early Mars. The MRO spacecraft MARCI & Mars MCS instruments have tracked the decay phase of the planet-encircling dust event, which sprang up in June 2018. By July, the initial dust storms had expanded to cover much of the planet. The decay (clearing) of the total column opacity was slightly faster than during the 2001 global dust storm, which occurred at a similar season. (Researchers provide opacities based on these data to the Opportunity and Curiosity rover teams for their locations.) With the clearing of the dust haze, the HiRISE, CTX, and CRISM instruments were able to expand observations outside the relatively clear (and sunlit) south polar region. These data were helping characterize the effects of dust fallout across the planet. In addition, MRO characterized and observed the landing site for the InSight Mars Lander.

MARS EXPLORATION ROVER 2003

In FY 2019, the Mars Exploration Rover Opportunity completed its historic mission of exploring the Red Planet. Initially designed as a 90-day mission, Opportunity exceeded expectations and explored geological settings on the surface of Mars for more than 14 years. It expanded our understanding of the history and the geological processes that shaped Mars, particularly those involving water. During its lifetime, Opportunity trekked 28.06 miles across the Martian surface (setting the distance record for traverse on a planetary body beyond Earth, well over a marathon), conducted field geology, made atmospheric observations, found evidence of ancient Martian environments where intermittently wet and habitable conditions existed, and sent back to Earth well over 223,000 spectacular, high-resolution images.

Recent Achievements

During its final operational months, Opportunity was conducting its 10th extended mission science campaign, involving an extensive campaign to explore and characterize sedimentary rocks inside Endeavour Crater. This included an ongoing investigation of the geology of a water-carved gulley, located in Endeavour Crater, for the first time from the surface. Simultaneously, Opportunity continued monitoring the atmospheric opacity, argon, and cloud dynamics into a seventh Martian year, with emphasis on inter-annual variations. During these observations, the rover was overcome by a planet-encircling dust event in June 2018. Atmospheric dust blocked available light required to energize the solar-powered rover, and the rover experienced a low-power fault due to the drainage of the on-board batteries. Numerous attempts by the rover team to re-establish communications with the rover proved unsuccessful and in February 2019, NASA concluded the record-breaking mission.

MARS ODYSSEY 2001

Mars Odyssey, currently in its seventh 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, and continues that role for the Opportunity and Curiosity rovers. In FY 2019, starting on Nov. 26, 2018, Odyssey will provide relay support for the InSight lander.

Recent Achievements

Odyssey used its Time History of Events and Macroscale Interactions during Substorms (THEMIS) camera system to obtain the first thermal infrared images of the Martian moons Phobos and Deimos. Scientists used the images to determine the composition and surface characteristics of the moons, and to obtain clues about their origin. Odyssey continues to observe atmospheric phenomena (hazes, clouds, fog, and frost) in the early morning and late evening hours not viewed systematically by other orbiters.

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 (MARSIS) and Analyzer of Space Plasmas and Energetic Atoms (ASPERA) instruments aboard Mars Express, and participates in the scientific analysis of mission data.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

Mars Express has been performing an ongoing series of tests between the spacecraft and the Opportunity and Curiosity rovers to demonstrate and evaluate proximity radio links between orbiting and surface assets. In parallel, Mars Express has been 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, successfully launched in 2013 and orbiting Mars since 2014, 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 (such as carbon dioxide and 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 also carries an Electra radio for communications with rovers and landers on the Mars surface. MAVEN has been carrying out relay activities at a low level for the past two years, and will be ramping up to support with the landing of InSight in November 2018. After successfully completing its primary mission in November 2015, MAVEN is in its third extended mission.

Recent Achievements

In FY 2018, MAVEN provided definitive measurements of the rate at which Martian atmosphere is being lost to space today. In addition, researchers can extrapolate the loss rate into the past based on the observations of the processes driving escape. Results demonstrate that loss to space has been a major driver of atmospheric change on Mars, largely explaining the transition from an early, warm, and wet environment to the cold, dry environment that we see today. MAVEN had its most significant opportunity thus far to observe the effects of solar storms on atmospheric loss when, on September 12, 2017, a coronal mass ejection from the Sun hit the Martian atmosphere and lit it up in a global ultraviolet aurora that was 25 times brighter than any previously seen by MAVEN. The MAVEN team uses measurements of events like this to infer how such storms may have stripped away so much of the Martian atmosphere over time, a primary mission objective.

In addition, NASA will use the observations of the recent global dust storm on Mars (in summer of 2018) to determine the influence on the upper atmosphere and on loss to space. In the coming year, the MAVEN team will continue this investigation of Mars' atmospheric loss over time while planning for science operations from a future modified orbit that will support relay communications for new and existing surface assets at Mars.

OUTER PLANETS AND OCEAN WORLDS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Jupiter Europa	595.0	740.0	**592.6**	530.8	445.1	207.3	54.6
Other Missions and Data Analysis	81.2	--	**15.8**	18.8	18.6	16.9	14.2
Total Budget	**676.2**	**--**	**608.4**	**549.6**	**463.7**	**224.2**	**68.8**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 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, just as Earth does. These liquid reservoirs, most notably those composed of liquid water, 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, Europa contains a global liquid water ocean twice as large as Earth's oceans. Recent observations suggest active plumes emanating from the surface of Europa, possibly bringing an ocean sample within easier reach. Scientists detected a similar though smaller global ocean on Enceladus, a small moon orbiting Saturn, also emanating active plumes. Other moons (such as Ganymede, Callisto, and Titan) have been shown to possess perched oceans deep beneath their surfaces, and Titan has also been shown to possess 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 have 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 providing energy, and 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 2020

This budget enables a Europa Clipper launch readiness date in 2023. This budget does not include funds for the $3.5-5.0 billion Europa Lander due to support of higher priorities and the planetary science community's recent Decadal Survey midterm recommendation that the Europa Lander mission be assessed in the context of other planetary priorities in the next decadal survey.

EUROPA CLIPPER

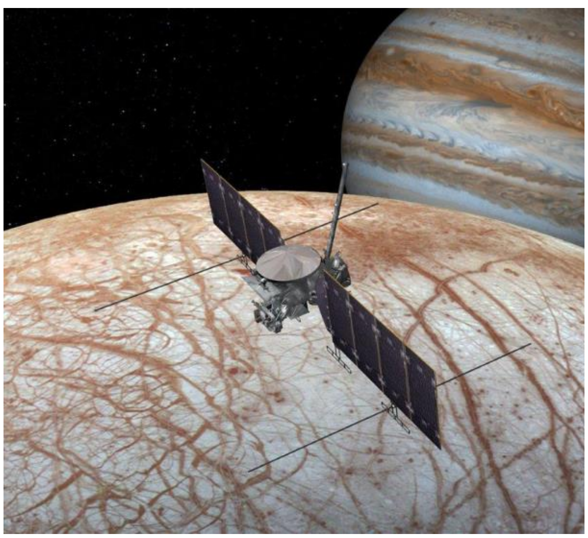
Formulation	Development	Operations

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	525.0	--	592.6	530.8	445.1	207.3	54.6

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



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. For over 20 years 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 that delivers the most science for the least cost and risk of all the concepts studied. The flyby concept 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.

NASA established the Europa Clipper project in FY 2015, initiating the formulation phase, and competitively selected nine instruments for development. In FY 2016, the project formulated requirements, architecture, planetary protection requirements, risk identification and mitigation plans, cost and schedule range estimates, and payload accommodation for a mission to Europa. In FY 2017, the project entered its preliminary design phase, and in FY 2018 conducted approximately 21 independent or peer reviewed preliminary design reviews at the sub-system, system, instrument or mission level.

EUROPA CLIPPER

Formulation	Development	Operations

Costs and schedule for the Europa Clipper mission are not baselined, as the mission is still in formulation and NASA does not commit to costs and schedules until KDP-C.

EXPLANATION OF MAJOR CHANGES IN FY 2020

The Budget proposes to launch the Europa Clipper in 2023 on a commercially procured launch vehicle. Following an analysis of availability of launch hardware and facilities, overall launch manifest optimization, and cost, the Administration believes it would be more appropriate for the Europa Clipper to utilize a commercially procured launch vehicle instead of a Space Launch System (SLS) variant. Using a commercial vehicle is estimated to result in over $700 million in savings compared to use of an SLS rocket.

The Interior Characterization of Europa Using Magnetometry (ICEMAG) instrument has been terminated as a result of continued, significant cost growth and remaining cost risk. Recognizing the important science objectives to be gained, NASA is investigating options for including a simpler, less complex magnetometer. In addition, all ICEMAG Co-Investigators will be invited to remain on the Europa Clipper science team to support the mission.

PROJECT PRELIMINARY PARAMETERS

NASA formulated the Europa Clipper mission in response to the National Research Council's Vision and Voyages for Planetary Science in the Decade 2013-2022 (2011), which identified a strategic mission to Europa as the second highest priority for planetary science flagship missions. This mission will leverage the selected payload of nine 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 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.

The Administration proposes to launch the Clipper on a commercial launch vehicle (see Explanation of Major Changes above).

ACHIEVEMENTS IN FY 2018

The Europa Clipper mission conducted all instrument, subsystem and mission level Preliminary Design Reviews and procured long lead parts in FY 2018.

EUROPA CLIPPER

Formulation	Development	Operations

WORK IN PROGRESS IN FY 2019

The Europa Clipper mission will complete its preliminary design and technology development efforts, final preliminary design reviews, and initiate critical design reviews for some subsystems and instruments. The Europa Clipper mission will advance from Phase B (preliminary design and technology completion) to Phase C (final design and fabrication) during FY 2019. This transition will formally establish and baseline the cost and schedule commitments for this mission. Consistent with the FY 2019 Consolidated Appropriations Act (Public Law 116-6), NASA is currently maintaining the capability to launch the Clipper on an SLS rocket. If the Congress were to enact a bill removing the requirement to use an SLS rocket for the Clipper, NASA would be able to proceed immediately with procurement of a commercial launch vehicle.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

Integration of the Propulsion Module Electronics to the Propulsion Module; Complete Subsystems, Flight system, and Mission Level Critical Design Reviews.

Estimated Budget for 2023 Launch:

Per Public Law 116-6, Division C, Title V the following table provides preliminary estimates for the current mission design, launch vehicle, and an assumed launch in 2023. NASA can no longer support a launch in 2022 based on a delay in the solar array design and accommodation of the radar instrument, complexity of the mission and interactions between spacecraft and payload, and significant contractor staffing underruns.

	FY19	FY20	FY21	FY22	FY23	FY 24
Europa 2023 ($M)	545.0	592.6	530.8	445.1	207.3	54.6

The profile assumes $432 million for a launch vehicle; however, commercial offerings and pricing continue to evolve.

ESTIMATED PROJECT SCHEDULE

The dates below are consistent with launch in 2023. As noted above, costs and schedule for the Europa Clipper mission are not baselined, as the mission is still in formulation and NASA does not commit to costs and schedules until KDP-C.

Milestone	Formulation Authorization Document	FY 2020 PB Request
Formulation Authorization	Apr 2015	Apr 2015
SRR	Jun 2016	Jan 2017
KDP-B	Jul 2016	Feb 2017
PDR	Mar 2019	Aug 2018

EUROPA CLIPPER

Formulation	Development	Operations

Milestone	Formulation Authorization Document	FY 2020 PB Request
Delta PDR		June 2019
KDP-C	May 2019	August 2019
CDR		May 2020
SIR		March 2021
KDP-D	TBD	April 2021
Launch (or equivalent)	TBD	Jul 2023

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 a non-advocate review and/or preliminary design review.

KDP-B Date	Estimated Life Cycle Cost Range ($M)	Key Milestone	Key Milestone Estimated Date Range
Feb 2017	3,100-4,000	LRD	June 2022 to July 2023

Project Management & Commitments

Responsibility for Europa Clipper project management resides at Jet Propulsion Laboratory (JPL), with program management authority assigned to Marshall Space Flight Center (MSFC).

Element	Description	Provider Details	Change from Formulation Agreement
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	

EUROPA CLIPPER

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
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	The ICEMAG instrument was terminated.
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	

EUROPA CLIPPER

Formulation	Development	Operations

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 Evolved Expendable Launch Vehicles (EELV) 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.

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 U. of Iowa	Austin, TX Pasadena, CA Iowa City, IA
MISE instrument	JPL APL	Pasadena, CA Laurel, MD
ICEMAG instrument	JPL	Pasadena, CA
SUDA instrument	LASP - University of Colorado	Boulder, CO

EUROPA CLIPPER

Formulation	Development	Operations

Element	Vendor	Location (of work performance)
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	SRB recommend project proceed into phase B	Aug. 2018
Performance	SRB	Aug 2018	PDR	Delta PDR will be required due to outstanding work	June 2019
Performance	SRB	June 2019	Delta-PDR	TBD	May 2020
Performance	SRB	May 2020	CDR	TBD	March 2021
Performance	SRB	March 2021	SIR	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Icy Satellites Surface Technology	35.0	--	**2.2**	5.0	5.0	5.0	5.0
JUICE - Jupiter Icy Moons Explorer	18.5	--	**5.1**	5.3	5.1	3.4	0.7
Outer Planets Research	8.5	--	**8.5**	8.5	8.5	8.5	8.5
Cassini	19.2	--	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**81.2**	**--**	**15.8**	**18.8**	**18.6**	**16.9**	**14.2**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

Other Missions and Data Analysis includes the Jupiter Icy Moons Explorer (JUICE), 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. Autonomous spacecraft operations and sample acquisition are required to maximize the amount of science return with little human intervention because these moons are so far from Earth. Researchers also need cryogenic containment systems to maintain the integrity of samples returned to Earth.

Recent Achievements

Demonstration of a new silicon carbide nano-vacuum transistor, combining the inherent radiation immunity of vacuum electronics, the stability of wide bandgap materials, and advanced nanofabrication methods. This represents one step on the way to developing electronics that will be capable of long-duration operations in the high radiation environments of icy moons.

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 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. It has a tentative model payload of 11 scientific instruments. 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, have completed their NASA Critical Design Reviews (CDR), with the completion of the RIME CDR in September 2018. Scheduled for November 2018 is the RIME instrument CDR.

EUROPA LANDER CONCEPT

Public Law 116-6 directed NASA to provide a 5-year funding profile for a Europa lander mission. The 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. Given the early nature of this project, NASA cannot provide a year-by-year funding profile, as the mission configuration and required budget are to be determined. Recent estimates of for a notional lander concept have been in the range of $3.5-5.0 billion.
Outer Planets Research increases the scientific return of current and past NASA outer planets missions, guides current mission operations (e.g., selecting Cassini imaging targets), and paves the way for future missions (e.g., refining landing sites on Titan, reconsidering the ice shell thickness on Europa).

RECENT ACHIEVEMENTS

Research funded by the Cassini Data Analysis Program and the Planetary Data Archiving, Restoration, and Tools Program has recently shown that Jupiter radiates more internal energy than previously thought because it gets less energy from the sun than earlier estimates. Based on measurements made during Cassini’s flyby of Jupiter in 2000-2001, Jupiter’s albedo has recently been revised upwards significantly, from about a third (0.34 ± 0.03), to about a half (0.50 ± 0.01), meaning that half of the solar energy that hits Jupiter reflects off. For the giant planets, knowing the albedo is crucial for understanding their energy budgets — especially how much heat is generated inside.

This result means that Jupiter is generating far more heat inside than previously estimated: 7.48 ± 0.16 W/m2, (watts per meter squared) compared to the old estimate of 5.44 ± 0.42 W/m2. This higher value for Jupiter’s internal heat production is not consistent with earlier models of the planet’s formation and evolution, and opens the door for a better understanding of gas giant planets in our solar system and in other solar systems.

RADIOISOTOPE POWER

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	139.8	--	147.9	151.3	142.1	102.5	168.8

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

MMRTG undergoing acceptance testing at Idaho National Laboratory.

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 project, in partnership with the U.S. Department of Energy (DOE)-managed plutonium-238 production and production operations infrastructure activities.

EXPLANATION OF MAJOR CHANGES IN FY 2020

The RPS Program was the major portion of the Technology Program requested in prior years, and is elevated to a stand-alone program for better visibility. The Advanced Multi-Mission Operations System project moved to Planetary Science Research, as it provides software tools for supporting operational missions, and develops integrated tools with the Planetary Data System. Execution of technology projects in support of future Discovery, New Frontiers, Mars, and Outer Planets missions are within those program budgets. This budget provides less funding for Icy Satellites Surface Technology in FY 2020 due to budget constraints and higher priorities.

ACHIEVEMENTS IN FY 2018

The program, working with DOE, completed fabrication of all of the Plutonium-238 fuel clads necessary to fuel the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) for the Mars 2020 mission. Selection of one of the two MMRTG flight units was completed and delivered to DOE for use on the Mars 2020 mission.

RADIOISOTOPE POWER

The RPS Program initiated planning for three technology development projects expected to lead to three distinctly different operational classes of RPS for future planetary missions. First, the RPS Program continued development of thermoelectric technologies, initiating planning of a "next-generation" RPS. This system configuration would be modular and would allow smaller planetary spacecraft and larger strategic mission systems to use a common modular, vacuum-based design. Such a modular system could serve missions that are higher-powered orbiters, as well as mid-to-low power landers and rovers. The RPS Program also continued to advance towards a gate review of the Skutterudite (SKD) thermoelectric technology transfer effort and develop the plan for the next phase, with a plan to enhance the existing MMRTG performance. The RPS Program continued three contracts developing future dynamic power conversion components as well. This technology could support both a dynamic RPS suitable for science and human missions as well as power conversion for fission reactor development for human Lunar or Mars surface power.

In FY 2018, DOE successfully re-established the production of plutonium-238 (Pu-238), producing approximately 350 grams of plutonium oxide, using a portion of that inventory to make fuel clads for the Mars 2020 mission.

As part of preparing to support future flight missions that require nuclear power, such as New Frontiers, NASA worked with DOE to develop a new strategy to reduce schedule risk and mission support cost by producing an inventory of heat-source plutonium oxide and fueled clads for mission use. The strategy, called Constant Rate Production, establishes broad goals and objectives to maintain the RPS infrastructure and technical expertise within DOE. The goal of this strategy is to achieve an annual production rate of 1.5 kilogram of heat-source plutonium-oxide and an annual fueled clad production rate of 10 to 15 units. DOE also completed the development of the capabilities and processes necessary to produce Light Weight Radioisotope Heater Unit (LWRHU) hardware. Additionally, the DOE completed the installation of a new hot press used for heat-source oxide production. This is an important risk mitigation activity, as current reliability is only on one operational press that is beyond its design life.

The RPS Program continues to support the New Frontiers Announcement of Opportunity (AO) process, enabling one of the missions selected for Phase A studies, a proposed mission to Titan, which would use one MMRTG. Based upon the new Constant Rate Production strategy, the RPS program was able to predict sufficient availability of Pu-238 to commit to flying up to two MMRTGs for the next Discovery AO cycle, enabling deep space or solar-limited missions to compete in the next AO.

WORK IN PROGRESS IN FY 2019

In FY 2019, the program supports Mars 2020 by fueling one flight MMRTG and preparing for launch operations. With Pu-238 production becoming operational, the Plutonium and the DOE Radioisotope Power System Infrastructure activities are integrated. The RPS Program, in partnership with DOE, has a number of activities underway that continue to reduce programmatic risk and optimize the RPS supply chain in support of Constant Rate Production goals. The activities include, but are not limited to, equipment modernization to improve operational throughput and reliability to maintain fuel clad production goals, qualification of the Advanced Test Reactor to produce Pu-238 and options to optimize plutonium irradiation capabilities the High Flux Isotope Reactor, and expanding plutonium packaging capabilities at Oak Ridge National Laboratory to support increased plutonium production.

The DOE will also test and initiate readiness activities for the newly installed hot press that will reduce the schedule risk for producing plutonium fueled clad assemblies to future NASA missions.

RADIOISOTOPE POWER

Deliver and review of contracts awarded for the development of the "next-generation" RPS, with concepts and technology maturation plans have begun. Development continues on the SKD couples and culminates in a gate review that will evaluate the couples for performance and manufacturability. Lastly, the building and testing of three different dynamic convertor configurations have begun.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

Delivery of the Mars 2020 MMRTG to the launch site for integration with the mission and its launch vehicle.

The RPS Program continues its three development activities, with the enhanced MMRTG project considered for transition to a flight design phase based on progress of the SKD couple technology.

Pu-238 production continues. Constant Rate Production continues to achieve the steady state 10-15 fuel clad production rate.

Program Elements

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 OakRidge National Laboratory leads the effort, and irradiates targets at their High Flux Isotope Reactor. The DOE Idaho National Lab participates in the development of targets for future irradiation at the Advanced Test reactor, which will be required to support target production rates. To date, DOE has produced approximately 350 grams, and 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. In FY 2019, the NASA incorporated the Plutonium project into the DOE Operations and Analysis budget as part of the DOE Constant Rate Production plan to better support NASA missions by producing plutonium heat sources at a constant rate, as opposed to periodic mission focused campaigns.

RADIOISOTOPE POWER SYSTEM

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 generations is impractical or impossible. Working with DOE to provide fueled RPS to the mission and support mission design and integration activities will achieve this goal. The project will continue to reduce the RPS costs to the missions and increase system performance. RPS will continue basic and applied energy conversion research and development to advance state-of-the-art performance in heat to electrical energy conversion. The goal of these investments is to provide higher conversion efficiency and improve mission performance over design life through robustness. Increased efficiency would benefit the program by extending the effective use of the Pu-238 supply.

RADIOISOTOPE POWER

Program Management & Commitments

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

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.

ASTROPHYSICS

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Astrophysics Research	203.1	--	**250.7**	309.3	302.5	299.1	298.8
Cosmic Origins	211.2	--	**185.3**	173.9	181.7	121.7	121.7
Physics of the Cosmos	118.0	--	**148.4**	128.5	123.3	117.8	117.4
Exoplanet Exploration	200.8	--	**46.4**	44.3	45.6	46.1	48.5
Astrophysics Explorer	117.4	--	**214.1**	246.4	312.0	328.8	321.4
Total Budget	**850.4**	**--**	**844.8**	**902.4**	**965.2**	**913.5**	**907.7**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

Astrophysics

ASTROPHYSICS RESEARCH

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Astrophysics Research and Analysis	74.1	--	**86.6**	90.2	92.2	94.2	94.2
Balloon Project	36.6	--	**44.8**	44.8	44.8	44.8	44.8
Science Activation	44.0	--	**45.6**	45.6	45.6	45.6	45.6
Other Missions and Data Analysis	48.5	--	**73.7**	128.7	119.9	114.5	114.2
Total Budget	**203.1**	**--**	**250.7**	**309.3**	**302.5**	**299.1**	**298.8**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

The FIREBALL payload launched from Fort Sumner on 9/22/2018. Mouser Williams took this photo from Los Alamos, showing the FIREBALL payload passing in front of the Moon.)

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.

EXPLANATION OF MAJOR CHANGES IN FY 2020

None.

ACHIEVEMENTS IN FY 2018

In FY 2018, NASA Astrophysics launched four sounding rocket payloads. The Dual-Channel Extreme Ultraviolet Continuum Experiment payload from the University of Colorado launched in October 2017 from White Sands Missile Range in New Mexico. The Dual-Channel Extreme Ultraviolet Continuum

Experiment mission measured the Lyman Continuum (LyC) radiation produced by early B stars in our own galaxy. This experiment addresses questions of how and when galaxies first formed and how their formation "feedback" into their circumgalactic environments.

On April 4, the Water Recovery X-ray Rocket Sounding Rocket mission from Penn State University launched from Roi-Namur Island. The Water Recovery X-ray Rocket payload was an X-ray spectrometer that studied the Vela Supernova Remnant. Soft X-ray emission characterization and comparison will lead to a more complete understanding of the evolution of supernova remnants and their interaction with the surrounding interstellar medium.

On April 16, the Colorado High-resolution Echelle Stellar Spectrograph (CHESS-4) from the University of Colorado - Boulder launched from Roi-Namur Island. CHESS was designed to study the interstellar medium in the ultraviolet part of the spectrum, the matter between stars, and specifically translucent clouds of gas that provide fundamental building blocks for star and planet formation. This mission studied translucent clouds by analyzing the ultraviolet absorption spectra of the two most abundant molecules (H2 and CO) which reside within them.

On July 22, the Micro-X payload from Northwestern University launched from White Sands Missile Range. Micro-X is a high-energy-resolution X-ray microcalorimeter with an imaging mirror. It obtained the first imaging X-ray microcalorimeter spectra from an astronomical source.

The Balloon project supported the annual Antarctic long-duration balloon flights, a super-pressure balloon campaign to New Zealand, and two conventional balloon campaigns from Palestine, TX and Fort Sumner, NM.

In FY 2018, NASA completed three balloon campaigns. The Sweden campaign launched three heliospheric balloon missions from Sweden and landed in Canada approximately five days later. The Palestine campaign flew two astrophysics balloon missions. The Fort Sumner campaign flew multiple engineering and student experiment missions.

Research on exoplanets confirmed the nature of exoplanet candidates and explored the nature of planets circling other stars. In addition, theoretical and computational efforts advanced our understanding of how black holes merging release gravitational waves.

HaloSat, the first Astrophysics-funded CubeSat, launched on May 21, 2018 from the NASA Wallops Flight Facility in Virginia. It subsequently deployed and is operating nominally. HaloSat made an all-sky map of the x-ray emission coming from the hot, diffuse gas surrounding the Milky Way to determine its properties.

WORK IN PROGRESS IN FY 2019

NASA scheduled four Astrophysics sounding rockets for launch in FY 2019. All four sounding rockets will fly from the White Sands Missile Range. The first sounding rocket experiment studies the impact of star formation on stellar environments. The second sounding rocket investigates the spectral and spatial properties of the extragalactic near-infrared background. The third and fourth sounding rocket payloads are new ultraviolet (UV) spectrographic instruments.

ASTROPHYSICS RESEARCH

NASA had planned four balloon campaigns in 2019. NASA completed the Antarctica campaign in January 2019. As a result of the partial Government shutdown from December to January, NASA cancelled the New Zealand campaign to launch one engineering test mission. The other two balloon campaigns will be in Palestine, TX, and Ft. Sumner, NM.

Currently, Astrophysics has three other CubeSats in development. CUTE, built in Boulder CO, that measures UV spectra of planets transitioning in front of stars. BurstCube, built at NASA GSFC in Maryland that detects sudden gamma-ray burst that occur when neutron stars collide. SPARCS, built at Arizona State University, measures the UV flares from red dwarf stars, in order to determine which flares are a hazard to life on planets orbiting such stars.

NASA held a continuation review of ISS-CREAM science operations in September 2018, following the prime mission of one year of on-orbit operations, and decided to terminate ISS-CREAM science operations in FY 2019.

During FY 2019, NASA will fund a new CubeSat called SPRITE, built at University of Colorado in Boulder. SPRITE will observe UV spectra of star forming regions in numerous nearby galaxies, to trace the history of star formation.

NASA initiated nine 6-month long studies of possible 'SmallSat' missions to do high priority astrophysics science at a lower cost than a typical Small Explorer Mission.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

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 Sounding Rocket program is planning a campaign in Australia in 2020. This will allow flights to observe celestial targets in the Southern Hemisphere.

The Balloon project plans to support the annual Antarctic long-duration balloon flight, a super-pressure balloon launch from New Zealand, and two domestic campaigns with conventional balloon flights from Palestine, TX, and Fort Sumner, NM.

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

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 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 2020 budget will continue to support multi-year Science Activation awards made in 2016. The peer-evaluated, competitive program 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 will conduct an overarching assessment of the program.

ASTROPHYSICS RESEARCH

By the end of 2020, the program aims to enable active learners in all 50 states; improve U.S. scientific literacy; support Federal STEM Education Five-Year Strategic Plan goals; strengthen the number of experts supporting the program, and increase the number of strategic partners, as appropriate, to enhance the overall effort. The budget includes additional funding for citizen science training and implementation. This will allow NASA to coordinate and amplify citizen science in every discipline.

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 2018	NRA Solicitation
Mar 2019	NRA Solicitation
May 2019	Senior Review Operating Missions
Apr 2020	Senior Review Data Archives
Feb 2020	NRA Solicitation
Feb 2021	NRA Solicitation
Mar 2022	Senior Review Operating Missions

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. As a result of the partial government shutdown from December to January, NASA will issue the solicitation no later than March. A Senior Review process 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 Orbital-ATK (now NGIS)	Palestine, TX and other balloon launch sites

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	Archives Senior Review Panel	2015	A comparative evaluation of Astrophysics data archives	Recommended improvements in archives	2019
Quality	Astrophysics Research Program Review Panel	2011	Review of competed research projects	Panel praised scope and impact of programs	TBD

ASTROPHYSICS RESEARCH

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	Mission Senior Review Panel	2019	A comparative evaluation of Astrophysics operating missions	Ranking of missions, citing strengths and weaknesses	2022, 2025
Quality	Independent Assessment of Science Activation	2019	Validation of approach and logic model	Baseline towards meeting overall desired outcome by 2020	One-Time

OTHER MISSIONS AND DATA ANALYSIS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Astrophysics Directed R&T	0.0	--	**19.4**	39.7	42.7	28.9	24.3
Contract Administration, Audit and Quality Assurance Services	12.7	--	**12.7**	12.7	12.7	12.7	12.7
Astrophysics Senior Review	0.0	--	**0.0**	33.5	20.5	27.3	31.6
Astrophysics Data Program	17.6	--	**20.4**	21.6	22.6	23.6	23.6
Astrophysics Data Curation and Archival Research	18.2	--	**21.2**	21.2	21.5	22.0	22.0
Total Budget	**48.5**	--	**73.7**	**128.7**	**119.9**	**114.5**	**114.2**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

The CHESS-4 mission launched from Roi Namur, Kwajalein Atoll, Marshall Islands on April 16, 2018. CHESS studies the interstellar medium in the ultraviolet, answering questions on star and planet formation.

The Astrophysics Research program prepares for the next generation of missions through both theoretical research and applied technology investigations. This program uses data from current missions and suborbital science investigations to advance NASA’s science goals. One of these goals is to create new knowledge as explorers of the universe, and to use that knowledge for the benefit of all humankind.

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. FY 2020 funding for the civil servants previously planned for WFIRST is included. NASA will identify work for those employees and propose funding transfers to other Projects in an FY 2020 Operating Plan.

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.

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 next Senior Review will take place in spring 2019. The following missions will be included: the Chandra X-ray Observatory (Chandra); Fermi Gamma-ray Space Telescope (Fermi); Gehrels Swift Observatory (Swift); Hubble Space Telescope (Hubble); Neutron Star Interior Composition Explorer (NICER); Nuclear Spectroscopic Telescope Array (NuSTAR); Transiting Exoplanet Survey Satellite (TESS); and X-ray Multi-Mirror Mission-Newton (XMM-Newton).

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 and the great observatories Hubble and Chandra. Investigations funded under the ADAP ensure that these 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 since combinations of data collected by different missions operating in different regions of the spectrum often yield scientific insight that are unobtainable through analysis of the individual data sets alone.

Recent Achievements

During FY 2018, the ADAP supported almost 160 science investigators at institutions across the U.S. The scope of those 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, 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, searched for clues into the nature of the Big Bang and insight into the fate of our universe.

ASTROPHYSICS DATA CURATION AND ARCHIVAL RESEARCH (ADCAR)

The Astrophysics Data Centers constitute an ensemble of archives that receive processed data from individual missions and makes 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 Centers tackled challenges and opportunities presented by a tremendous growth of content and collaborated effectively on integrated infrastructure in support of the NAVO. During FY 2018, the Astrophysics Data System (ADS) worked to complete the implementation of a new system. The new system includes a new search engine, bibliographic services, and a modern user interface that will replace the ADS legacy system ("ADS Classic") in 2019. As of September 2018, the new system has reached content and feature parity with ADS Classic while providing additional functionality such as full-text search, ORCID integration, and impact analysis.

The Mikulski Archive for Space Telescopes (MAST) continues to increase its data holdings to serve the Astrophysics community with TESS data arriving soon. Scientific publications referenced use of this data and programmatic queries to their catalog and observations holdings continue. MAST is ingesting community-contributed high-level science products at a faster rate than ever before. MAST has recently introduced a new initiative, ExoMAST, to enhance analysis of MAST exoplanet data, which is still in a beta phase.

The High Energy Astrophysics Science Archive Center (HEASARC) continue to support active NASA missions Chandra, Fermi, NICER, NuSTAR, and the Gehrels Swift Observatory. HEASARC supports NASA’s international collaboration with ESA’s XMM-Newton observatory and the legacy archive for 40 plus past high-energy astrophysics missions. A major recalibration of the entire Gehrels data archive was completed. The NICER archive is open to the public and fully integrated within the HEASARC.

The HEASARC reached an agreement to ingest data from the Japanese Monitor of All-Sky X-ray Image mission and has fully integrated these X-ray data into the HEASARC's standard interfaces, and its analysis tools into the HEASARC FTOOLS. The HEASARC will remain synchronized with the Japanese Aerospace Exploration Agency (JAXA) archive at the Data ARchives and Transmission System (DARTS) at the Japanese Institute of Space and Astronautical Science. The HEASARC made several releases of new capabilities in its web services. The archive total volume exceeds 100 TB. The HEASARC made numerous 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 33 million queries. IRSA deployed the NASA Infrared Telescope Facility (IRTF) archive serving data from two instruments. In addition, IRSA released about 15 new datasets, including the 2018 NEOWISE Data Release and Herschel Highly Processed data products. IRSA began development of the SOFIA archive. All major IRSA data sets (images, catalogs, and spectra) continue to be available through Virtual Observatory (VO) protocols.

OTHER MISSIONS AND DATA ANALYSIS

IRSA deploy new versions of its primary image exploration tools, IRSA Viewer and Finder Chart, including the capability to visualize all-sky maps in IRSA Viewer using a VO-standard format.

The NASA Extragalactic Database (NED) fielded nearly 90 million web server queries and added 314 million new objects from the literature and from catalogs (a 123 percent increase), most of which came from the 2MASS Point Source Catalog. In FY 2018, 832 refereed journal articles acknowledged using NED. NED released a major upgrade to its user interface including an integration of IPAC's Firefly toolkit, in use by IRSA and the Large Synoptic Survey Telescope project.

NAVO continues to provide a consistent interface to NASA mission data and other datasets deployed at NASA archives. In addition to the protocols for accessing tables, images and spectra, work has begun to provide a standard mechanism access to all mission datasets. During this period, the NAVO archives supports 31 million requests for data using VO protocols. NAVO continued to lead NASA's VO efforts within the United States and world communities. A major new focus of NAVO during the past year has been engagement with the AstroPy community. NAVO is working with the broader astronomical community to ensure that the popular Astroquery library can retrieve data from NASA archives consistently and effectively.

COSMIC ORIGINS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Hubble Space Telescope Operations	98.3	--	**83.3**	93.3	98.3	98.3	98.3
Stratospheric Observatory for Infrared Astronomy (SOFIA)	85.2	--	**73.0**	60.0	60.0	0.0	0.0
Other Missions and Data Analysis	27.7	--	**29.0**	20.6	23.4	23.4	23.4
Total Budget	**211.2**	**--**	**185.3**	**173.9**	**181.7**	**121.7**	**121.7**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

Much of the light in the universe comes from stars, and yet, star formation is still a vexing question in astronomy. To piece together a more complete picture of star birth, astronomers have used the Hubble Space Telescope to look at star formation among galaxies in our own cosmic back yard. The survey of 50 galaxies in the local universe, called the Legacy ExtraGalactic UV Survey (LEGUS), is the sharpest, most comprehensive ultraviolet-light look at nearby star-forming galaxies (Hubble Press Release, May 17, 2018).

"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 raise 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, Spitzer Space Telescope, and Stratospheric Observatory for Infrared Astronomy (SOFIA). Working collectively across a wide swath of wavelengths, from the far-ultraviolet through the far-infrared and sub-millimeter, these observatories create a comprehensive web of information and data that spans both the electromagnetic spectrum and time itself.

For more information, see: http://cor.gsfc.nasa.gov/.

COSMIC ORIGINS

EXPLANATION OF MAJOR CHANGES IN FY 2020

NASA has moved the James Webb Space Telescope to its own section, consistent with report language accompanying the 2019 Consolidated Appropriations Act (Public Law 116-006).

HUBBLE SPACE TELESCOPE OPERATIONS

Formulation	Development	Operations

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	98.3	--	83.3	93.3	98.3	98.3	98.3

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

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On August 17, 2017, the Laser Interferometer Gravitational-Wave Observatory detected gravitational waves from a neutron star collision. Within 12 hours, observatories had identified the source of the event within the galaxy NGC 4993, shown in this Hubble Space Telescope image, and located an associated stellar flare called a kilonova. Hubble observed that flare of light fade over the course of six days, as shown in these observations taken on August 22, 26, and 28 (insets).

One of NASA's most successful and long-lasting science missions, the Hubble Space Telescope, has beamed hundreds of thousands of 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, 2018 marked the start of Hubble's 28th year in orbit. The observatory is currently in its most scientifically productive period.

EXPLANATION OF MAJOR CHANGES IN FY 2020

As in recent years, this budget reflects efficiencies realized by the project's excellent cost performance over the last few years. 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 2020 and 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 2018

Astronomers used data from Hubble to find evidence for a stratosphere on a planet orbiting another star. As on Earth, the planet's stratosphere is a layer where temperatures increase with higher altitudes, rather than decrease. To study the stratosphere of WASP-121b, scientists analyzed how different molecules in the atmosphere react to particular wavelengths of light, using Hubble's capabilities for spectroscopy. Water vapor in the planet's atmosphere, for example, would glow at particular wavelengths depending on the temperature of the water. These observations found the telltale glow of water in the atmosphere of WASP-121b, indicating the planet has water in its atmosphere and the water is within the stratosphere. The 2016 Senior Review of Operating Missions recommended continuing Hubble operations as long as the observatory remains highly capable scientifically. This budget supports that recommendation.

WORK IN PROGRESS IN FY 2019

On Oct 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 Oct 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.

In FY 2019 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 announce Cycle 26 selections of GO proposals early in FY 2019. The 2019 Senior Review of Operating Missions will review Hubble extended mission operations for FY 2020 and beyond.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

The Space Telescope Science Institute (STScI), which manages Hubble’s science program, will select Cycle 27 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
May 2018	Release of Cycle 26 Call for Proposals
Aug 2018	Deadline for Cycle 26 Proposal Submissions
Nov 2018	Approximate date for Announcement of Cycle 26 selections
Jan 2019	Release of Cycle 27 Call for Proposals
May 2019	Senior Review of Operating Missions, including Hubble
Apr 2019	Deadline for Cycle 27 Proposal Submissions
Jul 2019	Approximate date for Announcement of Cycle 27 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): None	None
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)	None

Acquisition Strategy

NASA competes all new Hubble research opportunities.

HUBBLE SPACE TELESCOPE OPERATIONS

Formulation	Development	Operations

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	2016	Evaluate efficiency and productivity of Hubble operations	Maximize Hubble science return and reliability within available resources	2019, 2022, 2025

STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY (SOFIA)

Formulation	Development	Operations

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**85.2**	**--**	**73.0**	**60.0**	**60.0**	**0.0**	**0.0**

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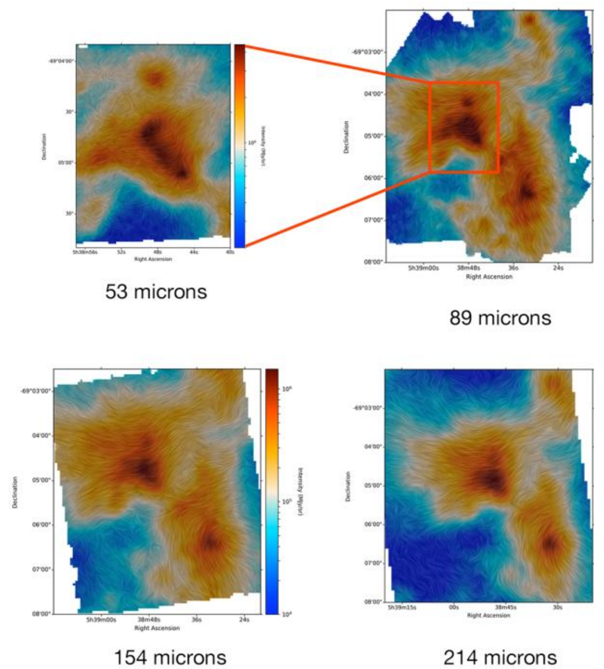

Images taken with SOFIA's newest instrument HAWC+ at multiple wavelengths showing dust and magnetic fields in the star-forming region 30 Doradus. The color scale shows the intensity of the infrared radiation from dust, or dust emission and the lines show the structure of the magnetic field.

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. These wavelengths are key to unlocking questions regarding:

- Earliest phases of star birth;
- Formation of new planetary systems and implications for life-supporting conditions;
- Dust grain production;
- Space chemistries of life-sustaining molecules like water;
- Composition of comets and asteroids, which are ancient relics from our own solar system and provide clues to its beginnings; and
- Physical properties of planets both near and far (exoplanets), which provide context in understanding the habitability of our own Earth.

SOFIA officially entered the operations phase for a five-year prime mission in May 2014.

STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY (SOFIA)

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2020

This budget supports the SOFIA mission fully with no impacts to science in FY 2020. NASA is conducting two reviews of SOFIA: an aircraft operations efficiency and maintenance review, and a science and mission operations review. Together these reviews will provide strategies for SOFIA to increase its scientific impact. NASA is budgeting for increased efficiencies in SOFIA's extended mission phase starting in FY 2020. In FY 2022 SOFIA will be included in the Senior Review along with other operating missions. The budget for FY 2023 and FY 2024 will be distributed to operating missions at the completion of the review.

ACHIEVEMENTS IN FY 2018

Researchers used SOFIA to solve questions on the formation and evolution of gas in clouds, local galaxies, and massive proto-star nurseries. In particular, the new HAWC+ instrument provided crucial insights into the role of magnetic fields in formation of stars and flow of gas in galaxies. SOFIA continues to provide important insights into the atmospheres of solar system bodies via occultations - it successfully flew a Titan occultation science flight on July 18, 2018.

NASA selected 104 of 198 submitted proposals for Cycle 6 in November 2017. Observations for Cycle 6 began in May 2018. In late June through mid-July 2018, NASA conducted a six-week deployment 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 2019

SOFIA is in the middle of completing Cycle 6 observations, with the start of Cycle 7 observations planned to commence in spring 2019. As a result of partial government shutdown from December to January, SOFIA operations ceased for seven weeks. In Cycle 7, there will be a new category of large, ambitious activities called "Legacy Science" activities, which will provide large, coherent datasets with archival and legacy value.

The development phase for the third-generation science instrument, the High Resolution Mid-Infrared Spectrometer (HIRMES) continues in FY 2019.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

The third-generation SOFIA instrument HIRMES will complete its commissioning in early FY 2020.

STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY (SOFIA)

Formulation	Development	Operations

Project Schedule

Date	Significant Event
Feb 2019	SOFIA Operations and Management Efficiency Review (Review of Aircraft Operations)
Apr 2019	SOFIA 5 Year Flagship Mission Review (Review of Science Operations)
Jun 2019	Summer Deployment Observation - New Zealand

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 Program Management	Program 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

STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY (SOFIA)

Formulation	Development	Operations

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.

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.	The goal is to achieve a substantially greater number of flights and/or reduce overall program cost.	TBD
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 significant improvement and optimization of the science output of SOFIA.	TBD

OTHER MISSIONS AND DATA ANALYSIS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Astrophysics Strategic Mission Program Management	0.0	--	**1.2**	1.2	1.2	1.2	1.2
Cosmic Origins Strategic Research and Technology (SR&T)	15.5	--	**17.1**	18.4	18.4	18.4	18.4
Cosmic Origins Future Missions	1.0	--	**2.2**	0.0	3.8	3.8	3.8
SIRTF/Spitzer	11.2	--	**8.5**	1.0	0.0	0.0	0.0
Total Budget	**27.7**	--	**29.0**	**20.6**	**23.4**	**23.4**	**23.4**

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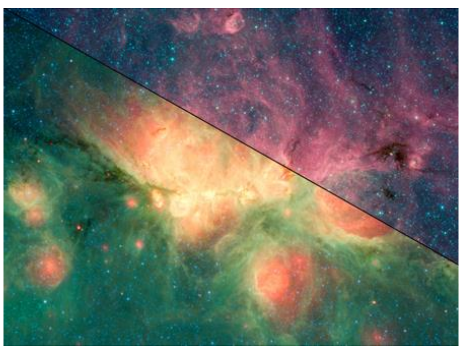

This image from NASA's Spitzer Space Telescope shows the Cat's Paw Nebula, so named for the large, round features that create the impression of a feline footprint. Newborn stars appear blowing bubbles in this nebula. This is a star-forming region in the Milky Way galaxy, located in the constellation Scorpius. Estimates of its distance from Earth range from about 4,200 to about 5,500 light-years (Top image is from the IRAC and MIPS, the second if from IRAC - Spitzer Press Release, October 23, 2018)

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 provides programmatic, technical, business management, and program science leadership.

Recent Achievements

In 2018, NASA merged the Cosmic Origins (COR) program office with the Physics of the Cosmos (PCOS) program office to create a single Astrophysics Strategic Mission program office. The office continued to provide support with communications, by publishing theme Newsletters; enabling and facilitating community forums and meetings; and monitoring two of the large mission concept studies. This support has provided a unified and clear approach to the Cosmic Origins' goals and objectives.

OTHER MISSIONS AND DATA ANALYSIS

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 2017. In addition, funding supports the study of future NASA space observatories.

This budget request supports a solicitation for industry for an on-going segmented-aperture Mirror Technology Development program. This new effort is currently developing end-to-end integrated telescope/coronagraph system-level engineering designs, modeling studies and associated testbed demonstrations.

The scientific community is actively working to mature mission concept studies and identify technology developments that will eventually provide inputs 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 will issue final reports during FY 2019.

Recent Achievements

The project was part of technology integration efforts that will assist in soliciting, prioritizing, and publishing technology gaps submitted by the community. These consolidated and streamlined efforts will now have a biennial cycle starting in 2019. NASA will call the new joint publication the 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 FY 2009 and extended warm operations through FY 2016. The 2016 Senior Review of Operating

OTHER MISSIONS AND DATA ANALYSIS

Missions recommended continuing Spitzer operations through CY 2019, with mission closeout in FY 2020. This budget supports that recommendation.

Recent Achievements

During 2018, in celebration of Spitzer's 15 years in space, NASA released two new multimedia products: the NASA Selfies app for iOS and Android, and the Exoplanet Excursions VR Experience for Oculus and Vive, as well as a 360-video version for smartphones. Spitzer's incredible discoveries and amazing images are at the center of these new products.

PHYSICS OF THE COSMOS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Other Missions and Data Analysis	118.0	--	**148.4**	128.5	123.3	117.8	117.4
Total Budget	**118.0**	**--**	**148.4**	**128.5**	**123.3**	**117.8**	**117.4**

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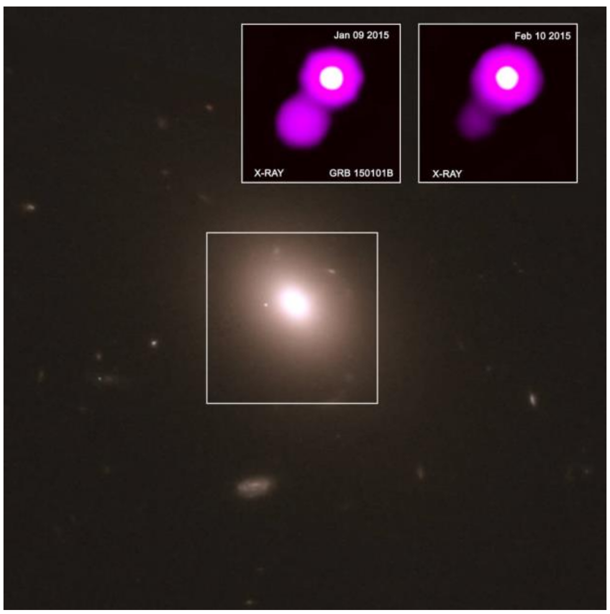


A distant cosmic relative to the first source that astronomers detected in both gravitational waves and light may have been discovered. This object, called GRB150101B, was first detected and identified as a gamma ray burst (GRB) by the NASA's Fermi satellite in January 2015. The image shows a Hubble picture of the host galaxy; the two insets are the Chandra images of GRB150101B at two different epochs.

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. Scientists using the Chandra X-ray Observatory have discovered a distant (1.7 billion light years) cousin of GW170817, the double neutron star merger producing gravitational waves detected in August 2017 by the National Science Foundation's Laser Interferometer Gravitational-Wave Observatory (LIGO) and in gamma rays by Fermi. This new X-ray object, dubbed GRB150101B, exhibits similar behavior as GW170817: both produced an unusually faint and short-lived gamma ray burst, and both were a source of bright, blue optical light lasting a few days. However, the lack of gravitational waves detected from GRB150101B implies that the mass of the pair is unknown; the source could be the merger of either two neutron stars or a neutron star and a black hole. This has substantial implications for the astrophysics of compact objects.

PHYSICS OF THE COSMOS

Other PCOS missions, such as the X-ray Multi-Mirror Mission-Newton (XMM-Newton), 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.

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, see: https://science.nasa.gov/about-us/smd-programs/physics-of-the-cosmos

EXPLANATION OF MAJOR CHANGES IN FY 2020

None.

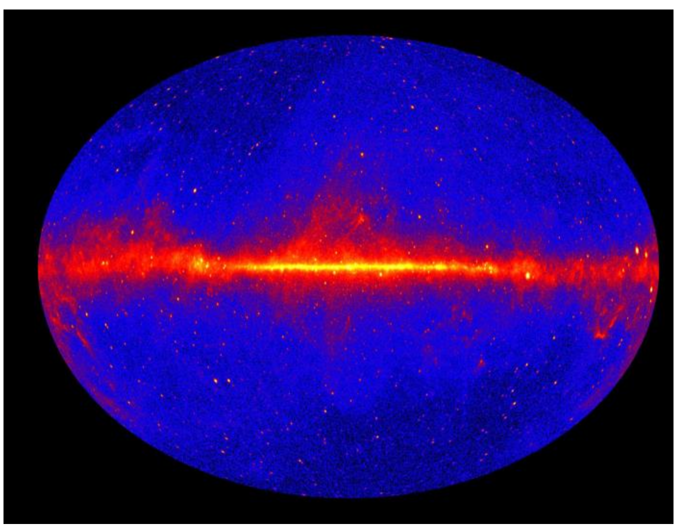
OTHER MISSIONS AND DATA ANALYSIS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Physics of the Cosmos SR&T	20.9	--	**50.9**	52.1	46.3	40.1	39.0
Euclid	19.8	--	**13.7**	11.0	8.9	9.9	10.3
PCOS/COR Technology Office Management	4.6	--	**5.9**	5.9	6.0	6.0	6.0
Physics of the Cosmos Future Missions	0.2	--	**2.0**	1.1	3.8	3.5	3.7
Fermi Gamma-ray Space Telescope	13.0	--	**14.0**	0.0	0.0	0.0	0.0
Chandra X-Ray Observatory	56.9	--	**58.4**	58.4	58.4	58.4	58.4
X-ray Multi-Mirror Mission (XMM)	2.5	--	**3.5**	0.0	0.0	0.0	0.0
Total Budget	**118.0**	--	**148.4**	**128.5**	**123.3**	**117.8**	**117.4**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



Gamma-ray image of the sky, after 10 years of operations of NASA's Fermi Telescope. Brighter colors indicated a larger number of gamma rays. On the right is the sharper, more detailed all-sky map produced by the Fermi Gamma-ray Space Telescope using nine years of data collected from 2008 to 2017.

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. This includes program-specific research and advanced technology development efforts, such as the Strategic Astrophysics Technology (SAT) solicitation issued in FY 2017.

OTHER MISSIONS AND DATA ANALYSIS

NASA and 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

NASA selected three new awards under the PCOS SAT Program, addressing technology developments in the Cosmic Microwave Background, X-ray optics, and gratings fields. The PCOS/COR Technology Management Office is working with the Exoplanet Program Office to integrate the PCOS, COR, and Exoplanet Programs' technology gaps solicitation, prioritization, and reporting processes. Starting in 2019 NASA will replace the Program Annual Technology Report with an Astrophysics Biennial Technology Report for the three themes.

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 has delivered to ESA all 20 flight-grade detectors and Cold Flexible Cables (16 flight parts and 4 spares) as of June 2018. However, the Sensor Cold Electronics (SCE) developed a significant problem during the testing at cryogenic temperatures. NASA developed and accepted a recovery plan in September 2018. The recovery plan includes a new, alternative SCE design and a revised budget and schedule. The new SCE design passed both Preliminary and Critical Design Reviews and the first batch of flight grade SCE are now under production and testing at JPL and GSFC as of October 2018. The first deliveries of the new SCE to ESA should occur in December 2019 and the last deliveries in March 2020. Despite the late deliveries of the SCEs, they are not on the ESA critical path because the Euclid project has had other delays that are longer than the SCE delays. JPL has delivered a set of non-flight, ground station electronics to ESA, which has allowed ESA to integrate and test the flight detectors and cables into the Near Infrared Spectrometer instrument.

OTHER MISSIONS AND DATA ANALYSIS

PCOS/COR TECHNOLOGY OFFICE MANAGEMENT

In 2018, NASA merged the PCOS program office with the Cosmic Origins (COR) program office to create a single PCOS/COR program office. The PCOS/COR Technology Office Management project provides programmatic, technical, and business management, as well as program science leadership.

Recent Achievements

NASA is contributing to the ESA-led Athena, an X-ray observatory dedicated to high-resolution spectroscopy, and is providing the microcalorimeter and elements of the Wide Field Imager. PCOS is leading the management of this contribution.

NASA is also collaborating with ESA on the LISA mission, a low-frequency gravitational wave observatory, and is contributing elements of the payload. NASA established a LISA study office, hosted by the PCOS/COR technology office management project, to manage the LISA technology development.

PCOS FUTURE MISSIONS

PCOS Future Missions funding supports concept studies of future missions.

Recent Achievements

The PCOS program is continuing to engage with the scientific community to lay the groundwork for design studies and technology development that will eventually provide inputs to the 2020 Astronomy and Astrophysics Decadal Survey. In addition, the program is working with the astrophysics community to develop white papers on science topics for the 2020 Decadal, due in January 2019.

Operating Missions

FERMI

The Fermi Gamma-ray Space Telescope explores extreme environments in the universe, from black holes to gamma-ray bursts, 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 international and the Department of Energy. Fermi entered extended mission operations in August 2013. The 2016 Senior Review of Operating Missions recommended continuing Fermi operations through FY 2019. The 2019 Senior Review of Operating Missions will consider a proposal for extended mission operations in FY 2020 and beyond.

Recent Achievements

On June 11, 2018, NASA's Fermi Gamma-ray Space Telescope celebrated a decade of using gamma rays, the highest-energy form of light in the cosmos, to study black holes, neutron stars, and other extreme cosmic objects and events. By scanning the entire sky every three hours, Fermi's main instrument, the

OTHER MISSIONS AND DATA ANALYSIS

Large Area Telescope (LAT), has observed more than 5,000 individual gamma-ray sources, including an explosion called GRB 130427A, the most powerful gamma-ray burst scientists have detected.

For the first time ever, scientists using Fermi have found the source of a high-energy neutrino from outside our galaxy. This neutrino traveled 3.7 billion years at almost the speed of light before detection on Earth by the National Science Foundation's Ice Cube Neutrino Observatory. This is farther than any other neutrino whose origin scientists can identify. High-energy neutrinos are hard-to-catch particles that scientists think originate in the most powerful events in the cosmos, such as galaxy mergers and material falling onto supermassive black holes. Data from Fermi's LAT revealed enhanced gamma-ray emission from a well-known active galaxy at the time the neutrino arrived. This is a type of active galaxy called a blazar, with a supermassive black hole with millions to billions of times the Sun's mass that blasts jets of particles outward in opposite directions at nearly the speed of light. Blazars are especially bright and active because one of these jets happens to point almost directly toward Earth.

About a year ago, astronomers reported the first detection of electromagnetic waves, or light, from a gravitational wave source. Fermi observed a burst of gamma rays named GRB 170817A as gravitational waves swept past Earth producing a signal detected by LIGO and its European counterpart Virgo. The source of both signals was the merger of two neutron stars, compact objects that squeeze more mass than the Sun into spheres no bigger than a city. Astrophysicists noticed distinct features in the light emitted by the event and scoured archival data looking for analogs. Fermi data for the gamma-ray burst GRB 150101B showed similarities to GRB 170817A, prompting a reanalysis of the follow-up data from telescopes including NASA's Chandra X-ray observatory, Neil Gehrels Swift Observatory, the NASA Hubble Space Telescope (HST), and the Discovery Channel Telescope (DCT). Two new studies of GRB 150101B suggest it is a cosmic relative of the historic event GRB 170817A. Both GRBs featured a bright blue kilonova, a rarely seen flare of ultraviolet, visible, and infrared light powered by the radioactive decay of elements forged in the neutron stars' collision. Initially, the material is so densely packed light cannot escape. As the debris cloud expands, it disperses and cools. Light escapes and radioactive elements decay into stable forms. The visible light that escaped the kilonovas of GRB 170817A and GRB 150101B was so hot it was blue-white.

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 also discovered and studied hundreds of supermassive black holes in the centers of distant galaxies. The 2016 Senior Review of Operating Missions recommended continuing Chandra operations as long as the observatory remains highly capable scientifically. The 2019 Senior Review of Operating Missions will review Chandra extended mission operations for FY 2020 and beyond.

Recent Achievements

A Columbia University-led team of astrophysicists have discovered a dozen black holes gathered around Sagittarius A*, the supermassive black hole in the center of the Milky Way Galaxy. The finding is the first to support a decades-old prediction. For more than two decades, researchers have searched unsuccessfully for evidence to support a theory that thousands of black holes surround supermassive black holes (SMBHs) at the center of large galaxies. Using the Chandra X-ray Observatory the scientists searched for X-ray signatures of black hole-low mass binaries in their inactive state and were able to find 12 within three light years, of Sgr A*. Extrapolations from their observations shows that there must be between 300 and 500 black hole-low mass binaries and about 10,000 isolated black holes in the area surrounding Sgr A*. The findings significantly advance gravitational wave research because knowing the number of black holes in the center of a typical galaxy can help in better predicting how many gravitational wave events may be associated with them. Scientists using Chandra have observed, for the first time, the destruction of a young planet or planets around a nearby star. The Chandra observations indicate that the parent star is now in the process of devouring the planetary debris. This discovery gives insight into the processes affecting the survival of infant planets. Using Chandra, a team of scientists may have uncovered what caused the star's most recent dimming event: a collision of two infant planetary bodies, including at least one object large enough to be a planet. As the resulting planetary debris fell into the star, it generates a thick veil of dust and gas, temporarily obscuring the star's light.

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 2016 Senior Review of Operating Missions recommended continuing operations through FY 2019. The 2019 Senior Review of Operating Missions will consider a proposal for extended mission operations in FY 2020 and beyond.

Recent Achievements

After a nearly twenty-year long game of cosmic hide-and-seek, astronomers using ESA/NASA’s XMM-Newton X-ray space observatory have found evidence of hot, diffuse gas permeating the cosmos, closing a puzzling gap in the overall budget of normal matter in the Universe. While astronomers have known for a long time how much ordinary matter -- matter made up of protons, neutrons, and electrons -- there is in the universe, only about 10 percent of the normal matter can be seen in stars; the rest of the normal matter is called "missing matter." XMM-Newton's data show signatures of oxygen in the hot intergalactic gas between Earth and the distant quasar, at two different locations along the line of sight. The discovery of the missing matter with XMM-Newton is the first step in fully characterizing the circumstances and structures in which this matter exists, and a step in filling in the gap between normal and dark matter. In September 2018, a team of astronomers reported the first detection of matter falling into a black hole at 30 percent of the speed of light, located in the center of the billion-light year distant galaxy PG211+143. The XMM-Newton observation agrees closely with recent theoretical work and shows that rings of gas around the black hole can break off and collide with each other, cancelling out their rotation and leaving gas to fall directly towards the black hole. An enigmatic X-ray source revealed as part of a data-mining project for high-school students shows unexplored avenues hidden in the vast archive of the XMM-Newton X-ray Observatory. The source identified by the students, displays brightness changes like no other known objects. An otherwise low-luminosity source of X-rays, XMM-Newton saw it brighten by up to 50 times its normal level and quickly fall again after about five minutes. This event is challenging our understanding of X-ray outbursts because it is too short to be an ordinary stellar flare, but too faint to be linked to a compact object.

EXOPLANET EXPLORATION

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Other Missions and Data Analysis	200.8	--	**46.4**	44.3	45.6	46.1	48.5
Total Budget	**200.8**	**--**	**46.4**	**44.3**	**45.6**	**46.1**	**48.5**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

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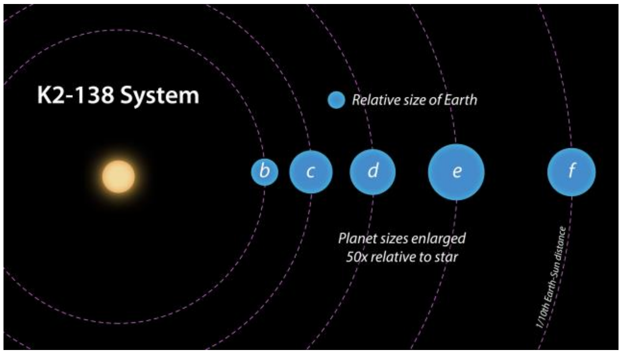


Layout of the K2-138 system, the first multi-planet system discovered by a "citizen science" project. Over 10,000 people participated in a crowd-sourced effort to classify datasets reporting measurements of the brightness of thousands of stars observed over several weeks by the Kepler spacecraft. Astronomer Jessie Christiansen led the 2017 discovery report of these five planets, all intermediate in size between Earth and Neptune, and without counterparts in our own solar system, which orbit and pass in front of their orangish star about 600 light years away. (credit: JPL/Caltech)

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 discovered and confirmed over 3,912 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 appear to be common. 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 2020

The Budget proposes termination of the WFIRST mission due to its significant cost and higher priorities within NASA, including completing the delayed 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 is estimated to cost $3.2-$3.9 billion.

OTHER MISSIONS AND DATA ANALYSIS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
WFIRST	150.0	--	**0.0**	0.0	0.0	0.0	0.0
Exoplanet Exploration Strategic Research and Technology	26.4	--	**29.1**	30.0	28.9	28.9	28.6
Exoplanet Exploration Technology Office Management	5.3	--	**6.5**	6.8	7.3	7.7	7.7
Exoplanet Exploration Future Missions	1.0	--	**2.8**	0.6	2.4	2.2	4.7
Keck Operations	6.2	--	**6.7**	6.9	7.0	7.2	7.4
Large Binocular Telescope Interferometer	1.8	--	**0.0**	0.0	0.0	0.0	0.0
Kepler	10.0	--	**1.3**	0.0	0.0	0.0	0.0
Total Budget	**200.8**	**--**	**46.4**	**44.3**	**45.6**	**46.1**	**48.5**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

This artist's illustration shows what the sky might look like from a planet in a particularly dusty solar system. The HOSTS scientists reported that a majority of Sun-like stars in their survey do not possess high levels of dust – good news for future efforts to study potentially habitable planets around those 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 LBTI telescopes, operating missions (Kepler), and funding for future mission selections.

EXOPLANET EXPLORATION STRATEGIC RESEARCH AND TECHNOLOGY

Exoplanet Exploration Strategic Research and Technology supports program-specific scientific research and technology development activities to enable future NASA space missions to discover and understand distant worlds.

NASA currently supports ten competitively selected exoplanet technology development projects involving researchers across the nation. The selected projects focus on advancing technologies to separate

OTHER MISSIONS AND DATA ANALYSIS

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 and Large Binocular Telescope Interferometer in Arizona. Those science investigations include ground-based follow-up observing programs that support the agency's Kepler/K2 and TESS missions 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. In addition, NASA is assessing via modeling and laboratory demonstrations new coronagraph techniques for their application to the segmented optics of future large telescopes. 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.

The NASA and NSF partnership to develop a new precision radial velocity instrument for the WIYN telescope is progressing well.

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 approximately 3,912 exoplanets among the approximately 6,100 candidates currently catalogued. Current estimates indicate that perhaps one in ten stars host rocky planets that exist in orbits where water may flow freely upon their surface. The program is managing design studies of mission opportunities. The program 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.

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.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

Community-based science and technology teams continue to be engaged to develop mission concepts and technology development plans. To prepare for the next decade, NASA is studying the scientific merits of exoplanet missions in both the probe (medium) and large classes.

Operating Missions

KECK OPERATIONS

Keck Operations is the NASA portion of the Keck Observatory partnership. NASA uses its share of observing time in support of Astrophysics and Planetary Science programs. The project allocates observing time for NASA astrophysics science goals, as well as solar system objects and direct space mission support. Observation time is competed, selected, and managed by the NASA Exoplanet Science Institute. NASA is partner for one-sixth of the observing nights with the W.M. Keck Observatory (WMKO) for both 10-meter telescopes, a pair of the largest optical telescopes in the world. 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. For example, in semester 2018A, scientists submitted 73 proposals requesting 143.26 nights, yielding an overall oversubscription of 4.34 for both Keck telescopes. In the past year, 19 percent of WMKO publications cite the archive as the source of the data. This is an increase from 13 percent in the previous year. The annual growth is attributable to the availability of data from a dozen instruments in KOA covering 25 years of the “Keck Sky.”

On September 7, 2017, NASA announced the approval of a five-year renewal of the cooperative agreement with the W.M. Keck Observatory after issuing a call for proposals, conducting an extensive evaluation, and considering the strategic value that the Keck observatory provides to NASA missions. This new Cooperative Agreement runs from March 1, 2018 until February 28, 2023.

LARGE BINOCULAR TELESCOPE INTERFEROMETER

The Large Binocular Telescope Interferometer (LBTI) is the NASA portion of the Large Binocular Telescope partnership managed by the Steward Observatory at the University of Arizona. Engineers and scientists designed the LBTI to allow high contrast, high spatial resolution infrared imaging of warm dust clouds in and around the habitable zones of nearby stars. The system surveys nearby stars for dust and debris disks that may hamper the detection of potentially habitable planets around those stars. This information will be crucial for designing future space observatories capable of detecting and characterizing those planets by direct imaging.

Recent Achievements

LBTI images the dust and planets around nearby stars at infrared wavelengths using a technique called Nulling Interferometry. These observations provide a first look at some of the most interesting exoplanetary systems in the solar neighborhood. LBTI recently successfully completed the Hunt for Observable Signatures of Terrestrial Systems (HOSTS) survey of 38 stars.

The interferometric data suggest that dust disks around stars are not an obvious hindrance to future exoplanet imaging missions. The LBTI project is studying instrument upgrades for potential higher sensitivity measurements, should the science community require them for the characterization of exoplanetary systems by future imaging missions.

KEPLER

Kepler, launched in March 2009, surveys stars in the local region of the Milky Way galaxy to detect and characterize rocky planets in or near the habitable zone of their host star. The habitable zone encompasses the distances from a star where liquid water can exist on a planet's surface. As time progresses, smaller planets with longer orbital periods emerge from the data.

In June 2014, NASA approved Kepler to enter a new phase of operations, called K2, in which the spacecraft observes along the ecliptic plane, opening up new possibilities for discovery. Both the 2014 and 2016 Senior Reviews of Operating Missions favorably reviewed the K2 operating mode. The original phase of the mission ended September 30, 2017, with the delivery of all of the data acquired during this fully calibrated and vetted data to the Mikulski Archives at Space Telescope (MAST) for future use by the astronomical community. The extended (K2) phase of the mission operated until October 2018. On October 30, 2018, NASA announced that the Kepler space telescope had run out of fuel needed for further science operations. NASA decided to retire the spacecraft within its current, safe orbit, away from Earth.

Recent Achievements

Kepler's observations of so many stars has been essential to understanding the basic properties of the planets that orbit them and is enhancing our understanding of the history and structure of our galaxy and the universe. In particular, Kepler has captured the beginning stages of exploding stars, called supernovae, with unprecedented precision, giving us new knowledge into how these stellar explosions begin.

The top science results from the Kepler mission are:

1) Planets outnumber stars. Kepler has proven there are more planets than stars in our galaxy — and knowing that revolutionizes our understanding of our place in the cosmos

2) Small planets are common. Kepler has shown us our galaxy is teeming with terrestrial-size worlds, and many of them may be similar to Earth in size and distance from their parent stars. Kepler found dozens of planets near in size to Earth and orbiting in the habitable zone of their stars where liquid water could pool on the surface. We still have much to learn about whether any of them could host life.

3) Planets are diverse. Kepler has discovered a diversity of planet types, opening our eyes to new possibilities. The most common size of planet Kepler found does not exist in our solar system — a world between the size of Earth and Neptune — and we know little about them.

OTHER MISSIONS AND DATA ANALYSIS

4) Solar systems are diverse too. While our own inner solar system has four planets, Kepler found systems with considerably more planets — up to eight — orbiting close to their parent stars. The existence of these compact systems raises questions about how solar systems form: Are these planets “born” close to their parent star, or do they form farther out and migrate in?

5) New insights revealed about stars. Besides launching us into the golden age of exoplanets, Kepler has reinvigorated the study of stars. Kepler observed more than a half million stars over the course of its nine years in operation, the largest survey measuring stars' changes in brightness.

Furthermore, on October 3, 2018, NASA announced the potential discovery of a huge exomoon around a gas giant planet, Kepler-1625b, which is three times more massive than Jupiter. A Columbia University pair of astronomers using NASA’s Hubble Space Telescope and Kepler space telescope have assembled compelling evidence for the existence of a moon orbiting a gas-giant planet located 8,000 light-years away. If confirmed by follow-up Hubble observations, this would be the first case of finding a moon outside of our solar system. The candidate exomoon, spotted by NASA's Kepler and Hubble space telescopes, may have similarly edged away from its planet over time, so it could have been much closer billions of years in the past.

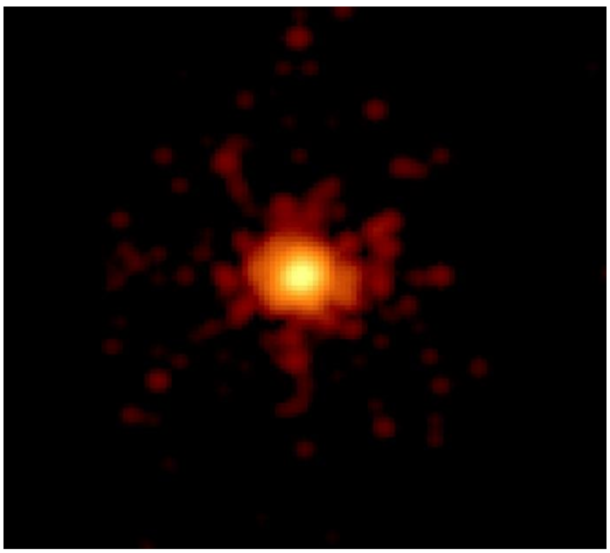
ASTROPHYSICS EXPLORER

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Other Missions and Data Analysis	117.4	--	**214.1**	246.4	312.0	328.8	321.4
Total Budget	**117.4**	**--**	**214.1**	**246.4**	**312.0**	**328.8**	**321.4**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



A titanic burst of energy from a dying star 13 billion light years away has been spotted (center) from Earth. The caption of the figure needs to identify the mission and the science.

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.

ASTROPHYSICS EXPLORER

EXPLANATION OF MAJOR CHANGES IN FY 2020

The requested budget supports funding needed for the upcoming MIDEX, MO, and future SMEX selections.

ACHIEVEMENTS IN FY 2018

The Transiting Exoplanet Survey Satellite (TESS) mission launched on April 18, 2018, and began science operations on July 25, 2018.

In June 2018, the Imaging X-ray Polarimetry Explorer (IXPE) successfully completed the Preliminary Design Review (PDR). IXPE will be launched into a low inclination, low Earth orbit for a two-year mission beginning in April 2021.

The GUSTO balloon payload, a Mission of Opportunity to launch on a high-altitude stratospheric balloon from Antarctica in December of 2021, began Phase B formulation in January 2018.

NASA and JAXA have jointly agreed to participate in the X-ray Imaging and Spectroscopy Mission (XRISM), previously named XARM, to recover the soft X-ray spectroscopic capability lost with the Hitomi mission in March 2016. NASA's contribution to XRISM, the Resolve soft X-ray spectrometer, entered Phase C implementation in January 2018.

In May 2018, NASA received the MIDEX and MO Phase A mission concept studies and began their review.

WORK IN PROGRESS IN FY 2019

TESS continues in Phase E science operations.

In November 2018, IXPE passed its review to enter into Phase C, the final design and fabrication activities phase of development. The mission is working towards Critical Design Review (CDR) in spring 2019.

GUSTO will transition into Phase C, and will continue payload development leading up to the Critical Design Review late in FY 2019.

NASA expects to complete fabrication and testing of the hardware for Resolve in FY 2019.

In the first half of FY 2019 NASA will select MIDEX and MO investigations to proceed into formulation and implementation, based on review of the Phase A mission concept studies. In the spring of 2019, NASA will release an Announcement of Opportunity for Astrophysics Small Explorers and Missions of Opportunity.

ASTROPHYSICS EXPLORER

KEY ACHIEVEMENTS PLANNED FOR FY 2020

IXPE will continue development, with the Systems Integration Review (SIR) planned for summer 2020. GUSTO will also continue in development. NASA expects to deliver Resolve, its contribution to XRISM, to JAXA in FY 2020, and will aid with payload integration. The MIDEX and MO investigations selected in FY 2019 will continue implementation. NASA will make Step 1 selections of SMEX and MO proposals, and selected investigations will initiate competitive Phase A mission concept studies. The 2019 Senior Review of Operating Missions will consider a proposal for TESS extended mission operations in FY 2020 and beyond.

Program Schedule

Date	Significant Event
Feb/Mar 2019	Downselect one MIDEX and one MO mission for implementation
Apr 2019	AO announcement of SMEX and MO opportunity to propose
Mar 2020	Select SMEX and Explorer MO proposals for competitive Phase A mission concept studies
Sep 2021	AO announcement for MIDEX and MO opportunity to propose
Aug 2021	Downselect one SMEX and one MO mission for implementation
Aug 2022	Select MIDEX 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.

Acquisition Strategy

NASA selects all Explorer missions through competitive AOs.

ASTROPHYSICS EXPLORER

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Program Independent Review	SRB	Oct 2014	Assess performance of program	Successful	Jun 2019

OTHER MISSIONS AND DATA ANALYSIS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Astrophysics Explorer Future Missions	11.8	--	**84.8**	154.2	267.0	295.1	299.2
Astrophysics Explorer Program Management	11.1	--	**0.0**	13.3	8.8	10.7	5.9
Neutron Star Interior Composition Explorer (NICER)	2.1	--	**0.0**	0.0	0.0	0.0	0.0
Neil Gehrels Swift Observatory	3.9	--	**5.5**	0.0	0.0	0.0	0.0
Nuclear Spectroscopic Telescope Array (NuSTAR)	4.8	--	**7.8**	0.0	0.0	0.0	0.0
Transiting Exoplanet Survey Satellite (TESS)	33.5	--	**5.0**	0.2	0.0	0.0	0.0
GUSTO	4.7	--	**11.1**	7.8	6.3	1.0	0.0
The Imaging X-Ray Polarimetry Explorer (IXPE)	23.5	--	**70.2**	45.3	7.4	4.5	0.5
The X-Ray Imaging and Spectroscopy Mission (XRISM)	22.0	--	**29.7**	25.7	22.5	17.6	15.8
Total Budget	**117.4**	--	**214.1**	**246.4**	**312.0**	**328.8**	**321.4**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

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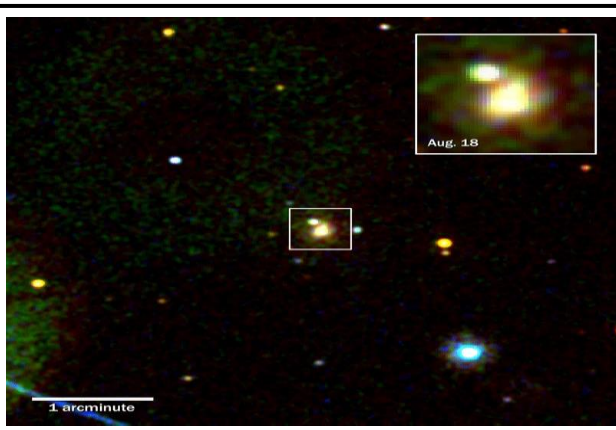

Swift's ultraviolet image of the galaxy NGC 4993 (box); the bright blob above the galaxy is the explosive result of two neutron stars merging. The picture combines images through three ultraviolet filters, taken about 15 hours after gravitational waves from the explosion and a burst of gamma rays arrived at Earth on August 17, 2017.

Astrophysics Explorers Other Missions and Data Analysis includes funding for small missions in formulation and development (GUSTO, IXPE, XRISM), operating missions (NICER, NuSTAR, Swift), and funding for future mission selections and program management functions.

Mission Planning and Other Projects

GALACTIC/EXTRAGALACTIC ULDB SPECTROSCOPIC TERAHERTZ OBSERVATORY (GUSTO)

In March of 2017, NASA's Astrophysics Explorers Program selected the GUSTO balloon payload as a Mission of Opportunity. GUSTO will launch on a high-altitude stratospheric balloon from McMurdo, Antarctica in December of 2021 for approximately 100 days. GUSTO's telescope and 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. GUSTO completed all requirements tailoring efforts required to begin Phase B formulation activities in January 2018, and will enter Phase C development in FY 2019. The FY 2020 request supports implementation activities leading up to integration of the payload into the gondola in FY 2021.

THE IMAGING X-RAY POLARIMETRY EXPLORER (IXPE)

NASA selected IXPE, a small Explorer-class mission, to continue into Phase B formulation in January 2017. IXPE entered Phase C development in November 2018, after completing the Key Decision Point-C (KDP-C). IXPE will examine polarized x-ray emissions from both galactic and extragalactic x-ray sources such as neutron stars and black holes. This will allow the investigation of general relativistic and quantum effects in the extreme environment associated with these sources. IXPE will launch into a low Earth orbit at a low inclination for a two-year mission beginning in October 2021.

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. 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, and will supply the X-ray mirror assemblies for the observatory. NASA's contribution to XRISM entered Phase C development after completing a combined Preliminary Design Review/Critical Design Review in November 2017 and the Key Decision Point B/C in January 2018. The NASA instrument contributions are on schedule to deliver to JAXA in October 2019. JAXA renamed the mission from XARM to XRISM at their Project Start on July 1, 2018. NASA selected five Participating Scientists in 2018 through peer review following an open call for proposals from the U.S. science community.

TRANSISTING EXOPLANET SURVEY SATELLITE (TESS)

The Transiting Exoplanet Survey Satellite 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 2-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

OTHER MISSIONS AND DATA ANALYSIS

targets will record every 2 minutes. TESS will also obtain full-frame images (FFIs) 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% of the sky (an area of sky 400 times larger than covered by Kepler) to search for planets around nearby stars (within ~200 parsec). TESS stars will typically be 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

TESS began Phase E science operation on July 25, 2018. In early January 2019 TESS found an exoplanet three times the size of Earth only 53 light-years away. It has also discovered a super-Earth and a rocky world, making three exoplanet discoveries in the first three months since it began surveying the sky in July. As of January 2019, using observations from TESS, astronomers are conducting follow-up observations on more than 280 exoplanet candidates.

The 2019 Senior Review of Operating Missions will consider a proposal for extended mission operations in FY 2020 and beyond.

ASTROPHYSICS EXPLORERS FUTURE MISSIONS

Astrophysics Explorers Future Missions funding supports future astrophysics Explorers missions and MOs through concept studies and selections. During FY 2019, NASA will release an Announcement of Opportunity for Astrophysics Small Explorers and Missions of Opportunity.

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 the external logistics carrier of the ISS for an 18-month 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 test models for how matter behaves at such extreme densities. A neutron star squeezes more than 1.4 solar masses into a city-size volume, so the density and pressure are higher than in atomic nuclei. NICER also 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 first NICER Guest Observer proposals are due in December 2018. NICER demonstrated achievement of its prime-mission science goals in a June 2018 review. The 2019 Senior Review of Operating Missions will consider a proposal for extended mission operations in FY 2020 and beyond.

Recent Achievements

NICER tracked the brightness and temperature of the “mushroom cloud” from a thermonuclear explosion on a neutron star as the “ash” layer lifted more than 100 km off the surface, revealing effects of the star’s extreme gravity. In a similar burst from another star, NICER detected short-lived but regular and very rapid (nearly 620 times every second) brightening and dimming of the X-ray emission that expose how the nuclear burning spreads over the surface before engulfing the entire star.

Monitoring the exceptionally bright outburst of a neutron star known as Swift J0243.6+6124, NICER showed that this object represents our own Galaxy’s first ultraluminous X-ray pulsar, a type of object previously seen only in other, distant galaxies. The NICER data demonstrated that the star is a powerful magnet, and showed how the neutron star could repel matter flowing from a companion star.

NICER discovered a warped accretion disk around the new black hole system MAXI J1535-571. In this source, the spectral lines from gas around the black hole show that the X-ray-bright gas travels at nearly the speed of light close to the black hole's event horizon.

As a technology testbed, NICER demonstrated, for the first time, autonomous navigation in deep space using the precise pulses from millisecond pulsars. Pulsar-based navigation works like X-ray GPS, but its beacons are pulsars distributed around the Galaxy. Such a system could guide humankind into the outer Solar system and beyond.

NEIL GEHRELS SWIFT OBSERVATORY

The Neil Gehrels Swift Observatory is a multi-wavelength space-based observatory that studies the position, brightness, and physical properties of gamma-ray bursts. Swift is a MIDEX class mission that launched in 2004 and is now in extended mission operations. It continues to provide data that allows scientists to solve the mystery of the origin of gamma-ray bursts and observe the birth cries of black holes. Swift is uniquely equipped to make rapid-response observations to fast-breaking events. Therefore, as well as revolutionizing gamma-ray burst science, Swift is a valuable facility for understanding the transient universe, ranging in distance from solar system studies to distant quasars, and in time from the present to the epoch of reionization. Scientists are now implementing the observations selected under

Cycle 14 of the Guest Observer program; NASA received proposals for Cycle 15 on September 28, 2018. The 2016 Senior Review of Operating Missions recommended continuing Swift operations through FY 2019. The 2019 Senior Review of Operating Missions will consider a proposal for extended mission operations in FY 2020 and beyond.

Recent Achievements

On May 13, 2018, the UltraViolet Optical Telescope (UVOT) on-board Swift obtained its one millionth image, of the active galaxy 2MASX J16110570+0234002. Swift's on-board X-ray telescope (XRT) was the first instrument to conduct follow-up observations of the high-energy neutrino IceCube-170922A: the discovery announcement in July 2018 marked the first time that an astronomical source (a flaring blazar) was associated with such high-energy neutrinos. In January 2018, Swift observed the most dramatic change in the rotation rate of a comet (41P/Tuttle-Giacobini-Kresák), indicating the surface of this comet is likely covered with small jets.

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 massive black holes in other galaxies, locate and examine the remnants of collapsed stars in our galaxy, 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. 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 micro flares on the surface of the Sun. NuSTAR performs follow-up observations to discoveries made by Chandra and Spitzer scientists. The NuSTAR mission implemented a Guest Observer Facility for U.S. observers in 2015. Scientists are now implementing the observations selected under Cycle 4 of the Guest Observer program. The observations NASA will select in Cycle 5 will begin in summer 2019. Some of these investigations utilize NuSTAR observations only, others involve coordinated observations with other missions including Swift and NICER.

The 2016 Senior Review of Operating Missions recommended continuing NuSTAR operations through FY 2019. The 2019 Senior Review of Operating Missions will consider a proposal for extended mission operations in FY 2020 and beyond.

Recent Achievements

NuSTAR continued its highly successful science program, providing new insights into the high-energy Universe. NuSTAR recently observed Eta Carinae, an unusual binary or triple of stars that together give out millions of times more light than our Sun. The most massive star, about 100 times the mass of our Sun, is coming to the end of its life: it throws off its outer layers in violent outbursts separated by decades, during which its visible light becomes several thousand times yet brighter. Both it and the second star continually blow off gas in fast winds; shock waves are produced where their winds collide, which heat the gas to X-ray-emitting temperatures. NuSTAR found X-rays three times more energetic than those expected from that hot gas. Most likely, magnetic fields in the shocked gas accelerate electrons to nearly the speed of light: Eta Carinae is a source of cosmic rays. Starlight can bounce off those speedy electrons and get a huge energy boost, turning visible light into the energetic X-rays seen by NuSTAR.

Black holes are ravenous eaters, but they do not swallow everything that comes close to them. Gas falling inward forms a rotating disk, circling faster and faster as it nears the black hole. Magnetic fields tangled

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up in the gas stretch and strengthen; as a result, two fast powerful jets form along the axis of spin, shooting a small portion of material back out. The jet close to the black hole, moving nearly at light-speed, is bright in X-rays, while visible light emanates from where the jet runs into surrounding cooler gas. NuSTAR studied two X-ray binaries in the Milky Way, each with a normal star circling a black hole that feeds off the stellar gas. The time delay between when NuSTAR first detected X-rays and ground-based astronomers detected flares in visible light was about a tenth of a second in both systems, meaning that the zone where the visible light arises is only about 19,000 miles out from the black hole.

JAMES WEBB SPACE TELESCOPE

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**533.7**	**375.1**	**352.6**	**415.1**	**175.4**	**172.0**	**172.0**

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James Webb Space Telescope

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

FY 2020 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	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	5380.0	533.7	375.1	**352.6**	357.8	3.4	0.0	0.0	0.0	7002.6
Operations/Close-out	0.0	0.0	0.0	**0.0**	57.3	172.0	172.0	172.0	286.7	860.1
2019 MPAR LCC Estimate	**7180.1**	**533.7**	**375.1**	**352.6**	**415.1**	**175.4**	**172.0**	**172.0**	**286.7**	**9662.7**
Total Budget	**7108.0**	**533.7**	**375.1**	**352.6**	**415.1**	**175.4**	**172.0**	**172.0**	**286.7**	**9590.7**
Change from FY 2019				**-22.5**						
Percentage change from FY 2019				**-6.0%**						

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

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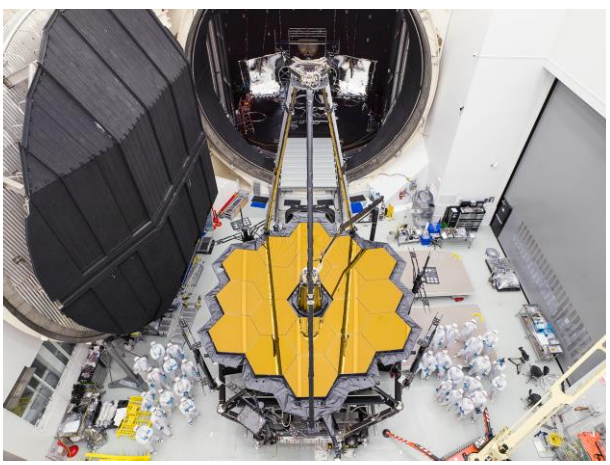


Completion of Webb telescope center-of-curvature test.

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:

- 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

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

- Measure the physical and chemical properties of planetary systems and investigate the potential for life in those systems.

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 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 2020

NASA announced in 2018 a delay in the anticipated launch of the James Webb Space Telescope until 2021. This budget includes the increase in cost for the FY 2021 launch date. The current estimated costs through development $8.8 billion is within the cap established in the FY 2019 Consolidated Appropriations Act.

NASA approved a re-plan in June 2018 that changed the launch date to March 2021. The new launch date followed a schedule assessment conducted by the Webb Standing Review Board (SRB) and an Independent Review Board (IRB). The change was due to delays associated with the spacecraft and sunshield schedules. Two propulsion problems required additional schedule to resolve and sunshield integration, as well as the initial sunshield deployment, fold and stow activities took longer than planned. During the spacecraft element acoustics test, NASA found loosened hardware (nuts, screws and washers) on the sunshield membrane cover assemblies and subsequently replaced it, further extending the schedule. NASA identified the problem that caused the loose hardware and fixed it. Thereafter the spacecraft element successfully passed the spacecraft element acoustics test as well as the sine/vibration tests.

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., can always be 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 one 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

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

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.

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 provides 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 2018

NASA made significant progress in the development, fabrication, and testing of many components of the Webb system. The project also completed the following significant and technically challenging developments and tests successfully:

- Shipped the Optical Telescope/Integrated Science (OTIS) module to the Northrop Grumman Space Park Facility in Redondo Beach, California;
- Initiated the spacecraft element acoustics testing; loosened hardware (nuts, screws, washers) was found on the sunshield membrane cover assemblies, requiring replacement, which was completed in October;
- Conducted re-plan activities which resulted in a move of the launch date to March 2021;
- Conducted electrical and command testing between the spacecraft element and OTIS; and
- Continued testing the integrated software system for Webb operations at the Space Telescope Science Institute, including mission rehearsals.

WORK IN PROGRESS IN FY 2019

- Complete acoustics testing of the spacecraft element
- Conduct spacecraft element vibration and thermal vacuum environmental testing;

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

- Conduct post-environmental sunshield deployment, fold and stow activities;
- Start integration of OTIS to the spacecraft element

KEY ACHIEVEMENTS PLANNED FOR FY 2020

The President's FY 2020 Budget request provides the full level of funding required to keep Webb on schedule for a 2021 launch. In FY 2020, the project plans to:

- Complete integration of OTIS to the spacecraft element;
- Issue General Observers Call for Proposals for the first year of Webb observing time;
- Conduct observatory level environmental testing;
- Conduct post-environmental sunshield deploy, stow and fold activities for launch configuration;
- Conduct testing of the Webb flight operations system and science processing system; and
- Transport Webb to the launch site in Kourou, French Guiana.

SCHEDULE COMMITMENTS/KEY MILESTONES

NASA plans to launch Webb in March 2021 to begin a five-year prime mission. The following timeline shows the development agreement schedule per the Agency re-plan from June 2018.

Milestone	Confirmation Baseline Date	FY 2020 PB Request
Key Decision Point (KDP)-C	Jul 2008	Jul 2008
Mission Critical Design Review (CDR)	Mar 2010	Apr 2010
Rebaseline/KDP-C Amendment	Sep 2011	Sep 2011
System Integration Review (SIR)	Jul 2017	Aug 2019
Launch	Oct 2018	Mar 2021
Begin Phase E	Apr 2019	Sept 2021
End of Prime Mission	Apr 2024	Sept 2026

JAMES WEBB SPACE TELESCOPE

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 (mths)
2012	6,197.9	66	2019	7,002.6	+13%	LRD	Oct 2018	Mar 2021	+29

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. The original baseline is provided in the Supporting Data section.*

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**6,197.9**	**7,002.6**	**+804.7**
Aircraft/Spacecraft	2,955.0	3,876.7	+921.7
Payloads	695.1	825.3	+130.2
Systems Integration & Test (I&T)	288.4	485.2	+196.8
Launch Vehicle	0.9	1.2	+0.3
Ground Systems	652.3	878.3	+226.0
Science/Technology	42.7	41.1	-1.6
Other Direct Project Costs	1,563.5	894.8	-668.7

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

Project Management & Commitments

NASA Headquarters is responsible for Webb program management. 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
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 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

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
MIRI	Operates over the wavelength range of 5 to 28 micrometers, providing 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	Ground control system and science operations and control center

Project Risks

Risk Statement	Mitigation
If: If major issues arise during environmental testing of spacecraft, sunshield, or observatory, Then: This may delay completion of testing of the affected element, adding risk to achieving 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.

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

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
Quality	Test Assessment Team	Aug 2010	Evaluate plans for integration and testing. See the full report at http://www.jwst.nasa.gov/publications.html	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

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
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	March 2018	Schedule risk assessment	SRB recommended new launch date	N/A
Other	IRB	April 2018	Conduct assessment of mission development for schedule & mission success	The IRB recommended to Agency rebaseline of schedule, cost, and launch date	N/A
Other	SRB	April 2019	Interim review schedule risk	TBD	TBD
Performance	SRB	Aug 2019	Observatory SIR	TBD	TBD
Performance	SRB	Oct 2020	ORR	TBD	TBD

HELIOPHYSICS

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Heliophysics Research	206.3	--	**237.0**	223.6	214.7	219.3	222.0
Living with a Star	376.1	--	**107.6**	83.6	108.7	121.9	118.3
Solar Terrestrial Probes	45.2	--	**177.9**	220.4	210.9	192.7	152.0
Heliophysics Explorer Program	60.9	--	**182.0**	111.1	235.0	158.1	217.5
Total Budget	**688.5**	**--**	**704.5**	**638.6**	**769.3**	**692.0**	**709.8**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

Heliophysics

HELIOPHYSICS RESEARCH

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Heliophysics Research and Analysis	54.5	--	**66.6**	58.6	58.6	58.6	58.6
Sounding Rockets	59.0	--	**63.1**	68.1	60.1	65.1	65.1
Research Range	24.8	--	**28.7**	27.0	26.0	26.4	26.4
Other Missions and Data Analysis	68.1	--	**78.6**	69.9	69.9	69.2	71.8
Total Budget	**206.3**	**--**	**237.0**	**223.6**	**214.7**	**219.3**	**222.0**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

The Colorado High-resolution Echelle Stellar Spectrograph, or CHESS 4, launched on a NASA Black Brant IX sounding rocket at 12:47 p.m. EDT, April 16 (4:47 a.m. local, April 17) from the Kwajalein Atoll in The Republic of the Marshall Islands.

The CHESS 4 mission will study the interstellar medium, the matter between stars. The mission focuses on translucent clouds of gas that provide the fundamental building blocks for stars and planets.

The Sun, a typical small 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 interact with the Earth and its space environment to produce space weather, which can affect human technological infrastructure and activities. Heliophysics seeks to understand the Sun, heliosphere, and planetary environments as a single connected system. NASA seeks 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, and 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'sN 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.

HELIOPHYSICS RESEARCH

For more information, go to: https://science.nasa.gov/heliophysics/programs/research.

EXPLANATION OF MAJOR CHANGES IN FY 2020

None.

ACHIEVEMENTS IN FY 2018

A robust competed research and analysis program enjoyed an increase in selection rates across its various elements. Additionally, to prepare for future rideshare opportunities, the Low-Cost Access to Space (LCAS) program element separated the CubeSat and suborbital sub-elements, and established the Research &Technology Prime sub-element to better manage proposals greater than $3.5 million.

NASA continued a competed Heliophysics Research program with emphasis on synergy of data analysis with key enhancement from numerical simulations, theory, or modeling. It 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 22 sounding rockets and four reimbursable missions. Four rockets successfully launched from the Poker Flat Research Range in Alaska between January and March 2018. Two technology demonstration missions from the Wallops Flight Facility (WFF) enabled water recovery of vacuum-sealed telescope payloads, as well as more reliable deployment and detonation of small vapor tracer ampules for the purpose of upper atmosphere wind measurements. The Program continued planning for a potential FY 2019 campaign in Australia, which will likely feature several missions investigating celestial targets of interest in the Southern sky.

In addition, Heliophysics launched three CubeSats in FY 2018. Compact Radiation Belt Explorer (CeREs) will study what energizes electrons and causes their escape from the radiation belts. Scintillation Observations and Response of The Ionosphere to Electrodynamics (SORTIE) will study space weather sources of wave-like plasma perturbations in the ionosphere. The Tandem Beacon-Explorer (TBEx) will study tropical weather relationship to ionospheric bubbles.

WORK IN PROGRESS IN FY 2019

In FY 2019, the Heliophysics Research program anticipates science results from the analysis of data from 17 active space missions (26 individual spacecraft) that comprise the Heliophysics System Observatory. These include ACE, AIM, Geotail, Hinode, Interstellar Boundary Explorer (IBEX), Interface Region Imaging Spectrograph (IRIS), Magnetospheric Multiscale Satellites (MMS) (four spacecraft), Ramaty High Energy Solar Spectroscopic Imager (RHESSI), Solar Dynamics Observatory (SDO), Solar and Heliospheric Observatory (SOHO), Solar Terrestrial Relations Observatory (STEREO), Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED), Time History of Events and Macroscale Interactions during Substorms (THEMIS) (five spacecraft), Two Wide-angle Imaging Neutral-atom Spectrometers (TWINS), Van Allen Probes (two spacecraft), Voyager (two spacecraft), and Wind. The anticipated awards of small research investigations will also continue to contribute to heliophysics science advancements.

The current sounding rockets mission manifest features 18 missions in FY 2019 in multiple remote locations. The program will go to the Poker Flat Research Range in the winter for four missions, Norway in the spring for two missions, and to Kwajalein in the summer for two missions. Furthermore, the Program will execute the bulk of the preparations for an early FY 2019 campaign in Norway, called the Grand Challenge. This will involve fabrication, testing, and ground support set-up for six missions from two launch sites (Andoya and Svalbard). NASA also plans to go to Australia, which will feature several missions investigating celestial targets of interest in the Southern sky.

The sounding rocket program will also launch the first in a series of rockets for the Jet Propulsion Laboratory to test the re-entry dynamics of supersonic parachutes for future Mars landings. Additionally, the final prototype Peregrine motor will undergo an instrumented disposal/test burn at WFF that will include an adapter section to measure insulation erosion.

NASA plans to launch at least two CubeSats in FY 2019. The Electron Losses and Fields Investigation (ELFIN) will study dominant wave-loss mechanism of relativistic electrons. Science will continue to collaborate with the Human Exploration and Operations Mission Directorate to enable the CubeSat mission to Understand Solar Particles (CUSP) on the first flight using the Space Launch System (SLS), Exploration Mission-1 (EM-1). The EM-1 CubeSat began implementation in FY 2015, preparing for possible launch in FY 2019.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

In FY 2020, the Heliophysics Research program anticipates significant science results from the analysis of data from the Ionospheric Connections Explorer (ICON) mission, from the Global-scale Observations of the Limb and Disk (GOLD) mission of opportunity, as well as results from 18 active space missions (27 individual spacecraft) that comprise the Heliophysics System Observatory. The anticipated awards of small research investigations will also continue to contribute to heliophysics science advancements.

The current sounding rockets mission manifest features 18 missions in FY 2020 in multiple remote locations. The Program will go to the Poker Flat Research Range in the winter for four missions.

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 the WFF 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.

HELIOPHYSICS RESEARCH

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 Earth and Space 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 Heliophysics Grand Challenge Research (GCR), Low Cost Access to Space (LCAS) investigations, instrument development, and necessary research directly linked to Heliophysics science questions.

Heliophysics GCR investigations are the foundation of the Heliophysics Research and Analysis project. They lead the way to new understanding of previous investigations and drive science concepts for future missions. The Heliophysics GCR element supports large Principal Investigator (PI)-proposed team efforts that require a critical mass of expertise to make significant progress in understanding complex physical processes with broad importance.

LCAS 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 (AOs) or Missions of Opportunity (MO) without significant additional technology development.

Supporting research investigations guide the direction and content of future science missions. They employ a variety of fundamental research techniques (e.g., theory, numerical simulation, and modeling), analysis, and interpretation of space data, development of new measurement concepts, and laboratory measurements of relevant atomic, plasma and nuclear parameters. 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.

Program Schedule

NASA implements the Heliophysics Research program via a competitively selected process. NASA releases research solicitations each year through the Research Opportunities in Earth and Space 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. Therefore, NASA will allocate FY 2020 funds to ROSES-2019, ROSES-2018, and ROSES-2017 selections.

Date	Significant Event
Q1, Q2 FY 2019	ROSES-2018 selections: Oct 2018–May 2019
Q2 FY 2019	ROSES-2019 solicitation: Mar 2019
Q3/Q4 FY 2019	Review of proposals submitted to Heliophysics ROSES-2019 elements
Q1 FY 2020	ROSES-2019 selection within six to nine months of receipt of proposals
Q2 FY 2020	ROSES-2020 solicitation
Q1 FY 2021	ROSES-2020 selection within six to nine months of receipt of proposals

HELIOPHYSICS RESEARCH

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

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

HELIOPHYSICS RESEARCH

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	NASA Advisory Council Heliophysics Advisory Committee	2017	To review progress towards Heliophysics objectives in the NASA Strategic Plan	All areas were rated green as documented in the FY 2017 Agency Financial Report	Future reviews will be conducted by newly chartered Helio-physics Advisory Committee
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	To be determined	2020

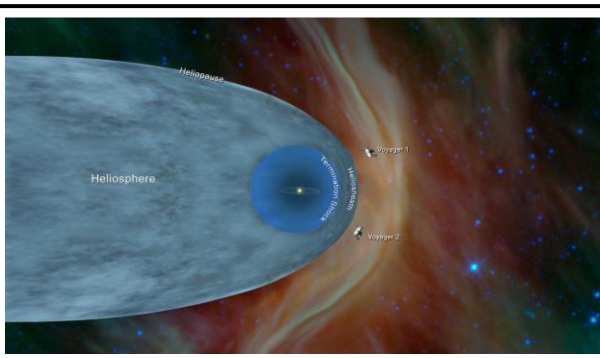
OTHER MISSIONS AND DATA ANALYSIS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Science Planning and Research Support	6.7	--	**6.7**	6.7	6.7	6.7	6.7
Directed Research & Technology	0.0	--	**0.0**	0.0	0.0	0.0	2.6
CubeSat	15.0	--	**18.5**	10.0	10.0	10.0	10.0
Solar Data Center	1.2	--	**1.2**	1.2	1.2	1.2	1.2
Data & Modeling Services	2.7	--	**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	15.9	--	**21.5**	21.5	21.5	21.5	21.5
Community Coordinated Modeling Center	2.3	--	**2.7**	2.8	2.8	2.7	2.7
Space Science Mission Ops Services	11.5	--	**11.9**	11.9	11.9	11.9	11.9
Voyager	5.6	--	**5.8**	5.5	5.5	5.0	5.0
Solar and Heliospheric Observatory (SOHO)	2.2	--	**2.3**	2.3	2.4	2.2	2.2
Wind	2.2	--	**2.2**	2.2	2.2	2.2	2.2
Geotail	0.4	--	**0.4**	0.4	0.4	0.4	0.4
Total Budget	**68.1**	**--**	**78.6**	**69.9**	**69.9**	**69.2**	**71.8**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



This illustration shows the position of NASA's Voyager 1 and Voyager 2 probes, outside of the heliosphere, a protective bubble created by the Sun that extends well past the orbit of Pluto. For the second time in history, a human-made object has reached the space between the stars. NASA's Voyager 2 probe now has exited the heliosphere – the protective bubble of particles and magnetic fields created by the Sun.

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 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 CubeSat project will complete the cross-discipline investigations already started and will initiate new Heliophysics investigations in the $1 million to $3 million range beginning in 2019. In addition, based on the capabilities demonstrated in the pathfinder stage, the CubeSat project will expand to take advantage of new science achievable via investigations in the $4 million to $7 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.

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 center 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 center 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 (JHU-APL), Orbital-Alliant Techsystems (Orbital-ATK), 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 138 astronomical units (AU), or 138 times Earth's distance from the Sun, and is traveling at a speed of 3.6 AU per year. Voyager 2 is about 114 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 2020.

Recent Achievements

NASA's Voyager 2 probe, currently on a journey toward interstellar space, has detected an increase in cosmic rays that originate outside our solar system. Launched in 1977, Voyager 2 is a little less than 11 billion miles (about 17.7 billion kilometers) from Earth, or more than 118 times the distance from Earth to the Sun.

Since 2007, the probe has been traveling through the outermost layer of the heliosphere -- the vast bubble around the Sun and the planets dominated by solar material and magnetic fields. Voyager scientists have been watching for the spacecraft to reach the outer boundary of the heliosphere, known as the heliopause. Once Voyager 2 exits the heliosphere, it will become the second human-made object, after Voyager 1, to enter interstellar space.

Since late August, the Cosmic Ray Subsystem instrument on Voyager 2 has measured about a five percent increase in the rate of cosmic rays hitting the spacecraft compared to early August. The probe's Low-Energy Charged Particle instrument has detected a similar increase in higher-energy cosmic rays.

Cosmic rays are fast-moving particles that originate outside the solar system. The heliosphere blocks some of these cosmic rays, so mission planners expect that Voyager 2 will measure an increase in the rate of cosmic rays as it approaches and crosses the boundary of the heliosphere.

In May 2012, Voyager 1 experienced an increase in the rate of cosmic rays similar to what Voyager 2 is now detecting. That was about three months before Voyager 1 crossed the heliopause and entered interstellar space.

However, Voyager team members note that the increase in cosmic rays is not a definitive sign that the probe is about to cross the heliopause. Voyager 2 is in a different location in the heliosheath -- the outer region of the heliosphere -- than Voyager 1 had been, and possible differences in these locations means Voyager 2 may experience a different exit timeline than Voyager 1.

OTHER MISSIONS AND DATA ANALYSIS

The fact that Voyager 2 may be approaching the heliopause six years after Voyager 1 is also relevant, because the heliopause moves inward and outward during the Sun's 11-year activity cycle. Solar activity refers to emissions from the Sun, including solar flares and eruptions of material called coronal mass ejections. During the 11-year solar cycle, the Sun reaches both a maximum and a minimum level of activity.

SOLAR AND HELIOSPHERIC OBSERVATORY (SOHO)

SOHO, launched in 1995, is a joint mission of the European Space Agency (ESA) and NASA, and 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. CMEs 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

The Sun produces a continual but highly variable electrically charged (ionized) outflow known as the solar wind. The speed, density, and magnetic field carried outward by that wind help determine the impact of mass ejections from the corona, the Sun's hot, tenuous outermost atmosphere, on space weather at the Earth and elsewhere in the solar system. One of the things scientists need to know in order to model solar wind-coronal mass ejection (CME) interactions is the state of the electrically neutral gas near the Sun, as an initial condition. Researchers working with data from SOHO as well as ground-based coronagraph measurements have demonstrated the feasibility of combining those data to produce maps of the outflow speed of neutral hydrogen gas in the inner corona, from near the solar surface to 4,000,000 km (2.4 million miles) above it.

Similar measurements from instruments on the upcoming European Solar Orbiter mission, combined with measurements made in the outflowing gas itself by the NASA Parker Solar Probe (PSP) mission, could provide the most complete picture to date of the solar wind through which solar storms propagate. The collective measurements from Solar Orbiter Collaboration (SOC), SOHO, and PSPwill give space weather forecasters more accurate inputs to their models that predict arrival times and severity of effects here at 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 with measurements from the PSP 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.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

New observations by the Wind spacecraft have found that the magnetic structure of collisionless shock waves is not a smooth, step-like transition, but rather riddled with large-amplitude waves as large as or larger than the shock itself.

The waves themselves act as a limiter or inhibitor for the shock. Shock waves are nonlinearly steepened waves, much like water waves on a windy day on the ocean. The difference is that shock waves have internal processes that limit the steepening so they do not break like water waves (sometimes called breakers or white caps). Shock waves balance the steepening and reach a step-like transition from the upstream (pre-shocked) region to the downstream (shocked region), in the simplest case. The balance is due to something called energy dissipation -- a process by which bulk flow kinetic energy irreversibly transforms into some other energy form, like heat. A simple way to think of this is that the upstream is cold with fast flow, while the downstream is hot with slow flow.

The waves in the study discussed here act as an energy dissipation mechanism to limit the shock steepening. The waves result from dispersive radiation, describable as follows: The shock ramp is a large gradient in the magnetic field caused by strong, time-varying currents. Time-varying currents radiate waves, much like an antenna, thus the shock ramp acts like a giant antenna. Once radiated, the waves carry energy and momentum away from the shock into the upstream, thus they can limit the nonlinear steepening. This is important because it can affect the evolution and propagation of collisionless shocks, which may affect the arrival time predictions for interplanetary shocks from the Sun to the Earth.

The waves -- called magnetosonic-whistler waves -- are larger than both the shock and the upstream averaged magnetic field. It would be like seeing two-foot water waves while standing in only 1 foot of water. That they were so large is critical because beyond the nonlinear threshold, the typical rules for the interactions with charged particles that most people investigate suddenly become blurred or broken. They also appear to propagate at oblique angles to the shock normal vector, the upstream magnetic field, and the plane formed by both of these vectors. In other words, the presence of the waves means the shocks are intrinsically three dimensional and cannot be approximated or reduced to two dimensions; an important conclusion with great implications for theory and simulation models.

GEOTAIL

Geotail, launched in1992, enables scientists to assess data on the interaction of the solar wind and magnetosphere. July 24, 2018 marked the 26th 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.

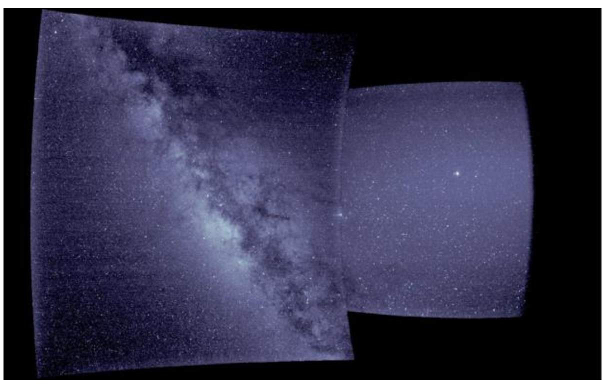
LIVING WITH A STAR

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Solar Orbiter Collaboration	59.2	62.3	**4.1**	4.2	4.2	4.3	4.3
Other Missions and Data Analysis	316.9	--	**103.5**	79.4	104.4	117.6	114.0
Total Budget	**376.1**	**--**	**107.6**	**83.6**	**108.7**	**121.9**	**118.3**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



This image shows the first-light data from Parker Solar Probe's WISPR (Wide-field Imager for Solar Probe) instrument suite. The right side of this image — from WISPR's inner telescope — has a 40-degree field of view, with its right edge 58.5 degrees from the Sun's center. The bright object slightly to the right of the image's center is Jupiter. The left side of the image is from WISPR's outer telescope, which has a 58-degree field of view and extends to about 160 degrees from the Sun. It shows the Milky Way, looking at the galactic center.

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 2020

None.

SOLAR ORBITER COLLABORATION

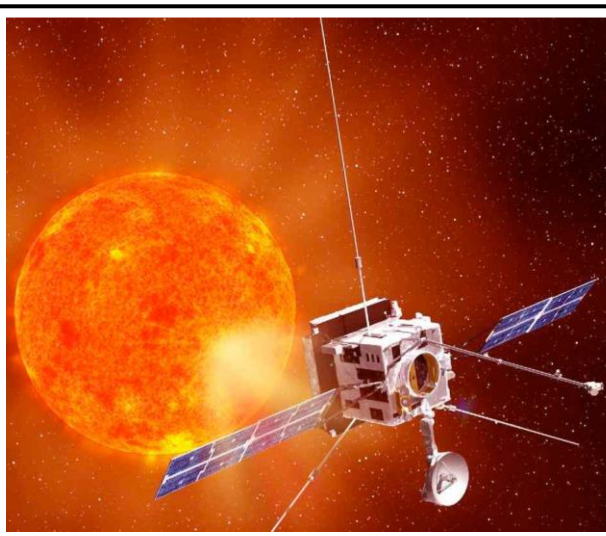
Formulation	Development	Operations

FY 2020 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	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	190.6	59.2	62.3	**4.1**	4.2	4.2	4.3	4.3	11.8	345.1
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2019 MPAR LCC Estimate	**232.1**	**59.2**	**62.3**	**4.1**	**4.2**	**4.2**	**4.3**	**4.3**	**11.8**	**386.6**
Total Budget	**232.1**	**59.2**	**62.3**	**4.1**	**4.2**	**4.2**	**4.3**	**4.3**	**11.8**	**386.6**
Change from FY 2019				**-58.2**						
Percentage change from FY 2019				**-93.4%**						

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



This ESA-led mission 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.

ESAprovides 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 2020

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 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 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 2018

The integrated spacecraft shipped to Germany for environmental testing.

WORK IN PROGRESS IN FY 2019

NASA, ESA, and the instrument teams will continue preparations for the anticipated February 2020 launch and the subsequent start of data collection. Environmental testing will continue through the summer of 2019. After environmental testing is complete, the spacecraft and instruments will ship to the Kennedy Space Center to begin pre-launch processing.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

NASA will launch Solar Orbiter Collaboration.

SOLAR ORBITER COLLABORATION

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2020 PB Request
KDP-C	Mar 2013	Mar 2013
SoloHI Instrument 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	Feb 2020
End of Prime Mission	Nov 2026	March 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 (mths)
2014	376.9	N/A	2019	310.0	-17.8	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 (*j*oint *c*onfidence *l*evel); all other CLs (*c*onfidence *l*evels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

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**	**310.0**	**-66.9**
Aircraft/Spacecraft	0.0	0.0	0.0
Payloads	23.7	71.0	47.3
Systems I&T	0.0	0.0	0.0

SOLAR ORBITER COLLABORATION

Formulation	Development	Operations

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
Launch Vehicle	250.0	173.6	-76.4
Ground Systems	N/A	N/A	N/A
Science/Technology	1.3	2.9	1.6
Other Direct Project Costs	101.9	62.4	-39.4

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
Expendable Launch Vehicle	Launch vehicle	Provider: ULA Lead Center: KSC Performing Center(s): KSC Cost Share Partner(s): N/A	N/A

SOLAR ORBITER COLLABORATION

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: ESA hardware delivery for launch is delayed, Then: NASA launch vehicle and development costs will increase.	Monitor ESA's progress during its hardware development and maintain frequent communication between NASA and ESA at all levels of management.

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	SRB	Nov 2012	PDR to assess readiness for KDP-C	Successful, project ready to proceed to development	Sept 2013
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	TBD
Performance	SRB	TBD	Operations Readiness Review/Mission Readiness Review to assess readiness for KDP-E	TBD	TBD

OTHER MISSIONS AND DATA ANALYSIS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
LWS Space Environment Testbeds	1.0	--	**0.0**	0.0	0.0	0.0	0.0
LWS Science	24.9	--	**30.3**	30.3	30.3	30.3	30.3
LWS Program Management and Future Missions	9.7	--	**16.9**	10.6	26.9	39.5	35.4
Van Allen Probes (RBSP)	13.0	--	**7.7**	0.0	0.0	0.0	0.0
Solar Dynamics Observatory (SDO)	12.0	--	**12.0**	12.0	12.0	12.0	12.0
Parker Solar Probe	241.6	--	**20.6**	21.5	20.6	21.2	21.7
Space Weather Science Applications	14.7	--	**15.9**	5.0	14.6	14.6	14.6
Total Budget	**316.9**	**--**	**103.5**	**79.4**	**104.4**	**117.6**	**114.0**

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A United Launch Alliance Delta IV Heavy rocket launches NASA's Parker Solar Probe on a mission to touch the Sun, on Sunday, Aug. 12, 2018 from Launch Complex 37 at Cape Canaveral Air Force Station, Florida. The Parker Solar Probe is humanity's first-ever mission into a part of the Sun's atmosphere called the corona. Once there, it will directly explore solar processes that are key to understanding and forecasting space weather events that can impact life on Earth.

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/.

OTHER MISSIONS AND DATA ANALYSIS

Mission Planning and Other Projects

SPACE WEATHER SCIENCE AND APPLICATIONS

The Space Weather Science and Applications (SWxSA) project works to effectively support the 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 recommendations of the 2013 Decadal Survey for Solar and Space Physics. Under SWxSA, 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 SWxSA 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 partner, investments in high end computing and the community coordinated modeling center.

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. 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. 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. The SET mission will reach medium-Earth orbit as a rideshare payload on the Air Force Research Laboratory’s (AFRL) Demonstration and Space Experiments (DSX) spacecraft, with the launch expected in late 2019.

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. To ensure this, the targeted research element solicits large-scale problems that cross discipline and technique boundaries.

OTHER MISSIONS AND DATA ANALYSIS

- 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 LWS Focused Science Topic studies produced significant progress by examining several areas of research in Heliophysics Science. One area of research, "Advances Toward a Near Real Time Description of the Solar Atmosphere and Inner Heliosphere," considered the Sun's atmosphere (photosphere, chromosphere, transition region, and corona) and solar wind, both of which play critical roles in space weather. Understanding the global state of the solar atmosphere and inner heliosphere to one astronomical unit (AU) is important to nearly all area of Heliophysics. Current models of the solar atmosphere and solar wind rely primarily on maps of the photospheric magnetic field, available from a number of ground-based and space-based observatories, to generate steady state solutions at the sun. This new research focuses on the innovative creation and use of heliophysics data products to address the time-dependent state of the inner heliosphere from the solar surface to one AU. Methods such as "data assimilation," and "ensemble modeling," used in the meteorological community, can be highly beneficial but must be adapted using the novel techniques being developed as part of this study. Planning for data from future missions is a long-term benefit of this ongoing study along with the use of existing data sets.

Another recent study is characterizing the Earth’s Radiation Environment between the troposphere and outer magnetosphere. This region can change rapidly due to varying galactic cosmic ray and solar energetic particles. Material and electro-magnetic fields streaming from the sun in the form of solar wind pressure effects due to high-speed streams (HSS), coronal mass ejections (CME), and periods of southward interplanetary magnetic field (IMF) affects this environment. These phenomena, HSS, CME, and southward IMF, cause changes to the radiation belt environment on time scales that range from tens of minutes to several days with the probability of occurrence of these events being dependent on the solar cycle. This study of the impact of these phenomena on the Earth’s Magnetosphere–Ionosphere–Thermosphere (M-I-T) system is improving our understanding of the events that create the "weather" of the radiation environment.

Global Electrodynamics of Ionospheric Disturbances is another study under LWS. Scientists observe the impact of electrical current systems in the magnetosphere in the high and middle latitude ionosphere by looking at the coupling of the magnetosphere with the ionosphere-thermosphere. This is advancing our understanding of the coupled ionosphere and magnetosphere system and will provide models of the coupled interaction of this region of the earth’s upper atmosphere. Improved specification of the ionospheric conductance will provide a more reliable description of the ionosphere and thermosphere environment, a more accurate representation of the interaction of that environment with the magnetosphere, and extend the effects of that interaction to include the impacts on ground and space based communication systems as well as ground induced currents.

OTHER MISSIONS AND DATA ANALYSIS

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 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 taking several steps in support of this upcoming opportunity. During FY 2017, NASA initiated a call for membership in the GDC Science and Technology Definition team (STDT). In addition, NASA issued a Request for Information to solicit input from the Heliophysics community for ideas on mission and technology concepts to address the GDC objectives and science goals as well as enhance those concepts outlined for GDC in the decadal survey. NASA convened the STDT in early 2018 with a completion date and final report due in mid-2019.

For more information, go to: https://science.nasa.gov/about-us/science-strategy/decadal-surveys.

Operating Missions

PARKER SOLAR PROBE

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.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

On August 12, 2018, Parker Solar Probe launched on a Delta IV Heavy rocket from Cape Canaveral, Florida, on target to begin its historic journey to the Sun. Since launch, the Parker Solar Probe team has successfully completed its commissioning of the spacecraft and all instruments. On October 4, 2018, the spacecraft completed its first of seven planned Venus gravity assists, which help the probe to move its approach to the Sun closer into the unexplored corona. On November 6, 2018, Parker Solar Probe successfully passed its first of 24 record-setting approaches to the Sun, at 16 percent of the distance of the Earth from the Sun, while taking a first sample of groundbreaking measurements of the near-Sun environment. Twenty three additional solar approaches are planned, with the last three bringing the probe to as close as ~4 percent of the Earth's distance from the Sun.

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

The precipitation of kilovolt electrons from the magnetosphere produces pulsating auroral light that release their energy as visible light as they enter the atmosphere. Earlier studies suggested that one of the main mechanisms of the electron precipitation that causes pulsating aurora is their pitch-angle scattering by lower band chorus waves at the magnetic equator. Recently, Van Allen Probes observations showed that time domain structures (TDS) to scatter equatorial electrons efficiently. To assess the relative importance of whistler waves and TDS for production of pulsating auroras, researchers used wave and particle measurements from Probe A during a pulsating aurora event, when the spacecraft was on a magnetic field line mapped into the field-of-view of the THEMIS all-sky camera. The analysis showed that precipitation of ~1 keV electrons during auroral emission was associated with TDS rather than lower band chorus, which led to the conclusion that TDS could be the dominant mechanism of pulsating aurora.

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.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

The strongest sunquake ever measured occurred on September 6, 2017. The explosive force of the most energetic solar flare of the solar cycle, an X9.3 flare in NOAA Active Region 12673 triggered powerful seismic waves. The pressure waves traveled deep inside the Sun, and tens of minutes later they returned to the surface, emerging in a pattern that resembled huge ripples expanding across the surface of an ocean. Measuring the vertical motions of surface material as the disturbance sweeps across large areas allows for the detection of sunquakes. This time some of the ripples passed through two nearby sunspots, giving helioseismologists an unprecedented opportunity to study the response of strong magnetic field regions to seismic waves. Indeed, for the first time the Helioseismic and Magnetic Imager on the Solar Dynamics Observatory (SDO/HMI) was able to detect the effects of sunquakes in the magnetic field. Scientists found nearly simultaneous changes in both magnetic field and Doppler velocity.

What caused the magnetic field variation, and what can we learn about the solar atmosphere from this rare event? Scientists analyzed the phase relations and the frequencies of the oscillatory power and found that the magnetic-wave power peaks near 3.5 and 6.0 mHz, indicating that the magnetic variations were magneto-acoustic waves excited by the sunquake. The relative phase reveals that opacity changes caused by the strong seismic waves probably drove the magnetic field variations. Sunquakes observed in magnetic field data are unprecedented. This is the only event observed so far that links sunquake seismic pressure waves and magnetic-acoustic waves. The analysis of multiple physical quantities observed in this event can reveal detailed physical processes in magnetohydrodynamic waves.

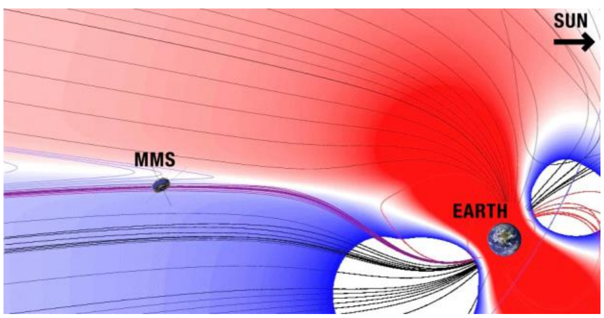
SOLAR TERRESTRIAL PROBES

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Other Missions and Data Analysis	45.2	--	**177.9**	220.4	210.9	192.7	152.0
Total Budget	**45.2**	**--**	**177.9**	**220.4**	**210.9**	**192.7**	**152.0**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



Recently, in the second phase of its mission, MMS saw reconnection in Earth's magnetotail — the part of Earth's magnetic environment trailing behind the planet, away from the Sun — with enough resolution to reveal its true nature more clearly. Magnetic reconnection occurs around Earth every day due to magnetic field lines twisting and reconnecting. It happens in different ways in different places, with different effects. In the magnetotail, for example, the process can create aurora near Earth.

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 (fluid 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 http://science.nasa.gov/about-us/smd-programs/solar-terrestrial-probes/.

EXPLANATION OF MAJOR CHANGES IN FY 2020

The increase in FY 2020 reflects the beginning of implementation for the Interstellar Mapping and Acceleration Probe (IMAP) mission. IMAP will help us understand the boundary in which the solar wind and the interstellar medium interact, which is the main barrier that shields the solar system against galactic cosmic rays. It will furthermore directly advance understanding of particle acceleration processes, knowledge that may become essential in reducing radiation exposure of astronauts on exploration missions.

SOLAR TERRESTRIAL PROBES

ACHIEVEMENTS IN FY 2018

NASA selected IMAP from the 2017 STP-5 Announcement of Opportunity. NASA released the Science Mission of Opportunity and Technology Demonstration Mission of Opportunity announcements. NASA and NOAA explored a potential partnership to use the same launch vehicle for IMAP and a NOAA space weather monitoring payload (Space Weather Follow-On). The partnership would provide NOAA access to the L1 Lagrange point for future space weather monitoring.

WORK IN PROGRESS IN FY 2019

Operations of the MMS, STEREO, Hinode, and TIMED missions continue. NASA plans to select and enter into Phase B for the Science Mission of Opportunity. NASA also plans to select no more than four proposals to enter into Phase A studies from the Technology Demonstration Mission of Opportunity.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

NASA plans to enter into Phase B, Preliminary Design and Technology Completion, of the IMAP mission.

Program Schedule

Date	Significant Event
FY 2017	AO for IMAP Mission
FY 2018	IMAP Phase A selection and MO release
FY 2019	MO selection
FY 2020	Technology Demonstration MO selection. IMAP Phase B

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 HEOMD, except when an international partner provides them under an approved agreement.

SOLAR TERRESTRIAL PROBES

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Program Independent Review	SRB	Nov 2014	Assess performance of program	Successful	Sept 2018
Program Independent Review	SRB	Apr 2019	Assess performance of program		Nov 2022
Program Independent Review	SRB	Nov 2022	Assess performance of program		

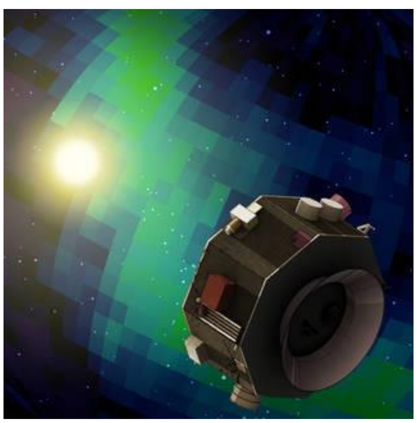
OTHER MISSIONS AND DATA ANALYSIS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
STP Program Management and Future Missions	4.5	--	**14.5**	22.9	35.2	51.1	50.3
Magnetospheric Multiscale (MMS)	20.6	--	**20.7**	18.7	16.8	16.8	16.8
Solar Terrestrial Relations Observatory (STEREO)	8.2	--	**7.8**	7.8	7.8	7.8	7.8
Hinode (Solar B)	6.8	--	**7.0**	7.0	7.0	6.5	6.5
TIMED	2.6	--	**2.7**	2.6	2.6	2.6	2.6
Interstellar Mapping and Acceleration Probe	2.5	--	**125.2**	161.3	141.5	108.0	68.0
Total Budget	**45.2**	**--**	**177.9**	**220.4**	**210.9**	**192.7**	**152.0**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



The Interstellar Mapping and Acceleration Probe observing signals from the interaction of the solar wind with the winds of other stars.

The Solar Terrestial 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

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.

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.

OTHER MISSIONS AND DATA ANALYSIS

The spacecraft will operate about one million miles (1.5 million kilometers) away from Earth towards the Sun at the first Lagrange point (L1). This 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.

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 will investigate 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.

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 six to 250 miles during science operations in the area of interest.

For more information, go to http://science.nasa.gov/missions/mms/.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

MMS ultra-high-resolution observations have revealed a new type of magnetic reconnection that occurs in turbulent plasmas. This finding has far-reaching implications for the understanding of how turbulence dissipates its energy throughout the cosmos.

Earth's magnetic field provides a barrier that protects Earth from the solar wind—a stream of charged particles launched from the Sun's outer layers. The protective properties of the magnetic field can fail due to a process known as magnetic reconnection, which occurs when two opposing magnetic field lines break and reconnect with each other, dissipating massive amounts of energy and accelerating particles that threaten air traffic and satellite communication systems.

Just outside of Earth's magnetic field, the solar wind's onslaught of electrons and ionized gases creates a turbulent maelstrom of magnetic energy known as the magnetosheath. While physicists understand magnetic reconnection in regions closer to Earth, they have sought to determine whether reconnection also happens in this turbulent zone.

Using electron measurements with resolution 400 times better than before, the MMS science team found the first evidence of magnetic reconnection occurring at very small spatial scales in the turbulent magnetosheath. However, unlike standard reconnection that occurs with the Earth's magnetic field, which involves electrons as well as ions, turbulent reconnection in the magnetosheath involves electrons alone. Because electrons are much lighter than ions, electron-only reconnection dissipates magnetic energy at a much faster rate than in standard reconnection. Turbulence occurs everywhere in space: on the Sun, in the solar wind, interstellar medium, and in accretion disks around stars and more. This discovery promises to advance scientists' understanding of how turbulent magnetic fields dissipate energy throughout the universe. For example, it could reveal the role that magnetic reconnection plays in heating the inexplicably hot solar corona—the Sun's outer atmosphere—and accelerating the supersonic solar wind.

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 consists of two spacecrafts, one Ahead (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 finally emerged from behind the Sun. NASA re-established contact with STEREO-B for a short period in 2016. NASA attempted to establish control of the spacecraft with limited success. As of December 2017, the project team began making monthly attempts to re-establish contact with the spacecraft. STEREO-A continues to operate nominally and is still providing significant science data.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

Scientists have developed new models to see how shocks associated with CMEs propagate from the Sun. This effort was made possible only by combining data from three NASA satellites to produce a much more robust mapping of a CME than any single spacecraft could do alone.

Much the way ships form bow waves as they move through water, CMEs set off interplanetary shocks when they erupt from the Sun at extreme speeds, propelling a wave of high-energy particles. These particles can spark space weather events around Earth, endangering spacecraft and astronauts.

Understanding a shock's structure, particularly how it develops and accelerates, is key to predicting how it might disrupt near-Earth space. Without a vast array of sensors scattered through space, these things are impossible to measure directly. Instead, scientists rely upon models that use satellite observations of the CME to simulate the ensuing shock's behavior.

The scientists fit the CME data to their models:one called the "croissant" model for the shape of nascent shocks, and the other the "ellipsoid" model for the shape of expanding shocks,to uncover the 3-D structure and trajectory of each CME and shock.

Each spacecraft's observations alone were not sufficient to model the shocks. However, with three sets of eyes on the eruption, each of them spaced nearly evenly around the Sun, the scientists could use their models to recreate a 3-D view. Their work confirmed long-held theoretical predictions of a strong shock near the CME nose and a weaker shock at the sides.

In time, shocks travel away from the Sun, and thanks to the 3-D information, the scientists could reconstruct their journey through space. The modeling helps scientists deduce important pieces of information for space weather forecasting. In this case, for the first time, the density of the plasma around the shock, in addition to the speed and strength of the energized particles. All of these factors are key to assessing the danger CMEs present to astronauts and spacecraft.

HINODE

Hinode, launched in 2006, is a joint JAXA and NASA mission, operating as a follow-on to the highly successful Japan, United States, and United Kingdom Yohkoh (Solar-A) collaboration. 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. 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.

Recent Achievements

During a set of Focused Mode observations, Hinode tracked an active region crossing the solar disk. Hinode's Solar Optical Telescope Spectro-Polarimeter (SOT-SP) measured magnetic field strengths of more than 6000 Gauss, which is ~10,000 times stronger than the Earth's and is the strongest field ever directly observed on the Sun.

These detections were made outside of the sunspot umbra (the dark area located within a sunspot), making the finding unusual. Studies of the region indicate that the strong fields likely arise because of compression between interacting sunspots forcing magnetized material to flow through highly constricted channels, similar to the process of subduction between Earth's tectonic plates. High-resolution measurements of the magnetic field on the solar surface enable our understanding of the formation mechanism for super strong fields.

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-lower thermosphere-ionosphere. This region of interest, 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.

Recent Achievements

Atomic oxygen plays a crucial role in the physics, chemistry, and energy budget of the mesosphere and lower thermosphere (MLT). It is one of the most abundant gases in this region of the atmosphere and contributes to both chemical heating and radiative cooling processes. Scientists traditionally infer densities of atomic oxygen from airglow observations of trace gases measured by instruments on board various satellites. These densities derived across all instruments agree generally except for SABER/TIMED, which is, on average, 30 percent higher.

Recently, scientists have derived new atomic oxygen densities from SABER/TIMED observations using a new methodology and hydroxyl model which bring densities into agreement with studies using other MLT instruments. Using a first-principles hydroxyl model, atomic oxygen is derived from two (instead of the traditional one) SABER hydroxyl emission bands. This novel methodology does not rely on the assumption of ozone equilibrium, which previous studies assumed and scientists no longer believe to be valid during the nighttime. The new, lower atomic oxygen requires the re-estimation of both chemical heating and radiative cooling of this region. Massive atomic oxygen retrievals, which follow this study, will allow the investigation of the spatial and temporal variabilities of atomic oxygen as well as the energy budget in the MLT at different scales.

These results provide a critical step forward in the understanding of the MLT physics and chemistry and solve a historical discrepancy regarding the amount of atomic oxygen in the nighttime MLT. The new atomic oxygen will bring the global annual chemical heating, which previously was extremely high, into a better agreement with the global radiative cooling. Massive atomic oxygen retrievals will enable the study of long-term trends, benefitting, compared to other observations, from a broad coverage and unprecedented duration (more than 16 years) of SABER observations.

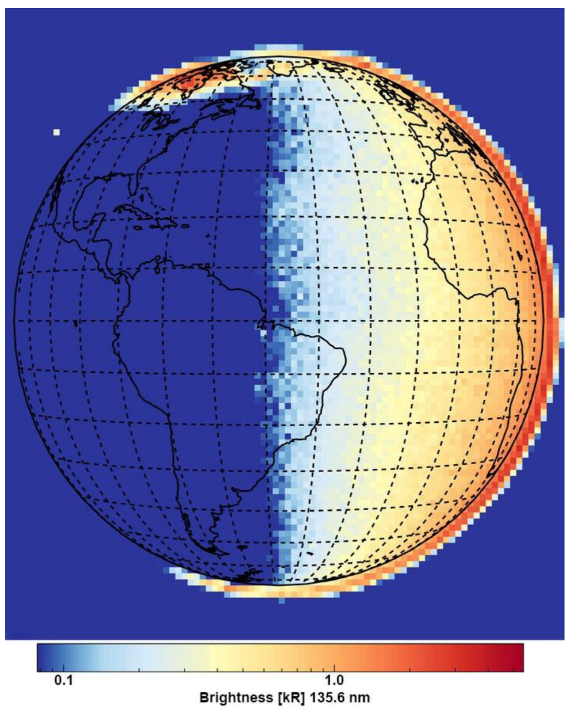
HELIOPHYSICS EXPLORER PROGRAM

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
ICON	19.0	4.7	**1.4**	0.0	0.0	0.0	0.0
Other Missions and Data Analysis	41.9	--	**180.6**	111.1	235.0	158.1	217.5
Total Budget	**60.9**	**--**	**182.0**	**111.1**	**235.0**	**158.1**	**217.5**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



Shown here is the "first light" image of ultraviolet atomic oxygen emission (135.6 nm wavelength) from the Earth's upper atmosphere captured by NASA's Global-scale Observations of the Limb and Disk (GOLD) instrument. GOLD captured it at approximately 6 a.m. local time, near sunrise in eastern South America. The colors correspond to emission brightness, with the strongest shown in red and the weakest in blue. This emission is produced at altitudes around 160 km (note how it extends above the Earth's surface on the horizon), when the Earth's upper atmosphere absorbs high energy photons and particles. The aurora, at the top and bottom of the image, and daytime airglow, on the right hand side, are also visible.

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 several 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.

The 2011 NASA Announcements of Opportunity (AO) introduced a new class of flight opportunity, the Explorers (EX) missions, in response to the currently available expendable launch vehicles. EX missions fall between the SMEX and MIDEX class missions. Awarded missions will utilize one of the several, lower-cost expendable launch vehicles available through NASA's Launch Services

HELIOPHYSICS EXPLORER PROGRAM

Program.

Explorer Missions of Opportunity (MO) are smaller investigations, typically an instrument, characterized as being part of a host space mission, sub-orbital flight, small complete missions, and new science investigations using existing spacecraft or ISS-attached payloads.

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 on Explorer missions, go to https://science.nasa.gov/about-us/smd-programs/explorers/.

EXPLANATION OF MAJOR CHANGES IN FY 2020

There are no major programmatic changes. However, funds for Heliophysics Explorer Future Missions have increased in anticipation of the upcoming SMEX and MO selections and to account for the MIDEX AO delay from FY 2018 to FY 2019.

ACHIEVEMENTS IN FY 2018

Missions selected for SMEX and MO Phase A concept studies (see https://www.nasa.gov/press-release/nasa-selects-proposals-to-study-sun-space-environment) delivered their reports to NASA for evaluation in early summer 2018. The GOLD mission launched on January 25, 2018, as a commercially hosted payload on the SES-14 satellite.

WORK IN PROGRESS IN FY 2019

NASA will make new mission selections from competitive concept studies (Phase A) for the SMEX and MO AO. NASA plans to release an AO for MIDEX.NASA will make initial Phase A selections for the Explorers Science MO. NASA will launch the ICON mission.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

NASA will make initial Phase A selections for MIDEX. Explorer's Science MO's selected for Phase A concept studies will deliver their reports to NASA for evaluation, and NASA will make new Explorers Science MO selections.

HELIOPHYSICS EXPLORER PROGRAM

Program Schedule

Date	Significant Event
Early Summer 2018	Down select at least one SMEX and one MO mission for implementation
Early Summer 2018	AO announcement for Explorers Science MO opportunity to propose
FY 2019	AO announcement for MIDEX opportunity to propose
FY 2019	Explorers Science MO Phase-A selections
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

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.

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 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	Nov 2014	Assess performance of program	Successful	Dec 2019

IONOSPHERIC CONNECTION EXPLORER

Formulation	Development	Operations

FY 2020 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	BTC	Total
Formulation	38.8	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	38.8
Development/Implementation	184.3	13.9	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	198.2
Operations/Close-out	4.7	5.0	4.7	**1.4**	0.0	0.0	0.0	0.0	0.0	15.9
2019 MPAR LCC Estimate	**227.8**	**19.0**	**4.7**	**1.4**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**252.9**
Total Budget	**227.8**	**19.0**	**4.7**	**1.4**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**252.9**
Change from FY 2019				**-3.3**						
Percentage change from FY 2019				**-70.2%**						

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

Recent discoveries show that unexplained variations in Earth's space environment connect to conditions in the atmosphere. NASA's Ionospheric Connection Explorer, or ICON, is the first mission to focus on this interplay between terrestrial weather and space weather. ICON explores a region of the upper atmosphere called the ionosphere, a little understood area close to home, but historically hard to observe. The mission focuses on one of the most eye-catching phenomena there, colorful bands called airglow, shown over the horizon in this artist's rendition of ICON in space.

PROJECT PURPOSE

Ionospheric Connection Explorer (ICON) 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.

EXPLANATION OF MAJOR CHANGES IN FY 2020

ICON will launch on a Northrop Grumman Pegasus XL. This small expendable rocket attaches beneath an L-1011 aircraft that carries it to 39,000 feet and releases it for launch. During pre-launch flights, sensor readings on the rocket's control system raised concerns. As a result, the launch provider delayed the launch, originally scheduled in October 2017, to a later

IONOSPHERIC CONNECTION EXPLORER

Formulation	Development	Operations

date in FY 2019. The launch delay will cause the mission on-orbit operations to start later than planned.

IONOSPHERIC CONNECTION EXPLORER

Formulation	Development	Operations

PROJECT PARAMETERS

ICON will simultaneously measure altitude profiles of the thermosphere and ionosphere's neutral winds, composition, density, temperature, and ion density. At the same time, it will make in-situ plasma measurements. Three institutions with a successful record of accomplishment of previous space missions will build the four high-heritage scientific instruments of ICON. The payload will fly on an Orbital ATK, LEOStar-2 spacecraft bus with heritage from Solar Radiation and Climate Experiment (SORCE), AIM, Orbiting Carbon Observatory (OCO), Glory, and Nuclear Spectroscopic Telescope Array (NuSTAR). ICON will provide the data to understand how neutral winds control ionospheric variability, which is a goal in the 2010 Science Plan for NASA's SMD.

ACHIEVEMENTS IN FY 2018

The Project completed all observatory testing and prepared the spacecraft for shipping. The Project shipped the spacecraft and integrated with the launch vehicle at Vandenburg Air Force Base (VAFB) after the resolution of launch vehicle Bolt Cutter Assembly issues. The mission successfully transitioned launch site, from Kwajalein Atoll in the Marshall Island to Cape Canaveral in Florida for range availability. Northrop Grumman acquired Orbital-ATK; therefore, all references to Orbital-ATK will change to Northrop Grumman.

WORK IN PROGRESS IN FY 2019

During the launch attempt in November 2018 from Cape Canaveral, Florida, the Pegasus XL Rocket experienced an anomalous telemetry sensor reading. The launch vehicle team is investigating the issue and will reschedule a launch readiness date when the investigation is complete.

NASA plans to launch ICON in FY 2019 to begin a two-year prime mission.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

In FY 2020, ICON will complete its first full year of operations.

IONOSPHERIC CONNECTION EXPLORER

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2020 PB Request
KDP-C	Oct 2014	Oct 2014
CDR	Apr 2015	Apr 2015
SIR	Jun 2016	Aug 2016
Launch	Oct 2017	2019
Start of Phase E	Nov 2017	2019
End of Prime Mission	Dec 2019	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 (mths)
2015	196.0	70	2019	196.0	0.0	LRD	Oct 2017	2019	TBD

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 (*j*oint *c*onfidence *l*evel); all other CLs (*c*onfidence *l*evels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

IONOSPHERIC CONNECTION EXPLORER

Formulation	Development	Operations

Development Cost Details

NASA confirmed ICON to proceed into implementation in October 2014.

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**196.0**	**198.2**	**2.2**
Aircraft/Spacecraft	29.8	50.3	20.5
Payloads	35.8	56.0	20.2
Systems I&T	9.4	3.2	-6.2
Launch Vehicle	54.3	56.3	2.0
Ground Systems	2.9	5.5	2.6
Science/Technology	3.0	3.9	0.9
Other Direct Project Costs	60.8	23.0	-37.8

IONOSPHERIC CONNECTION EXPLORER

Formulation	Development	Operations

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Expendable Launch Vehicle	Deliver the spacecraft to operational orbit	Provider: Northrop Grumman Lead Center: KSC Performing Center(s): KSC Cost Share Partner(s): n/a	N/A
Spacecraft	Transport instruments to science destination	Provider: Northrop Grumman Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): n/a	N/A
Michelson Interferometer for Global High-resolution Thermospheric Imaging (MIGH TI)	High resolution imager instrument	Provider: Naval Research Laboratory Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s):	N/A
EUV	Extreme UV instrument	Provider: University of California, Berkeley Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s):	N/A
FUV	Far UV instrument	Provider: University of California, Berkeley Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): Belgian Centre Spatial de Liège (CSL)	N/A
IVM	Ion velocity meter instrument	Provider: University of Texas, Dallas Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s):	N/A

IONOSPHERIC CONNECTION EXPLORER

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: The technical concerns with the Pegasus XL rocket cannot be resolved, Then: NASA may need to further delay launch.	NASA HQ will continue to monitor the trouble-shooting and evaluate schedules in planning for a new launch date. LSP will look at other launch opportunities for ICON in future.

Acquisition Strategy

All acquisitions are in place. NASA selected ICON through the AO two-step process, and awarded the science investigation to the University of California Berkeley PI in April 2013.

MAJOR CONTRACTS/AWARDS

NASA awarded the mission Phase B through F (formulation through operations and closeout) procurement to the University of California at Berkeley for the PI-controlled mission. All major contracts are in place.

Element	Vendor	Location (of work performance)
FUV and EUV instruments	University of California, Berkeley	Berkeley, CA
MIGHTI instrument	Naval Research Laboratory	Washington, DC
IVM instrument	University of Texas, Dallas	Dallas, TX
Spacecraft, I&T	Northrop Grumman	Dulles, VA
Payload integration	Space Dynamics Laboratory	Logan, UT
Launch Vehicle	KSC	KSC, FL

INDEPENDENT REVIEWS

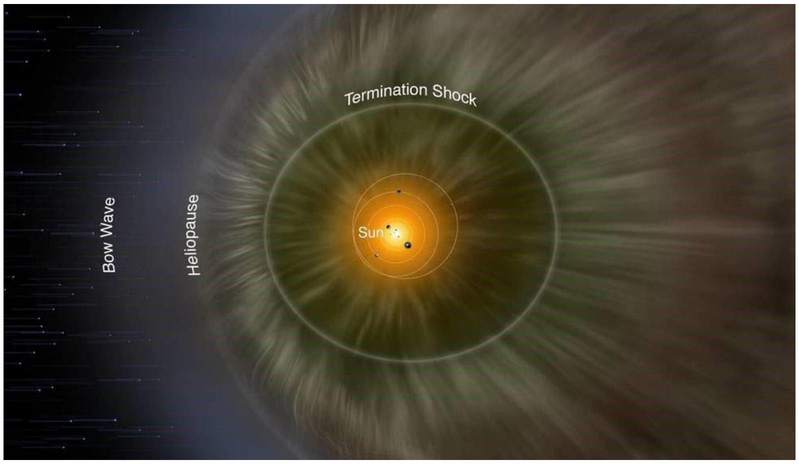
Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Apr 2017	ORR for KDP-E	Successful	Jul 2017
Performance	SRB	Jul 2017	Observatory Pre-Ship Review	Successful	May 2018
Performance	SRB	May 2018	KDP-E	Successful	TBD
Performance	SRB	TBD	LRR	TBD	

OTHER MISSIONS AND DATA ANALYSIS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Global-scale Observations of the Limb and Disk (GOLD)	5.1	--	**5.3**	0.4	0.0	0.0	0.0
Heliophysics Explorer Future Missions	1.0	--	**133.4**	83.9	208.6	131.8	190.3
Heliophysics Explorer Program Management	9.6	--	**20.2**	5.8	5.8	5.8	6.7
Interface Region Imaging Spectrograph (IRIS)	7.6	--	**6.5**	6.5	6.5	6.5	6.5
Interstellar Boundary Explorer (IBEX)	3.4	--	**3.4**	3.4	3.4	3.4	3.4
TWINS	0.6	--	**0.3**	0.1	0.0	0.0	0.0
CINDI	0.2	--	**0.0**	0.0	0.0	0.0	0.0
Aeronomy of Ice in Mesophere (AIM)	3.5	--	**3.0**	3.0	3.0	3.0	3.0
THEMIS	6.1	--	**5.0**	4.8	4.8	4.6	4.6
Advanced Composition Explorer (ACE)	3.0	--	**3.0**	3.0	3.0	3.0	3.0
RHESSI	1.9	--	**0.5**	0.2	0.0	0.0	0.0
Total Budget	**41.9**	--	**180.6**	**111.1**	**235.0**	**158.1**	**217.5**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.



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, the IBEX spacecraft detected the first sign of the aftermath. Solar wind particles from the 2014 pressure increase had reached the edge of the heliosphere, neutralized themselves, and shot all the way back to Earth. In two recent articles, scientists used IBEX data along with sophisticated numerical models to understand what these rebounding atoms can tell us about the evolving shape and structure of our heliosphere, the giant bubble carved out by the solar wind.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

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: http://science.nasa.gov/about-us/smd-programs/explorers/.

OTHER MISSIONS AND DATA ANALYSIS

Mission Planning and Other Projects

GLOBAL-SCALE OBSERVATIONS OF THE LIMB AND DISK (GOLD)

The GOLD investigation will perform unprecedented imaging of the Earth's thermosphere and ionosphere. 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.

Recent Achievements

GOLD launched on January 28, 2018 and is performing well.

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.

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

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 is enabling scientists to understand what energizes the solar atmosphere, providing significant new information to increase our understanding of energy transport into the corona and solar wind, which provides a model for all stellar atmospheres. The mission will extend the scientific output of existing heliophysics spacecraft that follow the effects of energy release processes from the Sun to Earth. 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.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

An international team of researchers have now utilized the very high resolution of NASA's IRIS and a new instrument at the Swedish Solar Telescope in the Canary Islands, Spain to reveal the presence of small-scale plasmoids during a reconnection event in the low solar atmosphere. Scientists believe that such plasmoids play a key role in speeding up the energy release during reconnection but conclusive evidence for their presence in reconnection events in the low solar atmosphere had been elusive. Previous work using IRIS observations and numerical models of reconnection had suggested that during reconnection the so-called tearing mode instability would form plasmoids that leave a distinct fingerprint in spectra observed with IRIS. IRIS is a spectrograph that splits up ultraviolet light into different "colors" allowing scientists to detect remotely whether the emitting gas is moving away or towards us. Numerical models predicted that the wide range of high velocities in the plasmoids should lead to oddly shaped spectral line profiles that are often triangular. While IRIS sees many such profiles, it remained unclear from previous work whether plasmoids were the actual culprit.

Coordinated observations of a so-called UV burst with IRIS and the powerful new CHROMIS instrument at the Swedish 1m Solar Telescope in the Canary Islands (Spain) have now revealed that plasmoids are indeed the cause of the oddly shaped profiles. UV bursts are explosive phenomena driven by magnetic reconnection low in the solar atmosphere. The very high spatial resolution of CHROMIS shows tiny (~100 km on the Sun) fast moving blobs escaping from the reconnection site where IRIS detects triangular shaped spectral line profiles. The combined observations show a striking similarity with numerical simulations of magnetic reconnection. This study provides exciting new insight into how reconnection can rapidly release energy in the solar atmosphere, elucidating the processes thought to heat the solar atmosphere and drive solar activity. It also provides a new diagnostic tool to detect the detailed workings of reconnection using spectroscopic data obtained with IRIS and other spectrographs.

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. 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

Our heliosphere—the bubble in the local interstellar medium produced by the Sun's outflowing solar wind—has finally responded to a large increase in solar wind output in the second half of 2014. NASA's Interstellar Boundary Explorer (IBEX) mission remotely monitors the outer heliosphere and its boundaries by observing energetic neutral atoms returned from the outer solar system beyond the reach of its most distant known planets. IBEX observed a large increase in energetic neutral atoms starting in late 2016. Over the previous decade, IBEX saw a general reduction of energetic neutral atoms, which showed that the outer boundaries of our solar system were deflating, and falling inward toward the Sun. The new observations show that the large increase in the solar wind output has caused the outward expansion of these outer solar system boundaries, and caused an increase in the energetic neutral atoms that IBEX measures. The increase occurs slightly south of the interstellar upwind direction, as previously predicted. The timing between the IBEX observations, a large transient pressure enhancement seen by Voyager 2, and the models of these boundaries indicates that the increased solar wind output caused changes that moved out beyond the innermost boundary, the termination shock, and then reflected off the surface separating solar wind from the local medium of our galaxy.

Researchers compared IBEX observations to Voyager 1's direct observations of the magnetic field in the local medium of our galaxy. They observed structured changes in the magnetic field that are driven by pressure changes across the boundary separating the solar wind from the local medium of our galaxy. The changes in the magnetic field observed by Voyager 1 occurred in 2015 and 2016, when the most powerful coronal mass ejections released from the Sun over the last 11-year solar cycle arrived at the outer boundaries surrounding our solar system. These events propagated over more than two years through the solar system, ultimately pounding through the boundaries surrounding our solar system and causing changes in the magnetic fields detected by Voyager 1 in the local medium of our galaxy. The results show that in coming years, we should see significant changes in the radiation environment of our solar system in response to these changes in the boundaries that surround our solar system.

TWO WIDE-ANGLE IMAGING NEUTRAL ATOM SPECTROMETERS (TWINS)

TWINS provides stereo imaging of Earth’s magnetosphere, the region surrounding the planet controlled by its magnetic field that contains the Van Allen radiation belts and other energetic charged particles. TWINS gives a three-dimensional global visualization of this region, which has 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 has been operational since 2008 and currently in extended operations.

Recent Achievements

Combined observations from the Two Wide-angle Imaging Neutral-atom Spectrometers (TWINS) and Van Allen Probes missions--plus global modeling--to understand system-level dynamic linkages between the magnetosphere and ionosphere during the 14 November 2012 storm. Van Allen Probes A measured several steep decreases ("dropouts") in particle flux over a broad range of energy. In tandem with two of these dropouts, TWINS observed strong modulation of particle precipitation, as measured by the low-altitude energetic neutral atom signal. To understand this connection, researchers compared field-aligned currents from AMPERE with those derived from the coupled BATSRUS-CRCM model. The new result confirms that open-closed boundary motion in the tail caused the dropouts. Moreover, the TWINS-BATSRUS-CRCM-AMPERE comparison established that the dropouts were a locally observed manifestation of a system-level effect coupling plasmas in the magnetotail and the ionosphere. This result is important because it reveals how different parts of geospace are part of one coupled, global system.

OTHER MISSIONS AND DATA ANALYSIS

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

The extended mission of the Aeronomy of Ice in the Mesosphere (AIM) satellite has enabled the production of a new data set from the AIM Cloud Imaging and Particle Size (CIPS) instrument. The new measurements, referred to as the Rayleigh Albedo Anomaly (RAA), show gravity waves (GWs) at an altitude of 50–55 km. The data have an unprecedented horizontal resolution of ~7.5×7.5 km, and are the first near-global measurements of gravity waves near the stratopause. Gravity waves observed by CIPS occur with numerous sources, including orographic uplift over the Andes Mountains, island topography, convection, the polar night jet, and the tropospheric jet stream. Gravity wave signatures in the CIPS data agree well with near-coincident but lower altitude measurements from the Atmospheric Infrared Sounder (AIRS). Results suggest the power of combining CIPS measurements with those from other instruments to investigate GW filtering and vertical propagation from the troposphere to the upper atmosphere. Vertically propagating GWs play a significant role in coupling the atmosphere, as they transfer momentum and energy from the troposphere to higher altitudes. They drive the circulation in the upper atmosphere, thereby affecting temperatures, transport of minor constituents, and chemistry.

However, global, high spatial resolution observations of GWs are only available at a few altitudes. The new CIPS GW data fill in the measurement gap near the stratopause and open up new areas of inquiry, enabling comprehensive investigations of GWs in the middle atmosphere on a global scale. This work also highlights the value of extended missions in enabling new and important observations.

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 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

Magnetopause Kelvin-Helmholtz waves grow faster/stronger when the solar wind driver is fluctuating. The solar wind sweeps past and constantly buffets Earth's space environment, imparting the momentum and energy that drive space weather. The magnetopause boundary, the dominant location of this interaction, develops large-scale Kelvin-Helmholz waves (like wind shear driven cloud layers in the atmosphere or wind shear driven waves on lakes) which facilitate momentum and energy transfer into Earth's space environment. THEMIS researchers had previously shown that these waves are far more common than previously thought. Now researchers motivated by these THEMIS observations have employed global simulations to demonstrate that omnipresent small-scale solar wind fluctuations can grow to large amplitudes and dominate the solar wind's magnetic field. Since the solar wind magnetic field is crucial to its interaction with Earth's space environment, the enhanced fluctuations have an important consequence for the magnetopause: they increase the amplitude of the Kelvin-Helmholz waves, which in turn enhances momentum and energy transport across the boundary into the magnetosphere and therefore intensifies space weather. This discovery explains how not only the average properties of the solar wind, but also their fluctuations, contribute to geospace mass, momentum and energy transport. This helps build models for global geospace mass and energy circulation that can better quantify and predict space weather.

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 Lagrangian point, located about a 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

Neutrons are among the reaction products produced in large solar flares when accelerated ions encounter the solar atmosphere. A 2010 paper suggested that solar-flare neutrons that decay to protons in the low corona could provide a seed-population for CME-driven shock acceleration. Scientists recently tested this idea by modeling the production of higher energy to lower energy protons in the low corona by the decay of neutrons produced in a large solar flare. Free neutrons undergo decay with a mean-life of ~882 seconds. This process produces protons with slightly less kinetic energy than the escaping neutrons. The protons and electrons spiral around the local interplanetary magnetic field and the solar wind convects them out.

To model neutron production they assumed accelerated protons >30 MeV, a value characteristic of the large June 4, 1991 X12 flare. To optimize the neutron yield they assumed a composition enriched in Helium and heavier ions. They also chose angular distributions of interacting protons to optimize the yield of escaping neutrons. In order to compare the modeled neutron-decay proton spectra to an estimated quiet-time ambient density they used quiet-time energy spectra measured in 2007 by the SWICS and ULEIS instruments on ACE. They derived a "quiet-time" proton density that is approximately thirty times larger than the modeled neutron-decay proton density. This suggests that neutron-decay protons make a negligible contribution to quiet-time seed-particle densities near the Sun.

OTHER MISSIONS AND DATA ANALYSIS

RAMATY HIGH ENERGY SOLAR SPECTROSCOPIC IMAGER (RHESSI)

After more than 16 years of successful operations since its launch in 2002, NASA decommissioned RHESSI on 16 August 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 will carry out the RHESSI Mission Archive Plan in FY 2019 and FY 2020. GSFC and SSL will share a minimum level effort to ensure the health and safety of the mission while retrieving over 95-percent of the data.

AERONAUTICS

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Airspace Operations and Safety Program	118.7	--	**121.2**	130.6	133.5	136.2	138.9
Advanced Air Vehicles Program	237.7	--	**188.1**	203.3	212.2	219.3	224.2
Integrated Aviation Systems Program	221.5	--	**233.2**	209.4	202.2	97.1	87.2
Transformative Aero Concepts Program	112.2	--	**124.4**	130.3	132.3	134.6	136.7
Total Budget	**690.0**	**725.0**	**666.9**	**673.6**	**680.3**	**587.1**	**587.0**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

AERONAUTICS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Airspace Operations and Safety Program	118.7	--	**121.2**	130.6	133.5	136.2	138.9
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Transformative Aero Concepts Program	112.2	--	**124.4**	130.3	132.3	134.6	136.7
Total Budget	**690.0**	**725.0**	**666.9**	**673.6**	**680.3**	**587.1**	**587.0**
Change from FY 2019			**-58.1**				
Percentage change from FY 2019			**-8.0%**				

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

NASA has contracted the Lockheed Martin Aeronautics Company to build the X-59 Quiet Supersonic Technology (QueSST) research aircraft, which will generate quiet sonic "thumps."

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 -- $84.8 billion in 2017 alone.[2] It supports more than 10.6 million direct and indirect jobs, including more than one million high-quality manufacturing jobs.

NASA explores technologies that reduce aircraft noise and fuel use, get passengers gate-to-gate safely and on time, and transform aviation into an economic engine at all altitudes.

[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 13, 2018

AERONAUTICS

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 is safe, economical and environmentally friendly 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 all vehicles at all altitudes, 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: http://www.aeronautics.nasa.gov/strategic-plan.htm. 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

NASA develops critical tools that are used by the Federal Aviation Administration (FAA) to efficiently and safely control air traffic. In order to transition these capabilities, extensive testing is needed in a realistic environment to ensure that they work as designed.

Thrust 2: Innovation in commercial supersonic aircraft

Among the key barriers in realizing this new market are regulations that prevent overland supersonic flight. Through ground testing and computational analysis, NASA has shown that it is possible to dramatically reduce a sonic boom from aircraft, but regulatory organizations require a comprehensive set of flight data and data on the perceptions of humans to inform regulatory changes. There are two key elements necessary to gather this data: (1) an aircraft is needed to generate the low boom, and (2) methods are needed to accurately measure the community response. The NASA X-59 Quiet Supersonic Technology (QueSST) aircraft is the first-of-its-kind aircraft that will generate the type of noise levels needed for a regulation change. NASA's Commercial Supersonic Technology project is developing complementary community response tools so that the X-59 QueSST aircraft can be used to generate the data needed by regulators.

Thrust 3: Ultra-efficient commercial vehicles

Large transport aircraft are critical to the operation of our modern aviation system, moving people and cargo across the globe and serving as an important element of our country's economic engine. Developing a new passenger aircraft is an extremely complex, time consuming and expensive endeavor, which is why only a few countries have been able to successfully do so. Modern airliners are very efficient and an array of new technologies are needed for the next generation of transport aircraft. NASA is working very closely with airframe and engine manufacturers to create these innovations that will help ensure American leadership in commercial aircraft development.

NASA's work to improve the efficiency and environmental performance of aircraft is not limited to large transport aircraft, but also benefits smaller aircraft including vertical lift vehicles. These vertical lift vehicles have unique challenges including noise reduction or implementation of new propulsion concepts that are more efficient and safer. These technology concepts will greatly improve the capabilities of the aircraft that perform such vital missions as emergency rescue, but also pave the way for a greater expansion into urban air mobility which will move people and goods in ways that are not possible today.

Thrust 4: Transition to alternative propulsion and energy

Jet airliners entered service just over 60 years ago and, in that time, there has been significant improvement in efficiency and reduction of noise through the development of new technologies. We are on the cusp of another significant advance in aviation propulsion with the introduction of practical more electric systems that have applicability from small to even large transport aircraft. These propulsion systems have the potential for not just changing the engines themselves, but also increasing the flexibility for aircraft designers to consider new vehicle concepts with greatly improved performance. Before these benefits can be realized, new components and powertrain architectures must be developed and proven to be safe.

Thrust 5: In-Time, system-wide safety assurance

The growing complexity of the National Airspace System (NAS), both with vehicles and operations, allows for much improved services and benefits, but also requires diligent effort to ensure that the incredible safety record of modern aviation is not impacted and, if possible, continues to improve. However, this means that traditional methods to ensure safety are often no longer sufficient. New methods are needed to analyze key aspects of the aviation system so that we can predict and eliminate failures before they become an issue. Concurrently, it becomes imperative to reduce the cost of verifying and validating these technologies because this has become a key factor in the high price of new systems and impeding innovations.

Thrust 6: Assured autonomy for aviation transformation

Autonomy is changing so many aspects of our lives and aviation is no exception. Autonomy and increased automation bring new opportunities to do the things we already do even better, but also hold the potential to open new markets and create new benefits that are not yet possible. For example, it would be impossible to scale modern air traffic control to monitor and ensure safety for the large number of small unmanned systems that are envisioned. However, the path to more autonomy in aviation does not take place overnight. NASA is taking some key steps to ensure that the United States is a leader in this transformation. In particular, NASA is working to both integrate operations of larger Unmanned Aircraft Systems (UAS) in the existing NAS as well as develop key technologies and approaches for managing smaller vehicles safely at lower altitudes.

NASA's investment strategy follows long-term research roadmaps in order to enable major outcomes in each of these thrusts. The roadmaps are implemented in partnership with the aviation community and reflect solutions to aviation system needs that will provide benefits in mobility, environmental sustainability, and safety; while ensuring continued long-term U.S. aviation technology leadership in this rapidly expanding global industry.

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 that are used by industry and other government organizations to improve national economy and expand the impact of U.S. aviation industry around the world. The FY 2020 Budget request includes major activities that are closely coordinated across the mission directorate. The following examples demonstrate how this approach works within several thrusts.

For Thrust 2, by FY 2020, NASA will be on the cusp of the first flight of the X-59 QueSST aircraft, which is a critically important element of the LBFD Mission. NASA's newest purpose-built experimental supersonic aircraft will now be known as the X-59 QueSST aircraft, development of which is led by Integrated Aviation Systems Program (IASP). The aircraft is being built to support the Low Boom Flight Demonstration (LBFD) Mission which is led by the Advanced Air Vehicles Program (AAVP) and the Commercial Supersonic Technology (CST) Project and supported by both the IASP, LBFD and Flight Demonstrations and Capabilities (FDC) projects. The purpose of the Mission is to develop a low-boom community response database that will be provided 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 is being conducted under the Low Boom Flight Demonstrator Project under the IASP, the FDC Project is a key contributor to the LBFD Mission and will handle flight operations during the community response testing phase of the Mission. In FY 2020,

- The LBFD Project will build X-59 QueSST aircraft and complete most ground testing.
- The CST Project will be developing, testing, and maturing the ability to predict the boom coming off the X-59 QueSST aircraft and the ability to accurately gather human response data from the people in the communities in the vicinity of the aircraft flight path.
- The FDC Project will be working on getting the operational and test infrastructure required to execute the community overflights ready for testing and deployment.

The LBFD Mission will be completed by FY 2026 when the test data is delivered to the International Civil Aviation Organization (ICAO), which can then establish a new supersonic noise standard. This standard will allow the U.S. aviation industry to deliver a new aviation capability that will reduce travel time significantly. This capability will position the U.S. aviation industry to be in a position of competitive strength in producing future supersonic aircraft products.

For Thrust 3, NASA will develop technologies that will be used on the next generation of subsonic transport technology. The technologies include advanced wing design, transformative structures, propulsion-airframe integration, small core turbine engines, and electric aircraft propulsion (EAP). Among these technologies, EAP is showing great potential and industry interest and is a focus of NASA. The NASA Electric Aircraft Test Facility (NEAT) is enabling full scale ground test of high-power electric propulsion systems, and technical accomplishments will be building blocks demonstrating progress with integration and test. In FY 2020, NASA will begin a multi-year effort to solve the technical challenges of a 1MW+ power electric propulsion system (1MW 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.

With the UAS market quickly becoming a reality and developing urban air mobility (UAM) market growing rapidly, NASA's FY 2020 investments related to Thrust 6 provide critical elements for the introduction of the needed vehicles and airspace systems. From air traffic management to quiet vertical lift, NASA is working to eliminate key barriers to establish these new markets. 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 2020, 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.

In FY 2020, NASA will complete the UAS integration in the NAS Project and UAS Traffic Management Project which will provide major contributions to enable UAS to fly safely in the airspace system. To continue and build on this work, NASA will also begin a new project, Advanced Air Mobility Project that will further accelerate the introduction of UAS into the airspace and enable a completely new capability of urban air mobility. Additionally, NASA research supporting vertical lift vehicles development in the Revolutionary Vertical Lift Technology Project and autonomous systems research in the Transformative Tools and Technology Project will support the emerging urban air mobility market.

EXPLANATION OF MAJOR CHANGES IN FY 2020

This request consolidates funding from across NASA mission directorates for certain aeroscience capabilities into a single project within Safety, Security, and Mission Service's Shared Capability Asset Program. This includes the transfer of the Aeronautics Evaluation & Testing Capability Project (AETC) from the Aeronautics account to the Safety, Security, and Mission Service account. AETC will continue to provide the necessary support for both Aeronautics and other Agency large ground test needs.

NASA will begin activities leading to a subsonic aircraft flight demonstration project. The project's initial focus will be integrating electric powertrain, power distribution, and energy storage components into an existing airframe and assessing performance in flight.

NASA will start a new Advanced Air Mobility Project that will accelerate research supporting UAM.

ACHIEVEMENTS IN FY 2018

Thrust 1: Safe, efficient growth in global operations

- In 2018, NASA began a comprehensive operational evaluation and demonstration of air traffic management technology known as ATD-2. The ATD-2 technologies enable sharing of operational information that significantly improves plan and schedule aircraft movement at busy airports. NASA is working with both the FAA and airline and airport operators to test this technology suite. Since the start of ATD-2 trial, NASA estimates a cumulative savings of over 600,000 lbs. of fuels and 89 hours of surface delays. The amount of reduction in carbon dioxide emissions is equivalent to 22,857 trees offsetting the CO_2 output, and 912 hours of reduced runtime on engines.

- NASA made significant progress on developing other tools that help fuse weather information with traffic flow data to allow controllers to more efficiently route aircraft – especially in adverse weather conditions. Better understanding the impact of weather will help minimize delay and improve the traveling experience. NASA demonstrated this new capability with a simulation that was well-received by the FAA and airline operators.

Additional information on the Thrust 1 work can be found in the Airspace Operations and Safety Program (AOSP) section below.

Thrust 2: Innovation in commercial supersonic aircraft

- In 2018, NASA awarded a $247.5 million contract to Lockheed Martin Aeronautics Company to design and build the X-59 QueSST aircraft, piloted X-plane, by the end of FY 2021 in support of the Low-Boom Flight Demonstration Mission. NASA completed a Delta Preliminary Design review that will guide final design and build of the aircraft. The review was very successful and is allowing NASA and Lockheed to proceed with the next steps to develop this new X-plane.

Additional information on the Thrust 2 work can be found in the AAVP and IASP sections below.

Thrust 3: Ultra-efficient commercial vehicles

- NASA completed several studies of "boundary layer ingestion" (BLI) propulsion systems in which the engine consumes (or ingests) the slower air near the aircraft surface. Experimental results of a propulsion system operating with this BLI flow showed potential aircraft fuel burn reduction of approximately 5-7 percent. This is an example of one of the new technologies that could be a key contributor to a future design. These NASA studies are the most comprehensive analysis of the concept ever created and have been shared with U.S. industry.

- NASA and Boeing also completed a flight demonstration of a new reduced-drag acoustic liner located within the inlet of an engine on a Boeing 737 MAX test aircraft. NASA's novel concept significantly reduced noise during take-off and landing while reducing the drag within the engine inlet by 30 percent compared to state-of-the-art acoustic liners. In addition to being a viable candidate technology for future aircraft, it is possible that this technology can also be utilized on future derivatives of current production aircraft such as the 737 MAX.

- Another important flight experiment involved NASA’s Landing Gear Noise Reduction effort that demonstrated technologies that achieved a significant reduction in airframe noise heard by communities near airports during landing. These technologies are tested in flight on an aircraft with modified landing gear treatments to alter airflow and reduce noise. Test flights using this technology shared in a reduction in airframe noise of more than 30 percent, which could benefit communities near airports and foster expanded airport operations. The tools needed to analyze the noise as well as the noise reduction technology is very much valued by industry.

- Not only is it important to develop new technologies, but more work is needed to make the design and manufacturing process more efficient and reduce the time and cost to build aircraft. Working very closely with a variety of industry partners, NASA completed the validation process of computer-based prediction tools for composite progressive damage analysis. These validated tools and methods can be used by aircraft structure designers to predict the damage tolerance of aircraft components while in the preliminary design phase. Additionally, the confidence in these prediction tools can reduce the amount of testing needed and reduce the potential for late-cycle design changes both of which contribute to overall design time.

- NASA successfully demonstrated a new design concept for simultaneous optimization of low-noise and low-emissions Vertical Take Off and Landing (VTOL) vehicle designs which will help improve the performance, efficiency, and noise reduction for these new higher-speed vertical lift configurations. This new ability, utilizing computational optimization processes, will enable design engineers to efficiently assess and compare design and technology options to create advanced concepts for cleaner and quieter VTOL configurations. These advances will also help pave the way for new vehicles that can be used for new missions such as economical inter-urban transport.

- NASA, in collaboration with the FAA and Army, developed low-noise flight procedures to minimize the noise from helicopter operations. Noise measurements from six different, commonly-used, commercial helicopters enabled NASA and its partners to develop general "rules of thumb" methods for flight maneuvers that can result in less noise perceived on the ground without any changes required to the helicopters. This means that these techniques do not need to wait for new concepts to be developed, but can start having an impact on today's helicopter operations.

Additional information on the Thrust 3 work can be found in the AAVP, IASP and TACP sections below.

Thrust 4: Transition to alternative propulsion and energy

- NASA completed single-aisle transport aircraft concept studies with Boeing and Liberty Works to develop hybrid gas-electric propulsion concepts and assess the potential benefits. NASA collaborated with several industry and university partners to demonstrate feasibility of achieving critical performance targets of power-to-weight ratio and efficiency for 1-MW electric components. It has been found that a 1-MW power level can have applicability across a wide spectrum of vehicles including smaller regional transports but also for airplanes as large as a Boeing 737.

- NASA demonstrated a 500-kW hybrid electric powertrain system in the NASA Electric Aircraft Testbed (NEAT) facility using commercial off-the-shelf components. The demonstration was the first in a series of tests leading toward a full-scale 1-MW powertrain system with advanced components to establish concept feasibility at the megawatt scale.

- NASA began work on the X-57 Maxwell aircraft in order to learn important lessons about designing, building and operating an all-electric system that can be shared with the community. A key step was completed with the testing of the X-57 motor controller and flight battery system to ensure safety in flight. These tests will help ensure developments of safer electric flight systems.

- NASA continued to advance the state-of-the-art of using alternative fuels. NASA, in collaboration with the FAA and the German Aerospace Center (DLR), completed a complex flight experiment to test the performance of alternative fuels in actual operations. This flight campaign included seven joint flights of the NASA DC-8 and the DLR A320 aircraft to collect jet engine emissions data when various blends of alternative fuels were used. The comprehensive data, combined with predictive models, will help better understand aircraft soot emissions and contrails. This builds on previous NASA work and provides critical data for industry, the FAA, and the scientific community to assess the benefits of new fuels.

Additional information on the Thrust 4 work can be found in the AAVP and IASP sections below.

Thrust 5: In-Time, system-wide safety assurance

- NASA delivered a new algorithm to the FAA Aviation Safety Information Analysis and Sharing (ASIAS) program to identify anomalies in large data sets. ASIAS is a tool that has been used by the FAA and others to help achieve the high levels of safety. This new algorithm has the ability to identify previously undetected operationally significant safety events within Flight Operational Quality Assurance (FOQA) data. NASA also began applying active learning to incorporate feedback from subject matter experts, which helps expand the capability of these algorithms. This helps improve the ability to distinguish operationally significant anomalies from other facets of the data that may not be an issue. This is important for ensuring that flaws are detected, but the instances of flagging something that is not an issue does not occur and lead to lack of trust in the capability.

Additional information on the Thrust 5 work can be found in the AOSP section below.

Thrust 6: Assured autonomy for aviation transformation

- NASA established agreements with industry partners to begin flight demonstrations of UAS in the NAS. NASA initiated a new activity in collaboration with industry that will lead to multiple flight demonstrations that focus on UAS missions at altitudes greater than 500 feet above ground level, and will include integrated Detect and Avoid and Command and Control technologies. These technologies are critical to ensure that these vehicles can safely operate near each other and in the vicinity of manned aircraft.

- NASA's remotely-piloted Ikhana aircraft successfully flew its first mission without a safety chase aircraft in the NAS. This test was possible because of extensive prior work and allowed the FAA to grant NASA special permission to use technologies which enable the remote pilot on the ground to detect and avoid other aircraft during flight. This was an important step in expanding the use of unmanned vehicles and included the first time that a civil unmanned vehicle coordinated with air traffic controllers to avoid other traffic. The Ikhana flew into airspace typically reserved for commercial airliners, detected aircraft in flight, and the pilot communicated in real-time with airport air traffic controllers throughout the flight. This milestone flight will help the United States to normalize and open new unmanned aircraft operations in the airspace used by commercial and private pilots.

- In order to facilitate the growing use of smaller unmanned systems, NASA developed and demonstrated a new technical capability level for the UAS Traffic Management (UTM) system that NASA has been pioneering for several years. This latest advancement focused on the requirements to manage separation by vehicle and/or ground-based capabilities under higher air traffic densities. These focus areas utilized research validated under previous NASA work that demonstrated operations beyond visual line-of-sight over moderately populated land with some interaction with manned aircraft. UTM is recognized both domestically and internationally as a key element in enabling broad use of these small vehicles for a variety of commercial purposes. The results of this experiment have been shared with the FAA and industry.

Additional information on the Thrust 6 work can be found in the AOSP, IASP and TACP sections below.

Cross-Cutting Capabilities

Not all of NASA's work is applicable to just one Strategic Thrust. Some fundamental work or new 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 a number of key aviation challenges.

- Under the University Innovation (UI) Project, a total of five first-round University Leadership Initiative (ULI) Solicitation Awards executed a full year of work. There are 22 universities and 136 students engaged in this research. Under ULI, NASA challenges the academic community to take a leadership position working across schools and departments to solve specific challenges that benefit the aviation community and are complimentary to NASA work. In addition to supporting this innovative work, NASA is helping ensure that the results are effectively communicated to the community. The first annual ULI Technical Interchange Event was held in June 2018 in cooperation with the American Institute of Aeronautics and Astronautics (AIAA) to get peer-reviewed and publicize the ULI efforts to academia and the aviation industry. The event received excellent feedback from the technical community and helped generate interest in future ULI solicitations.

In order to stimulate new ideas that can directly contribute to the challenges that NASA is addressing, the Convergent Aeronautics Solutions (CAS) initiative was established in 2015. In 2018, five activities under CAS completed critical feasibility assessments. This work holds the potential to improve key areas such as more electric propulsion, autonomy and advanced controls for new aviation systems.

- NASA completed an aerodynamic validation experiment that examined the turbulent airflow around the wing-body junction of an aircraft. NASA will apply the results from this study to delivering turbulence models and numerical methods for separated flows, which are needed to accurately simulate some of the most challenging aspects of flight that are beyond today's capabilities. This experiment provided the data leading to model improvements for a reduction in the predictive error rate by 40 percent against standard test cases. This research will provide validation data to assess and improve computational tools for separated flows and will lead to cheaper and more-optimal aircraft designs. This work directly supports some of the advanced wing research that is being conducted in AAVP.

- NASA also completed the Vision 2040 for Computational Materials and Systems Report that developed a roadmap toward achieving the capability for computational design and certification of advanced materials that is needed for use in emerging aeronautical vehicle applications. This capability will allow for greater speed and reduced cost in design and certification of novel aircraft configurations. More than 450 professionals from industry, academia, government agencies and national labs participated in the development of the roadmap.

Additional information on the Cross-cutting work can be found in the TACP section below.

Hypersonic Capabilities

Hypersonic flight involves speeds greater than Mach 5 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 to further mature necessary capabilities, while focusing on the fundamental research that will lead to new, long-term capabilities to lay the foundation for potential future commercial use. NASA expertise assists the DoD by solving key problems and reducing risk for a variety of activities, which also provide key validation data that NASA can, in turn, use to support its own research.

- One of the key challenges for hypersonics is creating a propulsion system that can operate at slower speeds for takeoff and landing and transition to high-speed operation in flight. NASA successfully explored propulsion mode transition at lower Mach numbers between a simulated low-speed turbine engine and a complete high-speed dual-mode ramjet engine. These tests increased understanding of the lowest speeds that a high-speed propulsion system powering a hypersonic aircraft can be expected to operate. The aeronautics experts have identified such advances in propulsion as critical for practical re-usable hypersonic flight.

WORK IN PROGRESS IN FY 2019

Thrust 1: Safe, efficient growth in global operations

- NASA will continue the ATD-2 demonstration and initiate a Phase 2 element to evaluate a new tool that helps improve the timing of arrivals and departures of aircraft. These Phase 2 operations will demonstrate the benefits of strategic surface metering during periods of significant demand/capacity imbalance and enhance tactical surface metering to improve non-movement area predictability and throughput at busy airports. This work will involve actual operation of the capability at the Charlotte airport American Airlines Ramp Tower, Charlotte Air Traffic Control Tower (ATCT), Charlotte Terminal Radar Approach Control (TRACON), Atlanta Air Route Traffic Control Center (ARTCC), and Washington ARTCC with real air traffic. Such a comprehensive experiment is critical for maturing the technology so that it can be used by the FAA, airports, and airlines across the country. The ATD-2 capability will be expanded to validate more scheduling scenarios for the Washington and Atlanta Air Route Traffic Control Centers and will culminate in a Phase 3 full system metroplex (multiple airports) Integrated Arrival, Departure, and Surface demonstration in FY 2020.

Thrust 2: Innovation in commercial supersonic aircraft

- NASA will continue to develop both the X-59 QueSST aircraft and the techniques to collect the data from the aircraft that is needed for changing the regulation on supersonic flight. Building on the successful review in 2018, NASA completed a KDP-C for the LBFD Project in early FY 2019. This review marks the transition of the project from preliminary design and technology completion to final design and fabrication. The successful completion of KDP-C will help the project ensure efficient operation through the important design and build stages. Another important step in the process is the Critical Design Review (CDR) which sets the final design for the X-59 QueSST aircraft. The aircraft contractor will conduct aircraft build activities that include component fabrication and assembly, integration of Government Furnished Equipment, and system checkouts in preparation for the Flight Readiness Review that immediately precedes the first flight of the aircraft.

- In order to better support the collection of data from the X-59 QueSST aircraft, in 2019 NASA will make key advancements in developing new measurement techniques. An example of one of these capabilities is a technique that allows the measurement of a shock-wave from a supersonic aircraft in flight. These data will help better understand the noise field and to make predictions about how the noise radiates to the ground.

- In addition, NASA will perform a series of community response flight tests with an F-18 performing a low-boom dive maneuver over Galveston, Texas. The purpose of these tests is to continue to gain additional experience with remote aircraft operations, community noise exposure estimations, social surveys, and overall community engagement. Data from these flights will be used to refine noise prediction methods and validate community response field study methods including indoor and outdoor noise metrics, exposure estimates, and survey tools and protocols. The data and experience gained will inform future community response studies that will use the X-59 QueSST aircraft currently under development in IASP. This data will also be shared with the international community, which will facilitate planning and support for regulation change at the global level.

Thrust 3: Ultra-efficient commercial vehicles

- NASA will continue to build on the previous year's progress in creating new innovative technologies and design tools for better commercial transport aircraft including a wing concept that NASA has been developing in partnership with industry for several years. These new tests will ensure that the performance improvement that has been found in previous tests is also applicable at more realistic cruise conditions. NASA plans to improve the aerodynamics of the wing and change how the structure is built.

- NASA, in collaboration with Aurora Flight Sciences and the University of Michigan, will complete static testing to maximum load and post-test analysis of an advanced composite wing structure to assess airframe weight limitations and fuel burn reduction potential of the technology. If successful, these concepts could be applicable to several potential new aircraft concepts.

- Through simulations, NASA will build upon the flight and computational work conducted recently to complete an effort aimed to reduce the noise from landing gear and high-lift systems of large civil transports. This effort plans to demonstrate a greater than 30 percent reduction in the airframe component of community noise with minimal impact on aircraft weight and performance. The results of this work will allow industry to create new designs that would greatly benefit communities near airports and expand airport operations.

- NASA will complete the Advanced Composites Project, which has been a six-year focused effort working with industry to deliver a set of computational tools and methods that can significantly reduce the time needed to develop and certify new composite structures for aerospace applications. This work benefits American industry by helping to reduce the required time for improved aircraft designs by providing approaches for accurately predicting the life and strength of composite materials; developing techniques to rapidly inspect and characterize composite materials; and creating efficient manufacturing processes.

- In an effort to expand the potential benefits of future vehicles, NASA will complete the demonstration of vehicle design and flight operation methods to reduce Vertical Take Off and Landing (VTOL) aircraft noise impacts. These methods target a 50 percent reduction in the Sound Exposure Level footprint area for commercial rotary wing vehicles through a combination of improved rotor/vehicle design, flight operation methods, and understanding the human response to rotorcraft noise. These enhanced methods will assist in future VTOL designs that will significantly reduce community noise impact while simultaneously maintaining or improving aerodynamic performance.

Thrust 4: Transition to alternative propulsion and energy

- Building on the successful developments in FY 2018, NASA will mature MW-class Hybrid Gas-Electric Propulsion (HGEP) aircraft concepts and technologies for commercial transport aircraft. A main focus for FY 2019 will be design, assembly and initial testing of a MW-scaled electric aircraft powertrain in the NASA Electric Aircraft Testbed (NEAT). A representative electrified aircraft powertrain with existing commercial components will be designed and assembled in the NEAT, and communications and controls will be demonstrated. This system will be too heavy for use in actual flight operations, but will prove key concepts that are needed to develop systems that can be tested in flight, which will happen in later years. In addition, aircraft concept system studies will be performed to determine how this advanced HGEP powertrain can provide an aircraft system-level fuel burn reduction and potentially enable new U.S. aviation markets for smaller transport aircraft.

- The X-57 effort continues aircraft integration activities in preparation for first flight in FY 2020. In addition, there is critical work that will be completed for future modifications of the design including fabrication of a new, high-aspect ratio wing. These future modifications will expand the applicability of the more electric systems and provide an expanded data set and lessons learned that can be used by the community to develop other more electric vehicle concepts.

- In addition to helping prove the applicability of new alternative fuels, NASA will help ensure that the jet engine hardware exists to fully take advantage of these new more environmentally friendly fuels. In 2019, NASA will demonstrate an advanced, low-emissions, fuel-flexible combustor concept for a small core engine, focusing on reducing harmful Nitrogen Oxide (NOx) emissions 80 percent below the 2008 international NOx emissions limits with minimal impacts on weight, noise, and component life. Jet engine combustors are often sensitive to the type of fuel used and this work helps ensure that future engine designs can continue to reduce NOx emissions while using a wider range of fuels.

Thrust 5: Real-time, system-wide safety assurance

- NASA will provide 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. This flight anomaly detection code will be transitioned into daily ASIAS program operations so that it can be used to help analyze a wide range of flight data.

- In 2019, NASA will also complete the final deliverables of a set of capabilities to the Commercial Aviation Safety Team (CAST). CAST is a U.S. Government and aviation industry partnership to significantly increase public safety by adopting an integrated, data-driven strategy to reduce the fatality risk in commercial air travel in the United States. Some of these new capabilities will enable pilots to better understand and respond safely to complex situations. Another benefit will be to improve a pilot's ability to prevent or recover from loss of control accidents.

Thrust 6: Assured autonomy for aviation transformation

- In order to further development of the critical detect and avoid systems, NASA will complete flight testing of a low size, weight, and power airborne surveillance capability for mid-size UAS. In addition, NASA will complete a flight test of a new control and non-payload communications radio in relevant operational environments. This is another capability needed to facilitate expanded UAS operations. Both of these flight demonstrations are key contributing events to developing the Minimal Operation Standards development in support of RTCA Special Committee 228 standards development for UAS. Not only will NASA help set the standards for future operations but will help create the concepts that allow more autonomous operations. NASA will conduct a 2019 flight test on Boeing's ecoDemonstrator aircraft as a next step to evaluating digital trajectory negotiations to ultimately determine requirements for future autonomous freighter operations.

- Building on the recent progress in monitoring smaller unmanned systems, NASA will develop and demonstrate the fourth and final technical capability level for UTM, focusing on large-scale UAS operations in higher-density urban areas. The demonstration will also test technologies that could be used to manage large-scale contingencies (i.e., communication/navigation failures, disaster scenarios, etc.). This final advancement represents a culmination of UTM research technology development to enable safe operations of the newest entrant into the skies. UTM has enabled adoption of global standards for small UAS operations, provided FAA with a federated architecture for further development of their flight information management interface, enabled commercial UAS Service Suppliers to develop their operational systems for their clients, and enabled the FAA to successfully execute its small UAS pilot programs.

Cross-Cutting Capabilities

- In 2019, NASA will award a second round of University Leadership Innovation (ULI) proposals to address a range of challenges across NASA Strategic Thrusts. In addition, NASA will complete another set of feasibility studies under CAS and initiate a new round of proposals for innovative ideas.

- NASA will begin support to enable a concept supported by industry known as Certification by Analysis, which allows greater application of computational tools to provide certification data that will reduce the time and cost of certifying new systems without compromising safety. These tools will 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.

Hypersonic Capabilities

- One of the key challenges to designing hypersonic systems is being able to understand and account for all of the uncertainties in the predictions while in the design process. For example, a vehicle traveling at Mach 5 or higher has tremendous thrust and drag with a small difference between the two, so the result of the design effort is very sensitive to any errors in the estimated contributing attributes used in the design process. NASA will begin to apply new methods to understand and account for uncertainties for approaches to hypersonic ground tests in FY 2019, building on those approaches that were identified in FY 2017 and successfully applied to a modeling & simulation problem in FY 2018. Application of these approaches to ground testing will allow for increased testing efficiency, better quantification of test uncertainty, improved understanding of technical risk, improved understanding of where to invest money to reduce uncertainty, and an improved understanding of what changes to the vehicle design will result in increased performance of hypersonic vehicles in flight.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

Thrust 1: Safe, efficient growth in global operations

- The third and final phase for ATD-2 will demonstrate a new capability that extends the capabilities demonstrated in 2019 and includes a concept and approach to integrate tower electronic flight data with surface and airspace scheduling. This third phase will be conducted at the Dallas/Fort Worth Terminal Radar Approach Control, Fort Worth Air Route Traffic Control Center, Dallas/Fort Worth (DFW) and Dallas Love Field (DAL) Air Traffic Control Towers, and American and Southwest Airlines facilities at DFW and DAL airports, respectively. Phase 3 will be a high-fidelity demonstration of all integrated system capabilities, and aims to validate the benefits of strategic surface metering during periods of significant demand/capacity imbalance. Successful completion of this final demonstration will support the delivery of research and development results to advance NextGen capabilities and improvements to meet the FAA's air traffic needs.

Thrust 2: Innovation in commercial supersonic aircraft

- Lockheed Martin will complete the final assembly of the X-59 QueSST aircraft by the end of FY 2020. NASA will complete final aircraft subsystem checkouts and ground testing in preparation for the Flight Readiness Review late in FY 2021. Significant testing and checkouts are required to ensure that the aircraft is ready to safely perform its mission. In addition, NASA will continue to hone the test techniques that will be needed to collect the community response data. As part of the preparation, NASA will host an international meeting to help ensure that there is international support for a new regulation.

Thrust 3: Ultra-efficient commercial vehicles

- NASA will continue the development of advanced wing concepts that are critical to future aircraft. A wind tunnel test will be conducted on a model establishing the feasibility of quiet high-lift technology concepts with use of advanced techniques to reduce aircraft noise. The 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.

Combined with the work in prior years, NASA will have made a significant advance in the ability to design wings that are more efficient, quieter and lighter compared to today, which translates into more efficient and economically competitive products.

- Recently, NASA has shifted its focus on VTOL propulsion research to investigate new concepts involving more electric propulsion. In FY 2020 NASA will complete assessments of electric propulsion system architecture failure mode, effects and associated criticality analyses for four electric vertical take-off and landing aircraft concept vehicles. These analyses will provide insights into the highest pay-off component areas and will help guide future research. These systems with more electric components have significant promise to improve efficiency and operability, but architecture studies are needed to ensure that the safety considerations are fully considered. Such analysis is needed by both the FAA and industry to help guide the safe development of these new systems that are anticipated to a wide range of vehicles including new urban air mobility concepts.

Thrust 4: Transition to alternative propulsion and energy

- In FY 2020, NASA will begin work to bring together concepts supporting both Thrust 3 and Thrust 4 to set the stage for further maturing of concepts to make a difference for American aviation products. This includes making progress on new turbine engine components that allow new "small core" engines to be developed that will be more efficient than today's turbine engines. In order to ensure that this work is closely aligned with industry, NASA will award one or more contracts to cooperatively integrate electric powertrain, power distribution, and energy storage components for primary propulsion onto an existing airframe and to assess the propulsion system performance through flight demonstration. The focus will be on high power electrified aircraft propulsion systems on the order of 1-megawatt power. These awards will be accomplished through open competition to determine the most impactful concepts for demonstration that provide the highest benefit to the U.S. aviation industry.

- NASA will conduct the first flight of the X-57 Maxwell aircraft. This first flight is expected to expand the knowledge base that has been established over the years in building the aircraft by testing these electrical systems in flight. NASA will work with industry partners to continue to address and document the newly discovered integration challenges and lessons learned associated with preparing the all-electric X-57 for flight. This will allow NASA to continue to support the development of manufacturing standards for electrified aircraft systems to further enable progress for U.S. companies to develop more electric aircraft.

Thrust 5: Real-time, system-wide safety assurance

- NASA plans to develop models and metrics to characterize safe operations in support of the development of new urban air mobility markets. This work will build on the development of NASA safety analyses over the past several years and apply them to help understand the challenges involved in bringing new vehicles and concepts of operation into practice.

- In addition, NASA will demonstrate Verification and Validation (V&V) methodologies in an integrated simulation demonstrated in a relevant airspace environment to address costs and difficulties associated with assuring the safety of increasingly complex and autonomous aviation systems. Industry estimates of costs associated with V&V activities reveal that these costs are becoming unsustainable and have begun to stifle innovation. NASA work will build on previous efforts with industry partners and includes development of additional tools and techniques that can reduce the costs and improve effectiveness of V&V, and therefore reduce overall development costs for a wide range of aviation systems.

Thrust 6: Assured autonomy for aviation transformation

- The UAS Integration in the NAS Project will complete its work on enabling UAS to safely fly in the National Airspace System. The final deliverables for the project will include research findings through a series of technology demonstrations and simulations, to enable development of Detect and Avoid and Command and Control Minimal Operational Performance Standards (MOPS) by RTCA for mid-size UAS.

- A major capstone of the UAS Integration in the NAS project will be NASA's 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 in FY 2020 that focus on UAS missions at altitudes greater than 500 feet above ground level, and will include integrated Detect and Avoid and Command and Control technologies.

- NASA will conduct a human-in-the-loop evaluation in collaboration with external partners to assess UAM operations and airspace integration. 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, a first for the Agency in regards to agreements for UAM operations modeling and simulations. NASA will leverage the technologies developed under the UTM and ATD projects to assess small aircraft impacts, including delivery drones and passenger aircraft with multiple take-off and landing capabilities in crowded environments. Uber will share its plans to implement an urban aviation rideshare network. Using the data supplied by Uber, NASA plans to simulate small passenger-carrying aircraft fights during peak scheduled air traffic.

- NASA is preparing to hold the first event in a series of “Grand Challenges” in FY 2020 that will provide a means to assess the maturity of key systems for UAM. NASA is in the process of evaluating the community’s readiness to participate in such an event by 2020, but it is likely that the first experiment will focus on safe operation of the vehicles, but may include some aspects of fleet operations and traffic management systems as well. An important aspect of the Grand Challenge is exercising the air worthiness process that will be needed to assess whether vehicles can safely conduct operations. Lessons learned from this process and the Grand Challenge itself will provide some key knowledge and data that will help inform eventual regulations and standards. The volume of responses to the Grand Challenge Request for Information and the Industry Day held in 2018 indicates significant interest in NASA’s plans.

Cross-Cutting Capabilities

- NASA will initiate/execute another round of the competitive ULI proposals that will address the technical barriers intrinsic to achieving ARMD's strategic outcomes. NASA will also continue to look for new ideas under CAS and anticipates completing key activities related to autonomy, unmanned systems and new aviation communications ideas.

- NASA plans to complete computational analyses using a number of cutting-edge approaches along with a set of detailed experiments to deliver key data to industry that will help better understand heat transfer in aircraft engine turbines and lead to better approaches for thermal management. This is a critical issue that often limits the designs of aviation propulsion systems.

- NASA will work directly with industry to initiate a flight test of a flexible, deployable vortex generator system using passive-shape that utilizes new materials, which will allow for cost-effective fuel burn reduction on transport aircraft. This is another example of work that is very complementary to the advanced wing work that is described under Thrust 3.

Hypersonic Capabilities

- NASA will conduct key experiments to demonstrate an automated mode transition between a low-speed propulsion mode utilizing an operational Turbojet Engine and a high-speed propulsion mode utilizing a simulated Dual Mode Ramjet. Demonstrating such a transition is a key enabler for practical operational hypersonic propulsion systems. NASA will develop the underlying algorithms and techniques that will allow the industry to implement this concept in a variety of concepts and provide a flexible, hypersonic operational capability that does not exist today.

Programs

NASA Aeronautics is organized into four major programs that are each focused on a particular area of research, but which are all well-coordinated in achieving key commitments at the Thrust level. For example, new vehicles such as supersonic aircraft or urban air mobility 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 is provided for each Program in the following sections, but it is important to remember that these 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: Real-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, more highly 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 commercial vehicles; and,
- Thrust 4: Transition to alternative propulsion and energy.

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 the 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. The program takes lead responsibility for the following Strategic Thrust 6: Assured autonomy for aviation transformation (co-lead).

TRANSFORMATIVE AERONAUTICS CONCEPTS

The Transformative Aeronautics Concepts Program (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.

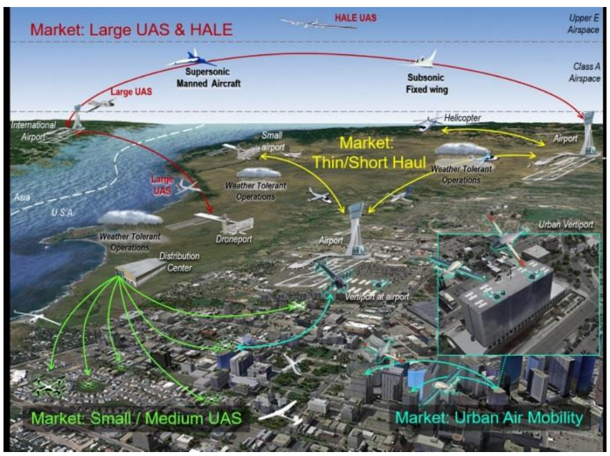
AIRSPACE OPERATIONS AND SAFETY PROGRAM

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	118.7	--	121.2	130.6	133.5	136.2	138.9

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



The Airspace Operations and Safety Program enables a revolutionary airspace paradigm for safe and efficient access for all emergent and existing users which is integrated, collaborative, scalable, flexible, resilient, and leverages user and third party services.

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 newer airspace users.

In order for the United States to meet 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. To achieve a modernized National Airspace System (NAS), the systems and processes of today must be rigorously and systematically transformed through the sustained, coordinated, and integrated efforts of many stakeholders. NASA looks to ensure that the future ATM system will accommodate these needs in a safe and affordable manner for service providers, vehicle/platform operators, and passengers as well as cargo. NASA will conduct research and develop autonomy technologies for aircraft/platforms as well as tools and technologies for managing the airspace to support 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, in partnership with the FAA and its other industry and academic partners, conceives, develops, and demonstrates NextGen 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 National Airspace architecture to enable seamless integration of emergent vehicles such as Unmanned Aircraft Systems (UAS) and Urban Air Mobility (UAM) vehicles with current day aircraft. AOSP also works with other Aeronautics Research Mission Directorate (ARMD) programs to define safe NAS operational requirements for next generation vehicles, maturation of new transformative seedling concepts, and demonstration of integrated systems. AOSP directly supports three of the ARMD Strategic Thrusts:

- Thrust 1: Safe, efficient growth in global operations
- Thrust 5: Real-time, system-wide safety assurance
- Thrust 6: Assured autonomy for aviation transformation

AOSP aims to:

- Enable completion of NextGen 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 safe operation of emerging aviation markets, including low altitude autonomous vehicles, such as UAM markets (small autonomous UAS up through passenger-carrying autonomous urban air taxis); high altitude, long endurance UAS; and the potential reemergence of short-haul/thin-haul aviation. 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 and mitigation of safety hazards through data-mining, and assurance of new systems and operations.

EXPLANATION OF MAJOR CHANGES IN FY 2020

The UAS Traffic Management (UTM) technology demonstrations concluded in 2019. The ATM Technology Demostration Project (ATD) will conclude at the end of 2020. The findings from these projects will inform requirements for the Air Traffic Management eXploration (ATM-X) Project, which will begin additional research activities in 2020.

The Advanced Air Mobility (AAM) Project will be initiated within the AOSP portfolio in FY 2020. AAM will continue development of the UTM constructs to enable urban air mobility (small autonomous UAS up through passenger-carrying autonomous urban air taxis) as well as increasingly autonomous systems operations.

ACHIEVEMENTS IN FY 2018

- In 2018, NASA began operational testing of the ATD-2 technologies for Integrated Arrival/Departure/Surface (IADS) operations at the FAA Charlotte terminal area control center, the American Airlines ramp tower, the FAA Charlotte airport air traffic control tower, and the En Route Centers for the Washington, D.C. and Atlanta, Georgia metropolitan areas. 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 demonstrated cumulative savings in the field of over 600,000 lbs. of fuel saved, 89 hours of surface delays, reduced carbon dioxide emissions equivalent to 22,857 trees offsetting the output, and 912 hours of reduced runtime on engines. (Thrust 1/ATD)

- NASA continued development of an Integrated Demand Management (IDM) concept that coordinates state-of-the-art capacity, demand, and weather forecasts across different traffic flow management capabilities to better regulate demand/capacity imbalances under adverse weather conditions. NASA demonstrated the IDM concept to FAA and airline stakeholders using simulated traffic at LaGuardia Airport and received stakeholder feedback on the validity of benefits, potential feasibility issues, and potential barriers for implementation of the IDM concept. NASA initiated a collaboration with the FAA to define a pathway for NASA's IDM concept and procedures to be implemented by the FAA. (Thrust 1/ATM-X)
- The System Wide Safety (SWS) project delivered the Multiple Kernel Anomaly Detection (MKAD) algorithm to the FAA's Aviation Safety Information Analysis and Sharing (ASIAS) program to identify anomalies in heterogeneous data. SWS demonstrated the ability of MKAD to identify previously undetected operationally significant safety events within Flight Operational Quality Assurance data. The MKAD anomaly detection code was handed off to the FAA and has been integrated into daily operations at ASIAS. (Thrust 5/SWS)
- NASA developed and demonstrated the third technical capability level (TCL3) for the UAS Traffic Management (UTM) project by embarking on an ambitious national test campaign involving six FAA test sites, 11 UAS ranges and 35 contributing partners that focused on the requirements to manage UAS separation by vehicle- and/or ground-based capabilities under higher air traffic densities. The campaign investigated information exchange protocols, sense and avoid technologies, and communication and navigation systems. The key impact of TCL3 was establishment and validation of the procedural requirements and data exchange between the airspace regulator, UAS air traffic service provider, and the UAS operators. (Thrust 6 /UTM)
- The NASA/Boeing ecoDemonstrator flight test team successfully completed a joint flight test that successfully demonstrated data communication of aircraft state and other parameters between the ecoDemonstrator aircraft and NASA's ground-based Air Traffic Management Exploration (ATM-X) Test Bed. The flight test provided the first opportunity to integrate and evaluate the operation of a conflict detection and resolution algorithm, which appropriately alerted projected conflicts between the Boeing aircraft and virtual aircraft that were generated and controlled via the ATM-X Test Bed. (Thrust 6/ATM-X)

WORK IN PROGRESS IN FY 2019

- NASA will conduct the ATD-2 Phase 2 demonstration to evaluate the fused Integrated Arrival/Departure/Surface (IADS) system capability. Phase 2 will demonstrate the benefits of strategic airport surface metering during periods of high traffic demand and will enhance tactical surface metering to improve schedule predictability and throughput at busy airports. This enables airlines to precisely schedule their gate pushback times such that aircraft have a non-stop taxi to the departure runway, and then a continuous climb to an available high altitude overhead stream slot with full coordination between the airline, airport tower, terminal area TRACON (Terminal Radar Approach Control Facilities), and the high altitude ARTCC (Air Route Traffic Control Centers). (Thrust 1/ATD)
- NASA will provide the FAA with an initial demonstration of near real-time hazard identification by using a NASA-developed framework to monitor and identify incident precursor patterns. NASA will complete a final handoff of a flight anomaly detection code that will be integrated into the FAA Aviation Safety Information Analysis and Sharing (ASIAS) program's daily

operations. In addition, NASA will develop a framework for representing and managing uncertainty in streaming aviation data. (Thrust 5/SWS)

- NASA will complete the final deliverables to the Commercial Aviation Safety Team (CAST) for the Technologies for Airplane State Awareness (TASA) subproject. CAST is a U.S. Government and aviation industry partnership which is working to significantly increase public safety by adopting an integrated, data-driven strategy to reduce the fatality risk in commercial air travel in the United States. TASA demonstrated new capabilities that enabled pilots to better understand and respond safely to complex situations, and improved operator effectiveness within aviation systems by incorporating design elements that enhance human contributions to aviation safety. Closeout activities for the effort will be completed by fourth quarter FY 2019. (Thrust 5/SWS)
- The ATM-X project will conduct a 2019 flight test on Boeing's ecoDemonstrator aircraft to determine requirements for digital trajectory negotiations, data exchange, and concepts of operations to determine research requirements for future research on autonomous freighter operations in FY 2020 and beyond. (Thrust 6/ATM-X)
- NASA will develop and demonstrate the fourth and final technical capability level (TCL4) for UTM, focusing on large-scale UAS operations in higher-density urban areas. The demonstration will also test technologies that could be used to manage large-scale contingencies (i.e., communication/navigation failures, disaster scenarios, etc.). UTM has enabled adoption of global standards for small UAS operations, provided FAA with a federated architecture for further development of their flight information management interface, enabled commercial UAS Service Suppliers (USS) to develop their operational systems for their clients, and enabled the FAA to successfully execute their small UAS pilot programs. (Thrust 6/UTM)

KEY ACHIEVEMENTS PLANNED FOR FY 2020

- ATD-2 will demonstrate a Terminal Departure Scheduling capability that extends the IADS concept and technologies to a metroplex and integrates tower electronic flight data with IADS surface and airspace scheduling. This third phase will be conducted at the Dallas/Fort Worth Terminal Radar Approach Control, Fort Worth Air Route Traffic Control Center, Dallas/Fort Worth (DFW) and Dallas Love Field (DAL) Air Traffic Control Towers, and American and Southwest Airlines facilities at DFW and DAL airports, respectively. Phase 3 will be a high-fidelity demonstration of all integrated system capabilities, and will aim to validate the benefits of strategic surface metering during periods of significant demand/capacity imbalance. Successful completion of this final demonstration will support delivery of the research and development results to advance NextGen capabilities and improvements to meet the FAA's air traffic needs. (Thrust 1/ATD)
- The System Wide Safety project will develop models and metrics to characterize safe operations of On Demand Mobility/Urban Air Mobility (UAM) air vehicles to allow safe integration and operation of these emergent users into the National Airspace System. In addition, the project will demonstrate Verification and Validation (V&V) methodologies in an integrated simulation demonstrated in a relevant airspace environment to address costs and difficulties associated with assuring the safety of increasingly complex and autonomous aviation systems. (Thrust 5/SWS)
- The ATM-X project 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 Grand Challenge. 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, a first for the Agency in regards to agreements for UAM operations modeling and simulations. NASA will leverage the

technologies developed under the UTM and ATD projects to assess small aircraft impacts, including delivery drones and passenger aircraft with multiple take-off and landing capabilities in crowded environments. Uber will share its plans to implement an urban aviation rideshare network. Using the data supplied by Uber, NASA plans to simulate small passenger-carrying aircraft fights during peak scheduled air traffic. This will enable establishment of the Concept of Operations for these emergent vehicles, as well the new airspace procedural requirements, and needed new automation technology. (Thrust 6/ATM-X)

- NASA is preparing to hold the first event in a series of "Grand Challenges" in FY 2020 that will provide a means to assess the maturity of key systems for Urban Air Mobility. NASA is evaluating the community's readiness to participate in such an event by 2020, but it is likely that the first experiment will focus on safe operation of UAM vehicles. The experiment may include some aspects of fleet operations and traffic management systems as well. An important aspect of the Challenge is exercising the air worthiness process that will be needed to assess whether vehicles can safely conduct operations. There was tremendous response to the Grand Challenge Request for Information (RFI) and the Industry Day held in 2018, which indicates strong support for NASA's plans. (Thrust 6/AAM)

Program Elements

AIRSPACE TECHNOLOGY DEMONSTRATIONS (ATD)

The ATD project is comprised of a suite of technology development and demonstration activities geared toward delivery of near-term benefits to air transportation system stakeholders. ATD supports ARMD's Strategic Thrust 1, Safe Efficient Growth in Global Operations, through two sub-projects, ATD-1 and ATD-2, with each focused on a technical challenge.

- The ATM Technology Demonstration 1 (ATD-1) delivered integrated aircraft-based and ground-based automation technologies to the FAA NextGen and Air Traffic Organizations, the FAA Surveillance Based Systems Program Office, and flight operators; to enable improved arrival operations efficiency while increasing arrival throughput.
- The second ATD technical challenge (ATD-2), the Integrated Arrival, Departure, Surface (IADS) technology demonstration, will develop and demonstrate an integrated suite of tools to provide the FAA and airline operators, precision schedules for gates, runways, arrival, and departure fixes while ensuring efficient individual aircraft routes. ATD-2 will reduce unnecessary buffers imposed by the human workload associated with the tasks of simultaneously coordinating and scheduling of arrivals, departures, and runway and surface operations.

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 their 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 of this would be 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 also demonstrate that an open architecture approach, integration of air traffic technologies, system-wide data use, and advances in human-machine teaming and increasingly autonomous decision-making will provide comprehensive situational awareness and improved coordinated decision-making and disruption management using advisories to enable flexible, user-preferred, predictable, and robust operations. The project will validate and transfer key concepts and technologies to the FAA and industry stakeholders.

ATM-X will leverage the FAA's infrastructure modernization investments and NASA's Airspace Technology Demonstrations, as well as the NASA Test Bed to support air traffic management research. The NASA Test Bed will provide the building blocks to enable the simulation of all current and future ARMD airspace operations.

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; and automated mitigation strategies.

The System-Wide Safety 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.

SWS research and development achieves its two-fold goal by developing and demonstrating:

- An integrated risk assessment capability that continuously monitors airport terminal area safety margins and recommends timely operational changes based on data analytics and predictive models derived from large heterogeneous data sets and their time histories;
- Dependable monitoring, assessment and mitigation capabilities for safety-critical risks to beyond visual line-of-sight low altitude unmanned aircraft operations near populated areas;
- Cost-efficient verification and validation methods that provide justifiable confidence in safety claims for designs of complex ATM/avionics systems, including increasingly autonomous, non-deterministic systems; and

- On-board systems and new training capabilities that reduce susceptibility to precursor conditions that have led (and can lead) to aircraft loss-of-control accidents in commercial aviation.

UAS TRAFFIC MANAGEMENT (UTM)

In support of ARMD's strategic thrusts toward assured autonomy for aviation transformation (Thrust 6) and safe, efficient growth in global operations (Thrust 1), the UTM project conducts research and development activities to ensure that the future airspace management system will accommodate small UAS operating in low-altitude airspace beyond visual line of sight, with far greater levels of system complexity. The airspace management system will need to accommodate the greater diversity in user business models, aircraft performance, and airspace requirements of these emerging airspace users. The system must also ensure scalability of operations, and affordability for service providers and users. The fundamental objective of the UTM project is to develop technologies, define roles and responsibilities, and establish procedures to demonstrate feasibility of autonomous aircraft operations in urban environments. The UTM Project concludes its planned Technical Capability Demonstrations in FY 2020. However, findings from UTM research will inform research and development conducted by the Air Traffic Management Exploration and Advanced Air Mobility projects going forward.

ADVANCED AIR MOBILITY (AAM)

ARMD will begin a new Advanced Air Mobility (AAM) Project with a focus on helping to enable a new market in urban air mobility. 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. 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. One of the initial primary functions of the project is to execute a series of community "Grand Challenge" flight demonstrations that will help the entire community better assess the advances of key technologies and systems and also help identify where future research needs to focus. NASA will work closely with other government and commercial entities to achieve this objective. In particular, NASA has already forged a close working relationship with the FAA in the planning of these "Grand Challenges". 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 will facilitate planning and development in the private sector and will help ensure US leadership in this emerging market.

Program Schedule

Date	Significant Event
Mar 2019	ATM-X – Conduct a flight test demonstration of automated system negotiation and trajectory management
June 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.
June 2020	SWS – Conduct a demonstration of tools for identifying, measuring, and tracking proximity to a variety of heterogeneous safety margins during airport terminal area operations. ATD – Conduct Phase 3 full-system demonstration of the IADS metroplex departure scheduling concept.
June 2020	UTM – Complete final concept of operations and project closeout.
Sep 2020	ATM-X – Complete final NASA Test Bed Build 3 and transition to the user community
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 V&V 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

Program Management & Commitments

Program Element	Provider
Airspace Technology Demonstrations (ATD)	Provider: ARC, Langley Research Center (LaRC), GRC Lead Center: ARC Performing Center(s): ARC, LaRC, GRC Cost Share Partner(s): FAA, NATCA Honeywell, General Electric, Boeing, Raytheon, Rockwell Collins, Goodrich, Cessna Aircraft Co., American Airlines, United Airlines, EasyJet, Southwest Airlines, DoD, French Aerospace Lab (ONERA)
Air Traffic Management - Exploration (ATM-X)	Provider: ARC, LaRC, GRC Lead Center: ARC Performing Center(s): ARC, LaRC, GRC Cost Share Partner(s): FAA, Boeing, General Electric, Uber, American Airlines, Port Authority of New York and New Jersey, DLR
System-Wide Safety (SWS)	Provider: ARC, LaRC, GRC Lead Center: LaRC Performing Center(s): ARC, LaRC, GRC Cost Share Partner(s): FAA, DHS, DoD-AFRL, DoD-NAMRU, NRC, NITRD, DARPA, MITRE, Rockwell-Collins, 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, ONERA, DLR
UAS Traffic Management (UTM)	Provider: ARC, LaRC, GRC Lead Center: ARC Performing Center(s): ARC, LaRC, GRC Cost Share Partner(s): FAA, DHS, DoD, Amazon, AT&T, Google, AirMap, General Electric, Gryphon Sensors, Intel, Qualcomm, Rockwell Collins, Simulyze, Verizon, Cellular Technologies Industry Assoc., American National Standards Institute, American Society for Testing and Materials Japanese Aerospace Exploration Agency, International Civil Aviation Organization
Advanced Air Mobility (AAM)	Provider: TBD Lead Center: TBD Performing Center(s): TBD Cost Share Partner(s): TBD

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. They are widely distributed across academia and industry.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Formulation: ATM-X Project	ARMD Senior Management and Expert Review	March 2018	The Key Decision Point (KDP) Formulation Review evaluates the projects' goals and stated deliverables to ensure proper formulation and alignment with Agency and ARMD strategic objectives. The review assesses the competence of technical challenge pre-formulation efforts.	ATM-X approved for FY 2018 execution in final KDP-C review.	Not Applicable
Performance (Annual)	Expert Review	Oct 2018	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 and met all annual performance indicators.	Oct 2019

AIRSPACE OPERATIONS AND SAFETY PROGRAM

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Formulation: AAM Project	ARMD Senior Management and Expert Review		The Key Decision Point (KDP) Formulation Review evaluates the projects' goals and stated deliverables to ensure proper formulation and alignment with Agency and ARMD strategic objectives. The review assesses the competence of technical challenge pre-formulation efforts.	AAM Project scheduled for KDP-A review of preliminary formulation plans with a targeted start in FY 2021.	Fall 2019

ADVANCED AIR VEHICLES PROGRAM

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**237.7**	**--**	**188.1**	**203.3**	**212.2**	**219.3**	**224.2**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

A fifteen percent scale model of Lockheed Martin's Quiet Supersonic Technology (QueSST) X-plane preliminary design is prepared for testing in in the NASA Langley 14-by-22-Foot Subsonic Tunnel.

AAVP develops knowledge, technologies, tools, and innovative concepts to enable safe new aircraft that will fly faster, cleaner, quieter, and use fuel far more efficiently than in the past. NASA research is incorporated into all major modern U.S. aircraft, and the type of research performed by AAVP is intended to prime the technology pipeline, enabling continued U.S. leadership, competitiveness, and high-quality jobs in the future. Technologies and design capabilities developed for these advanced vehicles will be simultaneously integrated - improving vehicle performance by reducing fuel usage, noise, emissions, and intrinsic safety. 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 Armed Research Mission Directorate (ARMD) Strategic Thrusts:

- Thrust 2: Innovation in Commercial Supersonic Aircraft
- Thrust 3: Ultra-efficient Commercial Vehicles
- Thrust 4: Transition to Alternative Propulsion and Energy

NASA’s newest purpose-built experimental supersonic aircraft will now be known as the X-59 QueSST aircraft, development of which is led by the Integrated Aviation Systems Program (IASP). The aircraft is being built to support the Low Boom Flight Demonstration (LBFD) Mission which is led by the AAVP Commercial Supersonic Technology (CST) Project and supported by both the IASP LBFD and the Flight Demonstrations and Capabilities (FDC) projects. The purpose of the Mission is to develop a low-boom community response database that will be provided 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 is being conducted under the Low Boom Flight Demonstrator Project under the IASP, the FDC Project is a key contributor to the LBFD Mission and will handle flight operations during the community response testing phase of the Mission.

In addition, the Program is responsible for advancing key hypersonic technologies for the country and inspiring a long-term vision for commercial hypersonic applications.

EXPLANATION OF MAJOR CHANGES IN FY 2020

This request consolidates funding from across NASA mission directorates for certain aeroscience capabilities into a single project within Safety, Security, and Mission Service's Shared Capability Asset Program. This includes the transfer of the Aeronautics Evaluation & Testing Capability Project (AETC) from the Advanced Air Vehicles program within Aeronautics to the Safety, Security, and Mission Service account. AETC will continue to provide the necessary support for both Aeronautics and other Agency large ground test needs.

ACHIEVEMENTS IN FY 2018

- NASA worked to be able to predict noise created by the overflight of the X-59 Quiet Supersonic Technology (QueSST) aircraft. Predicting the noise and measuring the corresponding community response are key elements of the data needed to define a noise standard for supersonic flight over land and the success of the Low-Boom Flight Demonstration Mission. Using simulations conducted in NASA's Interior Effects Room, models were created for assessing human response to sounds created by overflight from the X-59 QueSST aircraft as heard indoors. Outdoor models were also created. The combination of these models enables NASA to perform studies of simulated community response to overflight noise of future supersonic commercial aircraft. These modeling results, in conjunction with the X-59 QueSST aircraft preliminary design results (which were funded through the Integrated Aviation Systems Program (IASP)), are key steps in meeting NASA's commitment to delivering a database of community responses to quiet supersonic aircraft flight over land to the International Civil Aviation Organization. (Thrust 2/Commercial Supersonic Technology [CST])
- NASA completed several studies relevant to the potential of "boundary layer ingestion" (BLI) propulsion systems in which the engine consumes (or ingests) the slower air near the aircraft surface. Experimental results of a propulsion system operating with this BLI flow showed potential aircraft fuel burn reduction of approximately 5-7 percent. Significant fuel burn reduction was also predicted for a concept using electric motors to power BLI propulsors (fans) at the rear of the aircraft fuselage. (Thrust 3/Advanced Air Transport Technology [AATT])
- NASA and Boeing completed a flight demonstration of a new reduced-drag acoustic liner located within the inlet of an engine on a Boeing 737 MAX test aircraft. NASA's novel concept significantly reduced noise during take-off and landing while reducing the drag within the engine inlet by 30 percent compared to state-of-the-art acoustic liners. This technology also has the potential to impact future derivatives of current products such as the Boeing 737 MAX. (Thrust 3/AATT)

- NASA, in partnership with Aurora Flight Sciences and the University of Michigan, completed the design, build, static load, and ground vibration testing of an advanced wing structure for airframe weight and fuel burn reduction. The 39-ft long wing is the largest and most complex “tow-steered” wing to have been built and tested. Tow-steering is employed to optimize the efficiency of the structure and reduce the weight of composite wing skins. This technology could provide a new approach to the way wings can be designed and built in the future. (Thrust 3/AATT)
- NASA developed and tested a novel design method for modern swept aircraft wings that enables significant portions of the wing (extents of the wing) to experience laminar flow. The new technology was experimentally tested in the National Transonic Facility at the Langley Research Center and demonstrated the ability to obtain extents of laminar flow that double previous extents seen on similar swept aircraft wings. Sustaining laminar flow on aircraft wings offers the potential to extend the laminar flow drag-savings and fuel-burn benefits to modern high speed aircraft. (Thrust 3/AATT)
- NASA successfully demonstrated a vehicle conceptual design process using a Multidisciplinary Design Analysis and Optimization (MDAO) framework (developed under the Transformative Aeronautics Concepts Program). The new process, incorporating multiple design codes within the framework, enabled the design of many low-noise and low-emission Vertical Take Off and Landing (VTOL) vehicle concepts. These advances in conceptual design will pave the way for the design of new vehicles for new missions such as economical inter-urban transport. (Thrust 3/ Revolutionary Vertical Lift Technology [RVLT])
- NASA, in collaboration with the FAA and Army, developed low-noise flight procedures to minimize the noise from helicopter operations. Noise measurements from six different, commonly-used, commercial helicopters enabled NASA and its partners to develop general "rules of thumb" methods for flight maneuvers that can result in less noise perceived on the ground without any physical changes required to the helicopters. These general rules were disseminated widely to operators, to reduce the noise from vehicles that are flying today. (Thrust 3/RVLT)
- NASA completed the validation process of computer-based prediction tools for composite progressive damage analysis. These validated tools and methods can be used by aircraft structure designers to predict the damage tolerance of an aircraft component while it is in the preliminary design phase. Additionally, the confidence in these prediction tools can reduce the amount of testing needed and reduce the potential for late-cycle design changes both of which contribute to overall design time and cost. (Thrust 3/Advanced Composites Project [ACP])
- NASA completed single-aisle transport aircraft concept studies with Boeing and Liberty Works to develop hybrid gas-electric propulsion (HGEP) concepts and assess the potential benefits. NASA partnered with Boeing, General Electric, the University of Illinois, and the Ohio State University to demonstrate feasibility of achieving critical performance targets of power-to-weight ratio and efficiency for 1-MW electric components with application to both NASA in-house and industry HGEP concepts. NASA demonstrated a 500 kW hybrid electric powertrain system in the NASA Electric Aircraft Testbed facility using commercial off-the-shelf components. The demonstration was the first in a series of tests leading toward a full-scale 1-MW powertrain system with advanced components to establish concept feasibility at the megawatt scale. These tests are critical in paving the way to practical, more-electric propulsion for larger air vehicles. (Thrust 4/AATT)
- NASA, Woodward, and United Technologies Research Center completed component tests for future low nitrogen oxide (NOx) emissions combustor concepts needed for small core fuel-flexible advanced turbofan engines. These future combustors are designed to be capable of increased temperatures and pressures with much smaller physical size while maintaining

necessary combustion stability and durability and creating emissions 80 percent below the 2008 international NOx emissions limit. (Thrust 4/AATT)

- NASA, in collaboration with the FAA and the German Aerospace Center (DLR), completed the NASA/DLR Multidisciplinary Airborne Experiment Alternative Fuels Flight Campaign. This flight campaign included seven joint flights of the NASA DC-8 and the DLR A320 aircraft to collect jet engine emissions data when various blends of alternative fuels were used. The comprehensive data, combined with predictive models, will help better understand aircraft soot emissions and contrails. (Thrust 4/AATT)
- NASA explored propulsion mode transition at lower Mach numbers between a simulated low-speed turbine engine and a complete high-speed dual-mode ramjet engine. These tests increased understanding of the lowest speeds that a high-speed propulsion system powering a hypersonic aircraft can be expected to operate for civil and national security missions. (Hypersonic)

WORK IN PROGRESS IN FY 2019

- NASA will perform a series of community response flight tests with an F-18 performing a low-boom dive maneuver over Galveston, Texas. The purpose of these tests is to continue to gain experience with remote aircraft operations, community noise exposure estimations, social surveys, and overall community engagement. Data from these flights will define and validate community response field study methods including indoor and outdoor noise metrics, exposure estimates, and survey tools and protocols. The data and experience gained will inform future community response studies that will be conducted using the X-59 Quiet Supersonic Technology (QueSST) aircraft currently under development in IASP. (Thrust 2/CST)
- NASA and Boeing will conduct low- and high-speed tests of an advanced transonic truss-braced wing (TTBW) design for higher cruise speed and with an integrated high-lift system. The TTBW technology enables a larger wing span for reduced drag and fuel burn while meeting a reduced structural weight requirement. To investigate the structural weight reduction NASA, in collaboration with Aurora Flight Sciences and the University of Michigan, will complete post-test analysis of the advanced "tow-steered" wing structure to assess airframe weight limitations and fuel burn reduction potential of the technology. (Thrust 3/AATT)
- NASA will complete the demonstration of vehicle design and flight operation methods to reduce VTOL aircraft noise impacts. These methods target a 50 percent reduction in the Sound Exposure Level footprint area for commercial rotary wing vehicles through a combination of improved rotor/vehicle design, flight operation methods, and understanding the human response to rotorcraft noise. These enhanced methods will assist in creating future VTOL designs that will significantly reduce community noise impact while simultaneously maintaining or improving aerodynamic performance. (Thrust 3/RVLT)
- NASA will initiate the development of a database of Urban Air Mobility (UAM) vehicle sounds that can be used to assess the cumulative noise impact of UAM fleet operations on the community, a major barrier to the viability of the UAM market. Acoustic data does not exist for these new UAM vehicle configurations, and the potential noise impact on the community is unknown. This new focus area will leverage previous noise prediction research and tool development to develop initial predictions of UAM vehicle noise. The tools will be used by the FAA, industry, and municipalities to assess and minimize the impact of UAM operations on the community. Other ARMD projects will be engaged to provide the expected flight conditions and trajectories for the vehicle operations. (Thrust 3/RVLT)

- NASA will complete the Advanced Composites Project, delivering a set of computational tools and methods that can significantly reduce the time needed to develop and certify new composite structures for aerospace applications. This work benefits American industry by helping to reduce the required time for improved aircraft designs by providing approaches for accurately predicting the life and strength of composite materials; developing techniques to rapidly inspect and characterize composite materials; and creating efficient manufacturing processes. (Thrust 3/ACP)
- NASA will mature megawatt-class Hybrid Gas- Electric Propulsion (HGEP) aircraft concepts and technologies for commercial transport aircraft. A main focus for FY19 will be design, assembly and initial testing of a MW-scaled electric aircraft powertrain in the NASA Electric Aircraft Testbed (NEAT) facility. A representative electrified aircraft powertrain with commercial off-the-shelf (COTS) non-flight-weight components will be designed and assembled in NEAT, and communications and controls will be demonstrated. In addition, aircraft concept system studies will be performed to determine how this advanced HGEP powertrain can provide an aircraft system-level fuel burn reduction and potentially enable new U.S. aviation markets for smaller transport aircraft. (Thrust 4/AATT)
- NASA will complete test result assessments on an advanced, low-emissions, fuel-flexible combustor concept for a small core engine focused on reducing harmful NOx emissions 80 percent below the 2008 international NOx emissions limits with minimal impacts on weight, noise, and component life. NASA has identified stable and efficient combustion operations as critical to enable advanced, low-emissions, fuel-flexible small core engine combustors. (Thrust 4/AATT)
- NASA will begin to apply Uncertainty Quantification (UQ) analysis approaches to hypersonic ground tests in FY 2019, building on those approaches that were identified in FY 2017 and successfully applying to a modeling & simulation problem in FY 2018. Application of these UQ approaches to ground testing will allow for increased testing efficiency, better quantification of test uncertainty, improved understanding of risk, improved understanding of where to invest money to reduce uncertainty, and improved understanding of what changes to vehicle designs will result in increased performance of hypersonic vehicles in flight. (Hypersonic)

KEY ACHIEVEMENTS PLANNED FOR FY 2020

- NASA will continue to refine the test techniques that will be used to measure the community response from future flight tests with the X-59 Quiet Supersonic Technology (QueSST) aircraft. In addition, NASA will engage the international community to ensure that these methods are consistent with expectations from the appropriate regulatory bodies. (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 so that it can be tested by multiple organizations. Named the “High Lift Common Research Model,” testing of this research model will help establish the feasibility of quiet high-lift technology concepts with the 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. Therefore, this research will contribute to advancing wing designs that may be a major aspect of future product designs. (Thrust 3/AATT)
- NASA will complete safety assessments of electric propulsion system architecture failure mode effects and associated criticality analyses on four electric vertical take-off and landing (eVTOL) aircraft concept vehicles. These analyses will identify areas with limited information on safety, durability, means of compliance, etc., and guide future research by providing insights into

component areas with the most impact. Results can be used by the FAA to help inform standards for future certification needs and provide guidance to new aviation companies on how to conduct such an analysis. (Thrust 3/RVLT)

- NASA will complete testing and analysis for reduced size/flow high pressure compressors and high temperature disk/seals that are critical for advanced small-core turbofan engines with higher engine bypass and pressure ratios that improve fuel efficiency. (Thrust 4/AATT)
- NASA will conduct experiments to demonstrate an automated mode transition between a low-speed propulsion mode utilizing an operational Turbojet Engine and a high-speed propulsion mode utilizing a simulated Dual Mode Ramjet. Demonstrating such a transition is a key enabler for practical operational hypersonic propulsion systems. NASA will develop the underlying algorithms and techniques that will allow the industry to implement this concept in a variety of concepts and provide a flexible hypersonic capability that does not exist today. (Hypersonic)

Program Elements

ADVANCED AIR TRANSPORT TECHNOLOGY

NASA's efforts related to advanced subsonic commercial transports enable advances in future aircraft performance. Research explores solutions to advance knowledge, technologies, and concepts enabling major steps in energy efficiency and environmental compatibility resulting in less fuel burned, less direct impact on the atmosphere, and less noise around airports. This project identifies and addresses potential new safety considerations associated with these advanced technologies and concepts. 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 Thrusts 3 and 4 and focuses on developing advanced technologies and tools for future generations of commercial transports – including the core propulsion research needed to develop new engines that will ultimately power the new vehicles. Although this project focuses on the far-term technology timeframe, it also contributes to both near- and mid-term by demonstrating interim technology advancements.

REVOLUTIONARY VERTICAL LIFT TECHNOLOGY

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 urban air mobility 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 other operations. RVLT research advances technologies that will increase safety and reduce noise to overcome significant barriers for the emergence of a new aviation market for urban air mobility. 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 very small unmanned configurations to configurations that are viable as inter- and intra-city transportation. Advanced future vertical lift vehicles of all classes and sizes will require safe operations, lower noise, and economical operational costs. The RVLT project primarily supports ARMD Strategic Thrust 3.

COMMERCIAL SUPERSONIC TECHNOLOGY

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 future 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 QueSST aircraft to gather data on the human responses to low-level sonic booms. This human community response data informs both national and international regulatory organizations' efforts to define certification standards that commercial aircraft manufacturers can follow to create new supersonic aircraft. In preparation for the use of the X-59 QueSST aircraft, research establishes the necessary approaches and techniques for objectively measuring the level of supersonic overflight noise acceptable to communities living in the vicinity of future commercial supersonic flight paths. These approaches, techniques, and resulting data will be the foundation of annoyance limits in the international standards.

HYPERSONIC TECHNOLOGY PROJECT

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 so that NASA can leverage their investments in ground and flight activities to develop and validate advanced physics-based computational models as building blocks towards the long-term vision. At the same time, the Department of Defense benefits from NASA expertise, analyses, testing capabilities and computational models. Focus areas for the project include hypersonic propulsion systems, re-usable vehicle technologies, high-temperature materials, and systems analysis.

Program Schedule

Date	Significant Event
Sep 2018	RVLT – Completed the demonstration of a Multi-Disciplinary Analysis Optimization (MDAO) process for vertical lift vehicles.
June 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.

Date	Significant Event
Sep 2019	RVLT – Demonstration of design of flight operation methods for reduced Vertical Take-Off and Landing (VTOL) aircraft noise impact.
Dec 2019	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.
Dec 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.
Dec 2019	AC – Completion of accurate strength & 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 & characterization methodologies to develop and demonstrate Non-Destructive Evaluation (NDE) systems to enable technologies to 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 also to connect commercial design and analysis software to enable structural optimization while resolving predicted manufacturing issues.
Dec 2019	CST – Completion of the sonic boom community response metric and field study methodology including indoor and outdoor noise metrics, survey tools and test protocols to support community studies with a demonstrator aircraft.
Dec 2020	AATT – Completion of a compact high Operating Pressure Ratio (OPR) gas generator concept to enable 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 2021	AATT- Predict likelihood of icing events with 90 percent probability in current engines operating in ice crystal environments to enable icing susceptibility assessments of advanced ultra-efficient engines.

Date	Significant Event
Sep 2021	AATT – Completion of an advanced fan & high-lift noise concept to reduce fan (lateral and flyover) and High-lift system (approach) noise on a component basis by 4 decibels with minimal impact on weight and performance.
Sep 2021	CST – Completion of a field test of with acoustic measuring equipment to be used in the validation and community testing for the Low Boom Flight Demonstration (LBFD) Mission.

Program Management & Commitments

Program Element	Provider
Advanced Air Transport Technology (AATT)	Provider: 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, Exa Corp, U.S. Navy
Revolutionary Vertical Lift Technology (RVLT)	Provider: ARC, AFRC, GRC, LaRC Lead Center: LaRC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): FAA, UTRC, U.S. Army, Bell Boeing DLR, U.S. Navy, QuesTek, Joby Aviation, PSU-ARL
Commercial Supersonic Technology (CST)	Provider: ARC, GRC, LaRC, AFRC Lead Center: LaRC Performing Center(s): ARC, GRC, LaRC, AFRC Cost Share Partner(s): Boeing, General Electric Aviation, Gulfstream Aerospace, U.S. Air Force, FAA, JAXA, Honeywell RockwellCollins, Lockheed Martin, U.S. Navy, Brigham Young University, Dept of Transportation Volpe Center, ONERA
Advanced Composites (AC)	Provider: ARC, GRC, LaRC Lead Center: LaRC Performing Center(s): ARC, GRC, LaRC Cost Share Partner(s): Boeing, General Electric Aviation, Lockheed Martin, , United Technologies Corporation, McNAIR, NIAR, Collier, Aurora, TRI/Austin, Inc, NIA, USC at San Diego, ATK Systems, Univ. of Delaware
Hypersonic Technology (HT)	Provider: 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 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. They are widely distributed across academia and industry.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Expert Review	Oct 2018	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 2019

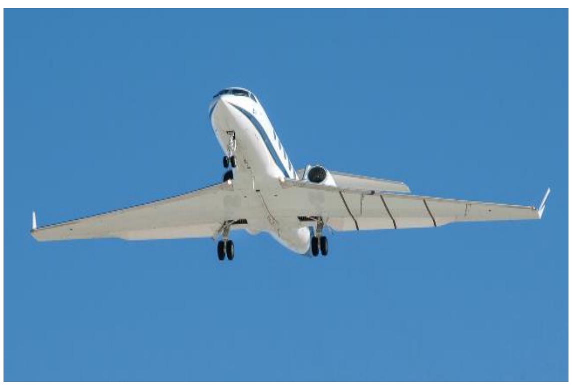
INTEGRATED AVIATION SYSTEMS PROGRAM

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Low Boom Flight Demonstrator	127.2	105.9	**103.5**	79.1	75.5	13.8	3.8
Integrated Aviation Systems Program	94.3	--	**129.7**	130.3	126.7	83.3	83.4
Total Budget	**221.5**	**--**	**233.2**	**209.4**	**202.2**	**97.1**	**87.2**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



The G3 SubsoniC Research Aircraft Testbed (SCRAT) aircraft within the Flight Demonstrations and Capabilities Project demonstrates noise reduction technologies that will be widely applicable for use on future aircraft.

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 new technologies to be incorporated 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. 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 (especially the Advanced Air Vehicles Program) to facilitate these 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 also addresses 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 civil UAS operations in the NAS. NASA will contribute 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.

NASA's newest purpose-built experimental supersonic aircraft will now be known as the X-59 QueSST aircraft, development of which is led by IASP. The aircraft is being built to support the Low Boom Flight Demonstration (LBFD) Mission which is led by the AAVP CST Project and supported by both the IASP LBFD and FDC projects. The purpose of the Mission is to develop a low-boom community response database that will be provided 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 is being conducted under the Low Boom Flight Demonstrator Project under the IASP, the Flight Demonstrations and Capabilities (FDC) Project is a key contributor to the LBFD Mission and will handle flight operations during the community response testing phase of the Mission. A separate section dedicated to the LBFD project follows the IASP program description.

IASP also leads the FDC project which provides flight testing of technologies that will enable new aircraft configurations that significantly reduce fuel consumption, noise, and emissions. IASP directly supports four of the ARMD Strategic Thrusts:

- Thrust 2: Innovation in Commercial Supersonic Aircraft
- Thrust 3: Ultra-efficient Commercial Vehicles
- Thrust 4: Transition to Alternative Propulsion and Energy
- Thrust 6: Assured autonomy for aviation transformation

EXPLANATION OF MAJOR CHANGES IN FY 2020

The Ultra-Efficient Subsonic Transport (UEST) Project will be included in the IASP portfolio for FY 2020. The project's initial focus will be integrating electric powertrain, power distribution, and energy storage components into an existing airframe and assessing performance in flight.

ACHIEVEMENTS IN FY 2018

- NASA's Landing Gear Noise Reduction effort within the FDC Project demonstrated technologies that achieved a significant reduction in airframe noise heard by communities near airports during landing. The testbed aircraft featured landing gear treatments to alter airflow and reduce noise. Test flights using this technology shared in a reduction in airframe noise of more than 30 percent, which could benefit communities near airports and foster expanded airport operations. (Thrust 3/FDC)
- NASA's FDC project successfully completed a flight test campaign with the X-56 vehicle. The FDC team demonstrated the X-56 vehicle in flight with suppressed flutter modes above 115 knots, which could be important to future long-range, fuel-efficient airliners. The goal is to prove enabling technology for designing aircraft with highly flexible, lightweight wings. This work was a cooperative effort by NASA's Advanced Air Transport Technology and Flight Demonstrations and Capabilities projects. (Thrust 3/FDC)
- NASA's FDC Project completed the X-57 Maxwell Aircraft motor controller and flight battery system testing to ensure safety in flight. Not only is this work critical for moving forward with X-57 development, but important data and lessons learned about these enabling systems are being

shared with the broader community which will aid in developing other vehicles as well. (Thrust 3/FDC)

- NASA's UAS in the NAS Project signed a Cooperative Agreement Notice with industry partners to begin flight demonstrations of Unmanned Aircraft Systems (UAS) in the NAS. NASA initiated the Systems Integration and Operationalization activity that, through collaboration with industry, will lead to multiple flight demonstrations that focus on UAS missions at altitudes greater than 500 feet above ground level, and will include integrated Detect and Avoid and Command and Control technologies. (Thrust 6/UAS-NAS)
- NASA's remotely-piloted Ikhana aircraft successfully flew its first mission without a safety chase aircraft in the NAS. The FAA granted NASA special permission to use Detect and Avoid technologies which enable the remote pilot on the ground to detect and avoid other aircraft during flight. The Ikhana flew into airspace typically reserved for commercial airliners, detected aircraft in flight, and generated data allowing the pilot to effectively communicate in real-time with airport air traffic controllers throughout various points of the flight. This milestone flight will help the United States to normalize and open new unmanned aircraft operations in the airspace used by commercial and private pilots. (Thrust 6/UAS-NAS)

WORK IN PROGRESS IN FY 2019

- In preparation for X-59 flight operations (begin in FY 2023), the FDC Project has stood up the Schlieren, Airborne Measurements, and Range Operations, for Quest (SCHAMROQ) sub-project. This sub-project is developing the capability to safely conduct in-situ measurements and optical observations of the X-59 aircraft shock wave structure and develop a mobile command center for LBFD Mission deployed community response operations. (Thrust 2/FDC)
- NASA is completing Landing Gear Noise Reduction work on a simulation-based airframe noise prediction methodology for the undercarriage and high-lift systems of large civil transports. Through simulations, this effort plans to demonstrate a greater than 30 percent reduction in the airframe component of community noise with minimal impact on aircraft weight and performance. This noise reduction would greatly benefit communities near airports and expand airport operations. (Thrust 3/FDC)
- NASA continues X-57 aircraft integration activities in preparation for first flight in FY 2020. These activities include engine mount testing, fabrication of a new, high-aspect ratio wing, and mounting electric motors for primary propulsion on the wingtips. As a result of these significant aircraft modifications, many of the integration challenges associated with installation of electrical and power distribution components will be addressed as the aircraft is prepared for flight. 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)
- UAS-NAS will complete flight testing of a low size, weight, and power airborne Detect and Avoid (DAA) surveillance capability for mid-size UAS. This flight demonstration is a key contributing event to inform standards that will define how unmanned aircraft can operate safely in the NAS. (Thrust 6/UAS-NAS)
- NASA will complete a flight test of a 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)

INTEGRATED AVIATION SYSTEMS PROGRAM

KEY ACHIEVEMENTS PLANNED FOR FY 2020

- The X-59 QueSST aircraft will be manufactured, integrated and ground tested while the community response methodology is being developed, tested and matured in preparation for the first flight and operational missions of the plane. The FDC Project is a key contributor to ensuring that operational and test infrastructure required to execute community response testing is ready for deployment. (Thrust 2/FDC)
- The UAS in the NAS Project will complete their contributions to enabling UAS to safely fly in the National Airspace System. The final deliverables for the project will include research findings through a series of technology demonstrations and simulations, to enable development of Detect and Avoid and Command and Control (C2) MOPS by RTCA for mid-size UAS. (Thrust 6/UAS-NAS)
- The UAS in the NAS Project will complete NASA's 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 in FY 2020 that focus on UAS missions at altitudes greater than 500 feet above ground level, and will include integrated Detect and Avoid and Command and Control technologies. (Thrust 6/UAS-NAS)
- The FDC Project will complete preparations and conduct the first flight of the X-57 Maxwell aircraft. NASA will continue to address and document the newly discovered integration challenges and lessons learned associated with preparing the all-electric X-57 for flight, including through the Empirical Systems Aerospace (ESAero) collaboration. FDC Project personnel will also continue to support the development of manufacturing standards for electrified aircraft systems to further enable progress for US companies to develop more electric aircraft. (Thrust 4/FDC)
- The Ultra Efficient Subsonic Transport Project will award one or more contracts to industry partners to cooperatively integrate electric powertrain, power distribution, and energy storage components for primary propulsion onto an existing airframe and then to assess the propulsion system performance through flight demonstration. The focus will be on high power electrified aircraft propulsion systems on the order of 1 megawatt power. These awards will be accomplished through open competition to determine the most impactful concepts for demonstration that provide the highest benefit to the U.S. aviation industry. (Thrust 3/UEST)

Program Elements

UNMANNED AIRCRAFT SYSTEMS (UAS) INTEGRATION IN THE NATIONAL AIRSPACE SYSTEM (NAS)

In this project, NASA focuses on technologies to enable routine civil operations for UAS. This research aligns primarily with ARMD’s Strategic Thrust 6: Assured Autonomy for Aviation Transformation, as well as Strategic Thrust 1: Safe, Efficient Growth in Global Operations. Since many of the current Federal aviation regulations support a pilot being in the aircraft, they are not directly applicable to UAS.

INTEGRATED AVIATION SYSTEMS PROGRAM

The UAS-NAS project leverages NASA expertise and capabilities to reduce technical barriers related to the safety and operational challenges associated with enabling routine UAS access to the NAS. The project is being conducted in two phases; Phase 1 began in May 2011 and ended in FY 2016. The primary focus of the Phase 1 work was development of research findings, through a series of demonstrations and simulations, to enable development of Detect and Avoid and Command and Control (C2) Minimum Operational Performance Standards (MOPS) by Radio Technical Commission for Aeronautics (RTCA) for large UAS.

The Phase 2 effort is currently underway with plans for completion by the end of FY 2020. During Phase 2, the project focuses on the development of research findings, through a series of demonstrations and simulations, to enable Phase 2 Detect and Avoid (DAA) MOPS development to expand operations to other classes of UAS. In addition, C2 MOPS development will use terrestrial communications to expand operations to other classifications of UAS. For both DAA and C2, the project will validate technologies necessary for integrating UAS into the NAS.

FLIGHT DEMONSTRATIONS AND CAPABILITIES (FDC)

NASA’s FDC project validates various technologies' benefits through focused flight experiments. FDC demonstrates the feasibility and maturity of new technologies through flight tests, utilizing collaborative partnerships from across the aeronautical industry, and includes international partners as appropriate. These demonstrations typically address technologies that have proven their potential merit through ground based or subscale testing and require results from a realistic flight environment for validation of the expected benefits.

Through the integrated use of appropriate flight test capabilities and assets, the FDC project works to validate benefits associated with critical selected technologies. The flight experiments are campaigns focused on aggressive, success-oriented schedules utilizing the most appropriate set of assets available to accomplish the experimental objectives. While many of the technologies are at relatively high TRLs, the FDC project supports all phases of technology maturation.

The FDC project utilizes specific flight research and test capabilities residing within NASA, including the Dryden Aeronautical Test Range and Simulation and Flight Loads Laboratories at the AFRC, necessary to address and achieve the ARMD Strategic Plan, and program/project activities. The project also utilizes flight research and test capabilities across the U.S. aeronautical industry and international partners as appropriate.

ULTRA-EFFICIENT SUBSONIC TRANSPORT (UEST)

NASA’s UEST Project is focused 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. The initial focus of this project is on flight demonstration of more electrified propulsion system technologies to determine the benefit of enabling technologies to further advance industry's focus on more electrified aircraft. The initial flight experiment(s) will be high power (1-megawatt) electrified powertrain demonstration(s) that evaluates 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.

Program Schedule

Date	Significant Event
Jun 2018	UAS-NAS – Completed Flights for No-Chase Certificate of Waiver or Authorization (COA)
Sep 2018	FDC – Completed Flights for X-56 Vehicle
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 First Flight
Aug 2020	SIO Demonstrations Complete
Aug 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	UAS-NAS - Project Closeout
Sep 2020	UEST – Complete Partner Selection for Electrified Aircraft Powertrain Flight Demonstration

Program Management & Commitments

Program Element	**Provider**
Flight Demonstrations and Capabilities (FDC)	Provider: 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: ARC, AFRC, GRC, LaRC Lead Center: AFRC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): None
Ultra-Efficient Subsonic Transport (UEST)	Provider: 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 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.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Annual Performance	Expert Review	Oct 2018	The 12-month review is designed for the purpose of tracking and documenting the Project's progress made towards the Strategic Thrusts and Outcomes during the fiscal year.	The Review Panel acknowledged the Projects were on the right path and expressed appreciation for the good work done by all projects to remain relevant to its stakeholders. There were no findings.	Oct 2019

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

FY 2020 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	BTC	Total
Formulation	60.9	39.6	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	100.5
Development/Implementation	12.3	88.0	105.9	**103.5**	79.1	75.5	3.5	0.0	0.0	467.8
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	10.4	3.8	0.0	14.2
2019 MPAR LCC Estimate	**73.2**	**127.6**	**105.9**	**103.5**	**79.1**	**75.5**	**13.9**	**3.8**	**0.0**	**582.5**
Total Budget	**0.0**	**127.2**	**105.9**	**103.5**	**79.1**	**75.5**	**13.8**	**3.8**	**0.0**	**508.8**
Change from FY 2019				**-2.4**						
Percentage change from FY 2019				**-2.3%**						

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

The contract for final design and manufacturing of the LBFD aircraft was awarded in FY18 paving the way to demonstrating quiet supersonic flight over land.

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 Project (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) which will be co-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 the flight research to be conducted and the IASP LBFD and Flight

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

Demonstrations and Capabilities (FDC) Projects will provide the flight vehicle and conduct flight test operations. The three-phase LBFD Mission 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 completed, NASA researchers will gather data on public acceptance of the technology by flying over a handful of U.S. cities. The finalized data is expected to be delivered in FY 2025 to the Federal Aviation Administration and the International Civil Aviation Organization, from which they can develop and adopt new rules to allow commercial supersonic flight over land.

Phase 1 of the Mission includes the LBFD aircraft development activities being led by the LBFD project, starting from detailed design, continuing through fabrication, and concluding 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. Phase 2 flights will be conducted through a collaborative effort from all three LBFD Mission projects: CST, LBFD, and FDC. For Phase 3, a NASA-led CST team will lead low-boom community response overflight studies with multiple flight test 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 be transferred from the LBFD Project team to the FDC Project to conduct planned Phase 3 flight operations. The LBFD Project will be concluded at the end of Phase 2.

EXPLANATION OF MAJOR CHANGES IN FY 2020

The LBFD project completed a successful Key Decision Point (KDP) on October 30, 2018, and the Project was given authority to proceed to the development phase. As part of the review, and incorporated into the Agency Baseline Commitment agreed to by NASA leadership, additional reserves were added in FY 2020 through FY 2024 to manage the risk associated with integration challenges related to final assembly of the aircraft.

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 improvement over the Concorde's level of 105 PLdB. Although the aircraft will be smaller in size than potential future supersonic airliners, its sonic boom ground signature will be sufficiently well-understood to enable the design and construction of larger aircraft that will be able to comply with the noise-based standards that will be set by regulators. 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 be used to conduct low-boom community response studies with multiple overflight test campaigns in varied locations over the course of two years.

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

ACHIEVEMENTS IN FY 2018

NASA awarded a $247.5 million contract to Lockheed Martin Aeronautics Company to build a single-piloted X-plane by the end of FY 2021 in support of the Low-Boom Flight Demonstration mission. The contract includes aircraft development activities from detailed design through the first flight and full aircraft envelope expansion. The project successfully completed an Integrated Baseline Review with the aircraft contractor as well as a Delta Preliminary Design Review. This design review was conducted by an Independent Review Board (IRB) comprised of subject matter experts to ensure a robust assessment of the LBFD Project; this group will continue to assess the project throughout the project life cycle. The IRB's assessment was that the project had made excellent progress toward final design and recommended they proceed out of the Formulation Phase of the project into the Development Phase.

A Joint Confidence Level Analysis was also completed in FY2018. This probabilistic analysis of the coupled cost and schedule of a project predicts the likelihood of completing all planned work at or below budgeted levels. The results of this analysis informed plans to establish the LBFD Project baseline for review at a KDP C meeting in early FY 2019.

WORK IN PROGRESS IN FY 2019

NASA completed a KDP C for the LBFD aircraft. The successful completion of KDP C represents Authorization to Proceed to the development phase of the project with approved baseline plans for the cost and schedule of the LBFD project.

NASA will conduct a Critical Design Review (CDR) to substantiate final design activities for the LBFD aircraft. The aircraft contractor will conduct aircraft build activities that include component fabrication and assembly, integration of Government Furnished Equipment, and system checkouts in preparation for the Flight Readiness Review. NASA will conduct a KDP D following the successful completion of the CDR.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

Following the successful completion of CDR, LBFD Project readiness to proceed with the next phase of hardware integration activities will be assessed at a KDP D review early in fiscal year. 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 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.

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Baseline Date	FY 2020 PB Request
Formulation Authorization	Sep 2016	Sep 2016
KDP B	Aug 2016	Aug 2016
ASM	Nov 2016	Nov 2016
PDR	Jun 2017	Jun 2017
Delta PDR	Jul 2018	Jul 2018
KDP C	Oct 2018	Oct 2018
CDR	Aug 2019	Sep 2019
KDP D	Oct 2019	Dec 2019
FRR	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 was given authority to proceed to development. The LBFD Project Life Cycle has been defined to include aircraft concept refinement studies, aircraft preliminary design, aircraft final design and build, and acoustic validation flight testing. These activities span FY 2014 - FY 2023 (Phase 1 and Phase 2 of the LBFD Mission). The LBFD Project was originally proposed to conduct the flight testing for community response testing (LBFD Mission Phase 3) through FY 2025, however, the decision was made to transition flight operations for Phase 3 activities to the Flight Demonstrations and Capabilities Project in support of community response testing that will be designed and led by the Commercial Supersonic Technology Project.

The LBFD design and build contract was awarded to Lockheed Martin on April 2, 2018. The LBFD Project and an Independent Review Board have conducted a Joint Confidence Level analysis of the Project cost and schedule and the results, along with cost and schedule reserve recommendations, were presented to the Decision Authority at KDP C. The cost and schedule for the Project will be baselined once the Decision Authority has signed the Decision Memo output from KDP C.

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

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 Mileston e Data	Milesto ne Change (mths)
2017	467.743	70%	2020	467.743	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 are denoted as JCL (*j*oint *c*onfidence *l*evel); all other CLs (*c*onfidence *l*evels) 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:	467.743	467.743	0
Flight Sciences	19.456	19.456	0
Flight Systems	17.002	17.002	0
Aircraft	230.913	230.913	0
Aircraft Operations	45.129	45.129	0
Other Direct Project Costs	155.243	155.243	0

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Flight Sciences	Vehicle sonic boom, aerodynamics, propulsion, and mission performance. NASA in-house flight simulation tools, and analysis of vehicle handling qualities and control laws Structures	Provider: ARC, AFRC, GRC, LaRC Lead Center: LaRC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): N/A	N/A
Flight Systems	Design, development, 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
Aircraft Operations	Airworthiness of aircraft, flight operations, 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, 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

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

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 70-75PLdb 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 are accomplished with 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 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.

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 will also supply 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

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

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 Independent Review Board (IRB)	Jul 2018	Delta PDR, assess readiness for KDP C	Successfully Completed	Sep 2019
Performance	LBFD Independent Review Board (IRB)	Sep 2019	CDR, assess readiness for KDP D	TBD	Dec 2021
Performance	LBFD Independent Review Board (IRB)	Dec 2021	FRR	TBD	N/A

TRANSFORMATIVE AERO CONCEPTS PROGRAM

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**112.2**	**--**	**124.4**	**130.3**	**132.3**	**134.6**	**136.7**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

Shown above is the on-board Laser-Doppler Velocimetry system specifically designed to fit inside a wind tunnel model and accurately measure the turbulent flow in the wing-body juncture region of an aircraft in tests conducted by the Transformational Tools and Technologies (TTT) Project.

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 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, thereby creating innovation for the aviation system. This results in advanced and improved computational tools, technologies, and experimental capabilities that are delivered to other aeronautics programs, industry partners, and federal collaborators inside and outside of NASA. TACP tools and capabilities have made contributions to past and present missions and hold the promise of future advances in aviation.

The program 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, the program’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 quicker adoption of program research products, TACP aggressively engages both the traditional aeronautics community and new non-traditional entities through tailored partnerships.

TRANSFORMATIVE AERO CONCEPTS PROGRAM

EXPLANATION OF MAJOR CHANGES IN FY 2020

None.

ACHIEVEMENTS IN FY 2018

- NASA completed feasibility assessments for several Convergent Aeronautics Solutions (CAS) activities. The feasibility studies culminated in the exploration of new aeronautics concepts. All activities demonstrated feasibility in key dimensions, but also revealed challenges that will need to be addressed prior to implementation. Contributions included:
    - A Learn2Fly concept that explored real-time aerodynamics modeling, adaptive controls and sensors to shave time and costs in designing, building and testing new aircraft. Both industry and the Federal Aviation Administration are pursuing transfer of these real-time modeling tools for rapid certification benefits.
    - A Digital Twin concept that developed a computer model of aircraft components to accurately predict how that aircraft will perform and ensure its safety and reliability. These models for mission safety performance may be used by future projects funded through the Exploration Technology account.
    - Mission Adaptive Digital Composite Aerostructure Technology that developed digital composite manufacturing methods to build an ultra-lightweight, adaptable aircraft wing. The robotic assembly technique developed as part of this work could be applied to advanced air and space vehicle concepts.
    - Autonomy Operating System for Unmanned Aerial Vehicles that built certified platforms needed to develop smart autonomous UAV operations applications. This work is being applied to systems research to support Urban Air Mobility concepts.
    - High Voltage Hybrid Electric Propulsion that advanced efficient power distribution systems to replace petroleum-fueled aircraft propulsion systems. This new power distribution system offers industry a light weight alternative to conventional electric drive systems. (Cross Cutting/CAS)
- Under the University Innovation (UI) Project, a total of five first-round University Leadership Initiative (ULI) Solicitation Awards executed a full year of work. 22 universities and 136 students are engaged in this research. During the year, each ULI Awardee began activities to address technical barriers inherent in achieving ARMD's strategic outcomes and proposed solutions. Activities included:
    - The University of South Carolina addressed communication capabilities for improving link/network capacity, reliability and security in support of new Air Traffic Management applications.
    - Texas A&M University addressed real-time geometric outer mold line reconfigurations that could potentially minimize sonic-boom signatures on supersonic aircraft.
    - The University of Tennessee at Knoxville began development of a slotted, natural laminar flow wing concept that could reduce wing profile drag.
    - Arizona State University released a community-based software system for analyzing safety prognostic problems for realistic air traffic environments.
    - The Ohio State University addressed the development of megawatt-class electrical powertrain components to enable electrified propulsion for future commercial aircraft. These universities and their partners are pursuing system-level research and training

students to innovate and solve challenges associate with future generation aeronautics systems to sustain U.S. competitiveness. (Cross Cutting/UI)

- The first annual ULI Technical Interchange Event was held in June 2018 in cooperation with the American Institute of Aeronautics and Astronautics to publicize the ULI efforts to academia and the aviation industry. The event received excellent feedback from the technical community and helped generate interest in future ULI solicitations. (Cross Cutting/UI)
- Under the Transformational Tools and Technologies (TTT) Project, NASA completed the juncture flow validation experiment that examined the turbulent airflow around the wing-body junction of an aircraft. NASA will apply the results from this study delivering critical turbulence models and numerical methods for separated flows. This experiment provided the critical data leading to model improvements for a reduction in the predictive error rate by 40 percent against standard test cases. This research will provide much needed validation data to assess and improve computational tools for separated flows and will lead to cheaper and more-optimal aircraft designs. (Cross Cutting/TTT)
- NASA completed the Vision 2040 for Computational Materials and Systems Report that developed a roadmap toward achieving the capability for computational design and certification of advanced materials that is needed for use in emerging aeronautical vehicle applications. This capability will allow for greater speed and reduced cost in design and certification of novel aircraft configurations. More than 450 professionals from industry, academia, government agencies and national labs participated in the development of the roadmap. (Cross Cutting/TTT)

WORK IN PROGRESS IN FY 2019

- NASA will award the second round of the competitive ULI solicitations and initiate the third round of ULI solicitations, under the UI Project. (Cross Cutting/UI)
- NASA's CAS Project has initiated three new activities. The first, Aqueous, Quick-Charging Battery Integration for Electric Flight Research, will develop nano-electrofuel aqueous batteries that will eliminate the need for long cables, reducing electro-magnetic interference, noise and fire/explosion hazards. The second activity, Adhesive-Free Bonding, will focus on replacing redundant fasteners on composite airframes with adhesive bond to reduce airframe weight and part costs. The third activity, High-Efficiency Electrified Aircraft Thermal Research, will produce a smaller thermal management system that will efficiently handle the waste heat that electrified aircraft systems will produce and improve overall performance, weight and operational costs. (Cross Cutting/CAS)
- NASA will continue to develop an open source Multidisciplinary Design Analysis and Optimization (MDAO) software framework that will enable refinement and optimization of Urban Air Mobility (UAM) vehicle designs that are characterized by tightly integrated propulsion-airframe systems that optimally account for competing requirements for performance, noise, and energy usage. Aspects of this work will support vertical lift vehicle-related activities, flight test campaign planning for the X-57 Maxwell airplane in, and could be useful to the broader UAM community. (Cross Cutting/ TTT)
- NASA will begin critical support for Certification by Analysis of future air vehicle tools. This is an effort to reduce the number of physical tests of these future vehicles and replace them with virtual tests to cut down on development and ultimately certification costs and lead times. These tools will 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 achieving improved and accelerated multidisciplinary aircraft designs,

reduced certification flight test requirements leading to substantial cost savings. (Cross Cutting/TTT)
- NASA will continue to develop cutting-edge software tools not only for computational fluid dynamics analysis, but also for areas such as Multidisciplinary Design, Analysis, and Optimization (MDAO) and Combustion Modeling. These tools are applicable to a broad range of vehicle designs and technologies, ranging from conventional subsonic fixed- and rotary-wing aircraft to UAM and other new aviation markets, and from conventional propulsion to future hybrid/electric propulsion systems. These tools will support research activities across all NASA Aeronautics programs, and other NASA Mission Directorates. They will enable U.S. airframe and engine companies to maintain superiority and leadership in both existing traditional as well as new aviation markets. (Cross Cutting/TTT)

KEY ACHIEVEMENTS PLANNED FOR FY 2020

- NASA will initiate/execute a fourth round of the competitive ULI proposals under the UI Project. These new proposals will address additional technical barriers intrinsic to achieving ARMD's strategic outcomes. (Cross Cutting/UI)
- NASA will begin new CAS activities supporting multiple ARMD strategic thrusts and the following CAS activities will go to close-out/transition and feasibility assessment:
  - Autonomy Teaming & Trajectories for Complex Trusted Operational Reliability that is building a basis for certification of autonomous systems.
  - Fit-2-Fly that creates automated procedures to speed up pre-flight and airworthiness checks for anticipated large and expanding future commercial fleets of Unmanned Aircraft Systems improving operational safety, efficiency, and cost.
  - Quantum Technologies that harnesses the power of quantum technologies to assure the availability of UAS communications without disruptions. (Cross Cutting/CAS)
- NASA plans to complete advanced high-fidelity computational analyses of the completed Turbulent Heat Flux (THX) experiment to assess the ability of such advanced techniques to accurately predict film cooling, such as that commonly used in modern jet engine turbines. These analyses, in conjunction with the detailed experimental measurements, will help U.S. industry to better understand fluid flow and heat transfer in aircraft engines and to develop new advanced designs. (Cross Cutting/TTT)

NASA will initiate a flight test of flexible, deployable vortex generator system using passive-shape, low-temperature shape memory alloys that will allow for cost-effective fuel burn reduction on transport aircraft. (Cross Cutting/TTT)

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. The project develops new computer-based tools, models, and associated scientific knowledge that provides 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 the community's design and introduction of advanced concepts. 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 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. Under TTT, the Autonomous Systems Sub-Project initiated exploration of opportunities in autonomous capabilities and architectures for autonomous airborne and ground-based systems.

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 are asked to assess the most critical technical challenges that must be solved to achieve the Strategic Implementation Plan strategic outcomes; and to propose independent, innovative research projects to solve those technical challenges. Universities develop their own success criteria, progress indicators, and technical approach. Universities pursue multi-disciplinary approaches and incorporate partnerships with other universities, industry, and U.S. entities.

Program Schedule

Date	Significant Event
Apr 2018	TTT – Completed Juncture Flow Experiment
May 2018	TTT – Completed Revolutionary Computational Aerosciences technical challenge to reduce error of turbulent flows
May 2018	TTT – Completed Physics-Based Turbulence Models and Simulations
Jul 2018	CAS – Closed out and initiated transition of Multifunctional Structures for High Efficiency Lightweight Load-bearing Storage

Jan 2019	CAS – Begin close out/transition of Spanwise Adaptive Wing and Fostering Ultra-Efficient, Low-Emitting Aviation Power
Feb 2019	UI – Award Round 2 ULI Solicitations
Mar 2019	UI – Release Round 3 ULI Solicitations
Jul 2019	CAS – Begin close out/transition of Lithium-Oxygen battery for NASA, Compact Additively Manufactured Innovative Electric Motor and Conformal Lightweight Antenna Systems for Aeronautical communication Technologies
Jan 2020	UI – Award Round 3 ULI Solicitations
Mar 2020	UI – Release Round 4 ULI Solicitations
May 2020	CAS – Begin close out/transition of Autonomy Teaming & Trajectories for Complex Trusted Operational Reliability, Fit-2-Fly and Quantum Technologies
Sep 2020	TTT – Complete deployable vortex generator system and NASA's Turbulent Heat Flux Experiment

Program Management & Commitments

Program Element	Provider
Convergent Aeronautics Solutions (CAS)	Provider: 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: 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: ARC, GRC, LaRC, AFRC Lead Center: HQ Performing Center(s): ARC, GRC, LaRC, AFRC Cost Share Partner(s): TBD

Acquisition Strategy

The research conducted through TACP activities will use a wide array of acquisition tools relevant to the research objectives including external solicitations through full and open competitions including challenges and prizes.

MAJOR CONTRACTS/AWARDS

NASA's Aeronautics programs award multiple smaller contracts, which are generally less than $5 million. They are widely distributed across academia and industry.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Expert Review	Oct 2018	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.	Nov 2019

STEM ENGAGEMENT

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**100.0**	**110.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

STEM ENGAGEMENT

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**100.0**	**110.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Change from FY 2019			**-110.0**				
Percentage change from FY 2019			**0.0%**				

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

The First Nations Launch winning teams from Chief Dull Knife College and Northwest Indian College at Kennedy Space Center August 14-16, 2018.

The FY 2020 Budget proposes the termination of NASA's traditional education portfolio of domestic assistance awards (grants and cooperative agreements). NASA will continue to support other STEM activities, such as internships and fellowships, within the Mission Directorates. A functional office at NASA headquarters (funded out of Agency Management and Operations) 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 2020

No funding is requested for Space Grant, Established Program to Stimulate Competitive Research (EPSCoR), and Minority Universe 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 2019

In August 2018, the Office of Education was replaced with the Office of STEM Engagement. In 2019 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 on-going work in FY 2019 includes imminent launch of 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, developed in 2018, will be employed.

- EPSCoR will administer the grants and support the researchers selected through their fourth year Research Infrastructure Development award, the FY 2019 Research Award and FY 2019 International Space Station Flight Opportunities award solicitations.
- In FY 2019, NASA MUREP will support multiple award selections to Minority Serving Institutions under the FY 2019 solicitation. In addition, MUREP and EPSCoR will initiate a collaborative pilot program to encourage the participation of women and other underrepresented groups in STEM research.
- Next Gen STEM will complete its pilot activities including evaluation of the initial success of the work. Also, through Museum Alliance, Next Gen STEM will connect informal education communities to STEM engagement collaborative opportunities. For FY 2019, these efforts will largely be anchored to the 50th Anniversary of Apollo 11, the first human moon landing.
- Space Grant consortia are currently implementing activities outlined in the 4-year extension to the previous 3-year base awards and the Space Grant program has released a solicitation that extends these current activities for one additional year.

WORK IN PROGRESS IN FY 2020

NASA will implement an orderly shutdown of the Office of STEM Engagement programs and projects. This effort will be guided by these overarching goals: minimize negative impact to awardees and perform closeout in a cost-effective and efficient manner.

SAFETY, SECURITY, AND MISSION SERVICES

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Center Management and Operations	1983.4	--	**2065.0**	2058.4	2052.9	1906.0	1905.8
Agency Management and Operations	843.5	--	**1019.6**	1026.2	1031.7	965.6	965.8
Total Budget	**2826.9**	**2755.0**	**3084.6**	**3084.6**	**3084.6**	**2871.6**	**2871.6**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

SAFETY, SECURITY, AND MISSION SERVICES

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Center Management and Operations	1983.4	--	**2065.0**	2058.4	2052.9	1906.0	1905.8
Agency Management and Operations	843.5	--	**1019.6**	1026.2	1031.7	965.6	965.8
Total Budget	**2826.9**	**2755.0**	**3084.6**	**3084.6**	**3084.6**	**2871.6**	**2871.6**
Change from FY 2019			**329.6**				
Percentage change from FY 2019			**12.0%**				

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

The facilities of the Arc Jet Complex are used to simulate the aerothermodynamic heating that a spacecraft endures throughout atmospheric entry, and to test candidate Thermal Protection Systems materials and systems.

Safety, Security, and Mission Services (SSMS) provides the capabilities, workforce, and facilities that enable NASA to meet national space policy priorities of scientific discovery, exploring and expanding the boundaries of human presence in space, and developing the technologies of tomorrow. These missions are accomplished by sustaining critical operations at NASA centers and facilities in ten states and the District of Columbia (Headquarters); and providing independent oversight that reduces risk to life and mission for all NASA programs.

SSMS maintains institutional and program capabilities across the Agency. Strategically, these capabilities meet workforce and infrastructure requirements necessary to enable NASA's mission.

Institutional capabilities ensure that critical Agency operations are effective, efficient, safe, and meet statutory, regulatory, and fiduciary responsibilities. Program capabilities ensure that competencies, technical skills and capabilities, and assets are readily available to meet programmatic requirements; mission and research endeavors are technically and scientifically sound; and Agency practices are consistently safe and reliable at NASA Centers.

These mission enabling capabilities and related processes are testament to the complexity of the support needed to successfully and safely implement and complete requisite missions. Following are several examples:

- Highly technical test facilities, laboratories, chambers, and other capabilities required to conduct research, development, and engineering for agency mission objectives;
- Engineering, systems engineering, and safety and mission assurance capabilities support technical activities;
- Information Technology (IT), infrastructure, and security capabilities support the productivity of NASA scientists and engineers;
- Human capital management, finance, procurement, occupational health and safety, equal employment opportunity and diversity provide needed resources throughout the Agency, and small business programs contribute to the strategic and operational planning and management that ensure resources are available when needed; and,
- International and interagency relations, legislative and intergovernmental affairs, and strategic communications facilitate communications with a broad range of internal and external communities.

EXPLANATION OF MAJOR CHANGES IN FY 2020

NASA is addressing the top priority for mission enabling capabilities by increasing facility maintenance activities at all Centers to reduce risk to missions. This funding will help reduce the backlog of facility maintenance projects and requirements associated with an aging infrastructure. This request also continues NASA's increased investment in proactive maintenance initiatives such as the conditioned-based maintenance (CBM) program to more strategically maintain mission critical capabilities.

In FY 2020, the budget, management, and oversight functions of the Aerosciences Evaluation and Test Capability (AETC) will be transferred from the Advanced Air Vehicles Program within the NASA Aeronautics Research Mission Directorate (ARMD) to the Strategic Capabilities Asset Program (SCAP). The AETC previously received funding from the Human Exploration and Operations Mission Directorate (HEOMD), Science Mission Directorate (SMD), and Space Technology Mission Directorate (STMD). This transfer will improve the overall efficiency and effectiveness of managing testing capabilities within the Agency.

ACHIEVEMENTS IN FY 2018

NASA has achieved many significant accomplishments across all mission enabling capabilities. Most notably:

- Since 2016, the Agency has increased investments in preventative and predictive maintenance, thereby reducing spending on unscheduled facility maintenance (from ~38% to 30% of total maintenance funding). In FY 2018, these investments resulted in a reduction to the amount/level of deferred maintenance (reversing a trend of increased deferred maintenance). This investment led to fewer facility failures and more reliable test schedules required to meet mission milestones.
- Agency Information Technology Services (AITS) continued the implementation of a new governance model for applications designed to promote application portfolio management, and achieved improvements across multiple portfolio health factors including cybersecurity, redundancy, interoperability, cost of ownership, and sustainability. NASA modernized cybersecurity services and governance and implemented enterprise security tools to reduce

cybersecurity risks. These efforts have resulted in NASA receiving a "managing risk" rating in the FISMA FY18 3rd quarter report.

- The Independent Verification and Validation (IV&V) program provided software expertise to 19 projects at eight NASA Centers. IV&V identified and documented 27 issues that if the issue were to manifest itself during spacecraft or system operations, NASA could experience loss of life, physical injury, and/or mission failure.
- The NASA Engineering and Safety Center (NESC) completed 31 independent assessments and satisfied 31 requests for technical support 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.
- Continued a disciplined approach to improving the Agency's operating model to deliver mission enabling capabilities more effectively and efficiently. In FY 2018, completed the framework for the program, defined the program's objectives and initiated the first phase of transformation projects in mission support. This transformation enabled mission enabling operations to be delivered in a more integrated manner providing services and support to programs and projects across geographic boundaries in a more effective, efficient and flexible manner. Phase 1 project transformations were the Office of Human Capital Management, the Office of Chief Financial Officer, and the Office of Legislative and Intergovernmental Affairs.
- NASA was named the "Best Place to Work" for the eighth year in a row among large agencies in the Federal Government. One of NASA's highly scored ratings was the "Employee Skills Mission Match" category index that measures the extent to which employees feel their skills and talents are used effectively and understand how their jobs are relevant to the organizational mission. In the Agency's Federal Employee Viewpoint Survey (FEVS) analysis, NASA identified three agency themes for employee engagement and encouraged Center-level action to address them. These three engagement levers included leadership excellence, superior communications, and employee involvement.
- Received a "Clean" financial audit opinion for the eighth consecutive year; and, for the fourth consecutive year received the Associate of Government Accountants Certificate of Excellence in Accountability Reporting (CEAR).

WORK IN PROGRESS IN FY 2019

SSMS continues its crosscutting support of the Agency's exploration, aeronautics, and science activities, using innovative approaches in providing the required programmatic, business, and administrative capabilities. Key activities underway include:

- Expand the condition-based maintenance (CBM) program to add capabilities for predictive maintenance and deploy resources where needed, when needed.
- Continue to implement several initiatives to safeguard NASA's data and IT assets. This includes improving resilience by implementing a Security Operations Center (SOC) Continuity of Operations Plan (COOP) in order to establish a plan to restore SOC operations in case of disruption. Verification testing for COOP equipment is underway, with completion planned in FY 2019.
- The Mission Support Directorate continues a multi-phase transition to new operating architectures with the alignment of budget and workforce management responsibilities to an

enterprise model. Phase 1 transitions the Office of Human Capital Management, the Office of the Chief Financial Officer, and the Office of Legislative and Intergovernmental Affairs.
- Public outreach activities promoting the NASA mission and the 50th anniversary of the first lunar landing.
- The 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.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

In FY 2020, SSMS programs will continue to balance the risks across Center and Agency services and activities to provide a safe, reliable infrastructure to conduct NASA's exploration, aeronautics, and science activities. SSMS programs will:

- Increase investments in facility maintenance and operations to enable more reliability of the infrastructure for the mission, 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.
- Continue the disciplined approach to improving the Agency's operating model to deliver mission enabling capabilities more effectively and efficiently by implementing the Phase 2 project transformations that include the Office of Small Business Programs, Office of Procurement, Office of Protective Services, Office of Diversity and Equal Opportunity, Office of Communications, and Office of STEM Engagement.
- Continue IV&V 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.
- Continue collaborative efforts between Office of Safety and Mission Assurance (OSMA), the Office of the Chief Engineer (OCE), and Office of the Chief Health Medical Officer (OCHMO) to strengthen the Agency's Technical Authority capability. The offices will work together, conducting safety reviews and independent technical assessments of NASA's missions (including ISS, Commercial Crew, Orion/SLS, Webb, robotic missions, and Space Technology investments).
- OCHMO continued implementation of all Health and Medical Technical Authority (HMTA) technical standards for research and technology (R&T) and human space flight (HSF) programs and projects; and, those related to occupational and / or environmental health requirements that are not established by the U.S. Department of Labor Occupational Safety Health Administration (OSHA) or the Environmental Protection Agency (EPA). OCHMO will continue to work as the health and medical technical authority on all human missions, including those to lunar and Mars surfaces.
- Transfer the management and oversight functions of the Aerosciences Evaluation and Test Capabilities (AETC) portfolio from ARMD, HEOMD, SMD, and STMD to the Strategic Capabilities Assets Program (SCAP). This transfer will improve the overall efficiency and effectiveness of managing testing capabilities within the Agency.

Themes

CENTER MANAGEMENT AND OPERATIONS

Center Management and Operations (CMO) provides ongoing management, operations, and maintenance of NASA Centers and component facilities throughout the United States. Centers provide the resources needed (skilled staff, specialized infrastructure, etc.) for Centers to accomplish strategic goals and objectives.

AGENCY MANAGEMENT AND OPERATIONS

Agency Management and Operations (AMO) provides management and oversight of NASA missions; and, facilitates the performance of Mission Support activities throughout the Agency. AMO activities ensure that core services are readily available across the Agency to perform mission-related roles and responsibilities.

CENTER MANAGEMENT AND OPERATIONS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Center Institutional Capabilities	1536.8	--	**1641.2**	1627.6	1613.4	1459.2	1454.2
Center Programmatic Capabilities	446.6	--	**423.8**	430.8	439.5	446.8	451.6
Total Budget	**1983.4**	**--**	**2065.0**	**2058.4**	**2052.9**	**1906.0**	**1905.8**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

Facilities Maintenance and Operations. Damage in the 10x10-Foot Supersonic Wind Tunnel complex at GRC caused by water supply leak leading to approximately 6-month delay to testing for replacement of multiple tubes. The repair was performed using CMO funds.

NASA's Center Management and Operations (CMO) budget funds ongoing management, operations, and maintenance at Centers and component facilities in nine states. CMO includes two major activities: Center Institutional Capabilities and Center Programmatic Capabilities.

Missions rely on these program and institutional capabilities to provide the skilled staff and specialized infrastructure required to accomplish their objectives.

Center institutional capabilities provide the facilities, staff, and administrative support for effective and efficient NASA Center operations. These capabilities enable NASA Centers and missions to meet its statutory, regulatory and fiduciary responsibilities.

Program capabilities support scientific and engineering activities at the Centers to reduce program risks. These program capabilities ensure that technical skills and assets are ready and available to meet program and project milestones; that missions and research are technically and scientifically sound; and that Center practices are safe and reliable.

EXPLANATION OF MAJOR CHANGES IN FY 2020

NASA is increasing facility maintenance activities at all Centers to reduce risk to missions by funding backlogged maintenance projects and requirements. Increasing failure rates for critical large equipment across Centers have affected mission testing schedules and regular maintenance requirements, reducing available funds for preventative and routine maintenance. This budget reflects NASA's priority in reducing backlogged maintenance for important buildings systems such as electrical, environmental (heating and cooling), plumbing, utilities and roofs. Due to the age of the majority of NASA's facilities (over 82% of NASA's infrastructure and facilities are beyond their constructed design life), these systems are due for replacement to improve reliability of NASA's facilities and utilities and to help reduce energy operations costs. NASA is focused on replacing aging systems that will reduce risk to mission requirements and future operating costs. NASA continues to increase its investment in its proactive maintenance initiatives such as the conditioned-based maintenance (CBM) program. Through this program, NASA will be able to lean towards industry standards for reduced unscheduled maintenance by including installing sensors and equipment to reduce scheduled maintenance inspections and allow real time monitoring.

ACHIEVEMENTS IN FY 2018

NASA continued to improve operations, enabling the Agency to meet mission requirements while conduct day-to-day technical and business operations more effectively. For example:

- Completed the Business Services Assessment (BSA) where NASA defined the health of nine business service areas within the mission support programs. With the recommendations approved over the three-year course of the BSA initiative, the Agency modified its operating principles to increase mission effectiveness and efficiency. This was achieved in a manner that maintained transparency and involved critical stakeholders throughout the process.
- NASA Centers continued to expand on the use of condition-based maintenance (CBM). Special attention was paid to remote sensing and monitoring of assets around the Centers to reduce maintenance costs and extend overall operational lifetime of assets. For example, Langley Research Center (LaRC) continued investments to expand the functionality of their CBM infrastructure that included instrumenting an additional 84 assets. Initial assessments identified approximately $170,000 in cost avoidance for FY 2018, as well as realizing the cost savings of approximately 2,500 labor hours per year through CBM-enabled adjustments to preventive maintenance plans.
- JSC completed the replacement of their antiquated commercial telephone system with a Voice over Internet Protocol (VoIP) infrastructure. This effort also included the installation of the components necessary to roll-out soft phone capability that will provide for a cheaper alternative to desk phones during the next obsolescence cycle. LaRC, Kennedy Space Center (KSC) and Stennis Space Center (SSC) also made major progress in its implementation of a VoIP telephone system. These replacement efforts align with the decline/ loss of vendor support for the existing legacy systems that pose an operational support risk to the Centers. The telephone system replacement will directly align with NASA Agency-wide voice architecture standardization and consolidation goals.
- MSFC replaced the end-of-life land mobile radio system across the Center. This system supports over 600 NASA radio users and approximately 1200 other federal government users that are Redstone Arsenal tenants (DoD, ATF, FBI, and Missile Defense Agency). SSC also established infrastructure (building enclosure and equipment) to begin the process of transitioning its aged land mobile radio system to the Mississippi Wireless Information Network (MSWIN) as an alternative and more affordable solution.
- SSC roadway improvements throughout the year included repairs made to correct deficiencies found to one of the site's entryway bridges to increase the service life and initiated project planning for the repaving of heavy trafficked streets and parking areas across the complex. Completed enhancements to several sewage lift stations, providing emergency back-up power and remote monitoring capability.

CENTER MANAGEMENT AND OPERATIONS

- White Sands Test Facility (WSTF) completed the purchase of a 300-ton mobile crane, mitigating one of WSTF's highest institutional risks. This ensures WSTF can address future program needs in heavy lift requirements to support NASA mission for the near future. The heavy lift crane supports multiple NASA programs and other Federal agencies.
- The Agency made progress in the area of Digital Transformation (DT). The High Performance Computing Incubator (HPCI) focused on advancing the Agency's readiness for a future where computational simulation architectures will be fundamentally different and orders of magnitude faster. This transformation increases NASA's and America's competitiveness through advanced simulation capability for future missions and aerospace product development. This incubator builds a critically needed high-performance computing (HPC) workforce and skillset by partnering with Department of Energy (DoE), Department of Defense (DoD), industry, and academia to rapidly evaluate and test multiple HPC architectures along with multiple numerical methods using "model" applications and, then, applying this knowledge to improve key applications.
- NASA Centers conducted a series of inspections, reviews, studies, and analysis that served to further enhance and promote NASA's Safety Culture: Annual Facility Safety Inspections, Annual Laboratory Safety Inspections, Facilities Drawing Reviews, Integration and Test Safety Operations, Construction Safety Inspections, Preconstruction Meetings/Reviews, Facility Adjacency Studies, Cryogenic Safety Analyses, Emergency Response, and Safety Program Analyses.
- Continued the multi-year effort to perform phased array ultrasonic test (PAUT) examination of MSFC layered pressure vessels. In FY 2018, MSFC examined 28 layered vessels using PAUT. These vessel inspections are one component of the overall MSFC layered pressure vessel risk mitigation plan that also includes decommission and relocation of layered vessels.
- The Centers continued a public outreach program of strategic engagement designed to reach stakeholders, external partners, employees, and the general public in support of Agency goals and objectives.

WORK IN PROGRESS IN FY 2019

In FY 2019, Centers are providing the essential day-to-day technical and business operations required to conduct NASA's exploration, aeronautics and space mission activities. Activities encompass the services, tools, and equipment required 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. Efforts underway include:

- Phase 1 of NASA's mission support transition to a new operating architecture aligned $175 million and 983 FTEs funded from the CMO program to the Agency/enterprise functional owner. Although funds remain in CMO, decisional authority and management for these dollars and workforce transitioned from the Centers to the Agency/enterprise functional owner.
- Modernize press site media hosting facility at KSC to optimize space and layout taking advantage of technology to facilitate greater coverage of NASA activities.
- Replace air handler units and appurtenances at JSC that pose the highest risk to the Agency's mission. Some units are 40 years old and their parts are obsolete. The cooling systems are past their useful life and need to be replaced.

- AFRC will invest in the digitization of 250,000 historical and irreplaceable negatives in its photo archive. The Center will accomplish this task through an agreement with JSC that will ensure the negatives are safeguarded against damage and loss. This initiative will realize an annual cost savings of $30,000.
- The HPCI project in support of Digital Transformation will focus on increased knowledge sharing among the core disciplines. The team will continue to maintain/grow strategic collaborations with other Government agencies and university partners to enable faster adoption of effective HPC for NASA missions and to rapidly achieve results that demonstrate mission relevant impact.
- The Centers will continue their proactive strategic engagement approach by supporting Agency communications events, selected conference and exhibition engagements, and other selected public outreach opportunities to engage academia, industry, and other Government agency partners.
- Continue to actively participate, lead, collaborate, and implement decisions from Business Services Assessment (BSA) and enterprise/Agency governance architecture activities. For example, in the budget/financial management area, the Agency budget formulation process was streamlined, personnel were realigned performing CFO functions, and multiple CFO functions were consolidated between AFRC and ARC.
- Continue to make CBM investments to expand the functionality of the CBM program as well as increase the number of assets within the CBM infrastructure with the goal to realize additional cost savings while increasing asset reliability in support of the Agency missions. Potential transformative/innovative pilot efforts include new CBM technologies, data analytics, and digital twin.
- Planning a significant upgrade to the WSTF Networking infrastructure as part of a planned network obsolescence. This activity will modernize the WSTF network infrastructure and will provide for a 10 gigabyte communications capability at the facility.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

Centers will provide the 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. In FY 2020, CMO will support:

- Reduction in backlogged maintenance to Center critical facility systems including electrical, utilities, corrosion mitigation, heating and cooling, water and sanitary systems as well as roofs.
- IT services and capabilities for video, voice, and desktop support at Centers to include efforts to reduce duplication of software licenses;
- Cybersecurity resources to more effectively and efficiently address vulnerabilities across the agency;
- Institutional operational safety support to protect personnel and assets, aviation safety, emergency preparedness, nuclear safety, construction safety, and other safety services;
- Realignment of the Office of Procurement, Office of Protective Services, Office of Diversity and Equal Opportunity, Office of Small Business Programs, Office of STEM Engagement and the Office of Communications from the current center-centric model to a more integrated and interdependent approach. This transformation will enable the accomplishment of ambitious

mission goals for years to come through more efficient operations, modernized capabilities, revitalized facilities, strong employee development, and more streamlined practices.

- Physical security, fire protection and response, emergency management, export control, and other basic and specialized protective services;
- Human resource management; including: recruitment, hiring, workforce planning, training, and performance management. NASA will continue to explore opportunities across the Agency to find efficiencies in workforce productivity. The Agency will apply the valued civil service workforce to priority mission work, adjusting the mix of skills where appropriate. Centers will explore cross-mission opportunities for employees whenever possible, use the range of tools available to reshape the workforce, and continue to identify, recruit, and retain a multi-generational workforce of employees who possess skills critical to the Agency.
- Senior leadership and management of the Centers, executive staff and administrative support, student programs, and developmental assignments;
- Administration and management of Center financial operations;
- Acquisition and contract management capabilities and practices supporting 41,000 procurement actions each year;
- Engineering assessment and safety oversight pertaining to the technical readiness and execution of NASA programs and projects. Analysis, design, research, test services, and fabrication capabilities to enable efficient implementation of the programs and projects.

Program Elements

CENTER INSTITUTIONAL CAPABILITIES

Center Institutional Capabilities encompasses a diverse set of activities essential for safe and effective operations. These activities provide the ongoing operations of NASA Centers and major component facilities and ensure a safe, healthy, and environmentally responsible workplace. Included are essential operations such as Center security, environmental management and safety services, and facility maintenance and operations. To support the Agency's Center-based workforce, Center Institutional Capabilities provide utilities, IT, legal, occupational health, equal employment opportunity, and human resources services. This capability manages and sustains Center staff, facilities, and operations.

CENTER PROGRAMMATIC CAPABILITIES

NASA's Center Programmatic Capabilities supports the Agency's scientific and engineering activities by providing 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, and fabrication capabilities to enable efficient implementation of the programs and projects conducted at the Centers.

Center Programmatic Capabilities provide a key component of NASA's overall system of checks and balances. The 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 at NASA Centers. These technical authorities 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.

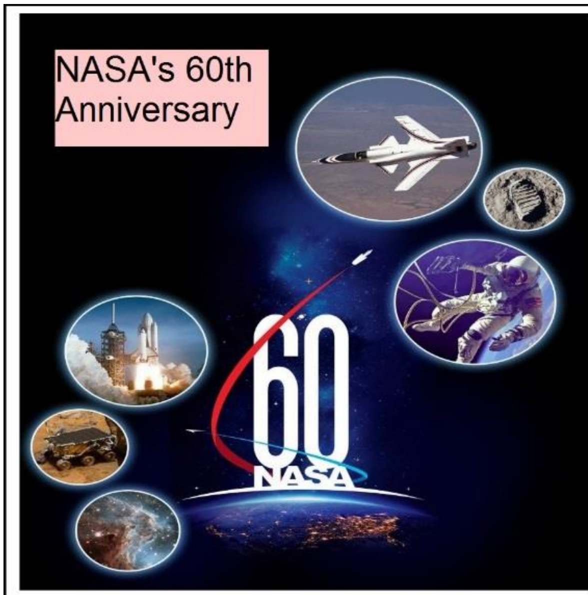
AGENCY MANAGEMENT AND OPERATIONS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Agency Management	363.7	--	**390.4**	397.0	402.3	336.9	343.0
Safety and Mission Success	175.7	--	**192.0**	192.0	194.2	186.2	186.2
Agency IT Services (AITS)	277.3	--	**275.7**	275.7	263.9	271.1	260.1
Strategic Capabilities Asset Program	26.8	--	**161.5**	161.5	171.3	171.4	176.5
Total Budget	**843.5**	**--**	**1019.6**	**1026.2**	**1031.7**	**965.6**	**965.8**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



Celebrating NASA's 60th birthday on October 1, 2018. Source: NASA History Division - NEWs and Notes. Website https://history.nasa.gov/nltrc.pdf

Agency Management & Operations (AMO) delivers management and oversight of NASA missions and performance of Agency-wide mission support activities. AMO activities at NASA Headquarters (HQ) ensure that core services are readily available throughout NASA to perform mission roles and responsibilities, and that Agency operations are effective and efficient and meet statutory, regulatory, and fiduciary requirements.

NASA HQ develops policy and guidance for the Centers and provides strategic planning and leadership; and, establishes Agency-wide requirements and capabilities that improve collaboration, efficiency, and effectiveness. Agency Management leverages resources and capabilities to meet mission needs, eliminate excess capacity, and scale assets accordingly.

AMO provides for policy-setting, executive management, direction for all corporate functions, and supports the operational activities of the HQ installation. The AMO theme consists of four programs: Agency Management (AM), Safety and Mission Success (SMS), Agency IT Services (AITS), and Strategic Capabilities Assets Program (SCAP).

AGENCY MANAGEMENT AND OPERATIONS

EXPLANATION OF MAJOR CHANGES IN FY 2020

Increased funding for Safety and Mission Assurance will begin to address the data gap for monitoring millimeter-sized orbital debris (OD), representing the highest penetration risk to most operational spacecraft in low earth orbit. The 2020 budget also establishes an engineering research & analysis initiative for NASA to advance engineering capabilities in targeted critical areas of discipline-based engineering approaches/techniques and more effectively accomplish future mission objectives through advancing the state of the art in engineering tools, techniques, and standards.

The FY 2020 Budget continues to strengthen Agency Information Technology Services (AITS). The FY 2020 request includes new investments in critical IT infrastructure and enterprise solutions. Funding will continue to support modernizing Agency systems, increased automation, and optimized delivery of enterprise-wide IT service solutions.

Strategic Capabilities Asset Program (SCAP) continues to provide effective and efficient operations for critical test capabilities. In FY 2020, the budget, management, and oversight functions of the Aerosciences Evaluation and Test Capability (AETC) will be transferred from the Advanced Air Vehicles Program within the NASA Aeronautics Research Mission Directorate (ARMD) to the Strategic Capabilities Asset Program (SCAP). This move is expected to improve the overall efficiency and effectiveness of managing Agency Testing Capabilities.

ACHIEVEMENTS IN FY 2018

AITS continued to implement a new governance model for applications designed to promote application portfolio management; and, achieve improvements across multiple portfolio health factors including cybersecurity, redundancy, interoperability, cost of ownership, and sustainability. NASA modernized cybersecurity services and governance; and, implemented enterprise security tools to reduce cybersecurity risks. The Agency implemented Phase II of Continuous Diagnostics and Mitigation CDM “Personal Identity Verification (PIV) Mandatory” project to deploy security tools that enforce PIV smartcard authentication by employees accessing NASA computers.

SCAP / JSC Chamber A completed the vacuum and cold soak testing for the Optical Telescope Element/Integrated Science Instrument Module (OTIS) hardware for James Webb Space Telescope.

Independent Verification and Validation (IV&V) provided software expertise to 19 projects at eight NASA Centers. IV&V uses a rating system to identify software issues. The ratings ranged from 1 to 5. A ‘one rating’ indicates that if the issue were to manifest itself during spacecraft or system operations, NASA could experience loss of life, physical injury, and/or mission failure. IV&V identified and documented 27 issues with a "one rating".

NASA Engineering and Safety Center (NESC) completed 31 independent assessments and satisfied 31 requests for technical support touching all of NASA’s Mission Directorates. These assessments favorably contributed towards Agency's goals and aligned directly to the mission through better-informed decision-making and an overall reduction of risk. The results included:

- A comprehensive assessment of the Multi-Purpose Crew Vehicle entry heatshield Avcoat mechanical and stress properties;
- An analysis of Carbon Overwrapped Pressure Vessel densified liquid oxygen compatibility; and,

- The applicability of these vessels to industry space vehicles. The results included a comprehensive assessment of the Explorations Systems Development (ESD) integrated vehicle dynamic test plan to an analysis of Micrometeoroid and Orbital Debris (MMOD) induced flight failures and implications for MMOD risk.

The Office of the Chief Medical Officer (OCHMO) performed Human System Integration (HSI) compliance assessment for Commercial Crew Transportation Capability (CCtCap) providers; and, developed a process that enabled Human-In-the-Loop testing at CCtCap facilities. The program published one new Agency policy directive that pertained to Human Genetics Testing; and, updated a number of Agency policy standards and directives that ensures the health and well-being of the NASA workforce.

OCHMO and the Commercial Crew Program (CCP) completed the update of the Health Stabilization Plan for Commercial Crew transport missions to the International Space Station (ISS).

Agency Management (AM) provided leadership in the development of the NASA's 2018 NASA Strategic Plan, which is the first strategic plan developed under Government Performance and Results Modernization Act (GPRAMA), including new requirements such as Strategic Reviews and Enterprise Risk Management; and NASA's implementation of the DATA Act.

NASA maintained its position as the top large agency in the 2018 rankings as the Best Place to Work in the Federal Government, improving the Agency's employee satisfaction and commitment score by continued focus on three key priority areas:

- Connecting people to each other and the mission;
- Building model supervisors; and,
- Recognizing and rewarding innovative performance.

WORK IN PROGRESS IN FY 2019

AITS will continue to implement several initiatives to safeguard NASA's data and IT assets. This includes improving its resilience by implementing a Security Operations Center (SOC) Continuity of Operations Plan (COOP) to restore SOC operations in case of disruption. NASA completed the final critical design of the COOP and procured and received the equipment required for the COOP operation. Verification testing for COOP equipment is underway; NASA anticipates COOP completion by Q2 FY 2019.

The SCAP AETC 9x15-Foot Subsonic Wind Tunnel modifications will complete tunnel background noise reduction activities. Aircraft engine fan acoustic performance has steadily improved (i.e., engines are quieter), and newer engine technologies require testing operation at Mach 0.2 to accurately simulate turbofan operating conditions and continue these noise reductions. This trend will continue, and Lower wind tunnel background acoustic noise levels are now required to record accurately record test aircraft engine acoustic data.

In FY 2019, the Mission Support Directorate will begin a multi-phase transition to new operating architectures with the alignment of budget and workforce management responsibilities. Phase 1 projects include the Office of Human Capital Management, the Office of the Chief Financial Officer, and the Office of Legislative Affairs.

AGENCY MANAGEMENT AND OPERATIONS

The Office of the Chief Engineer (OCE), including the NESC, continues to support the achievement of the Agency's major priorities. Through the Agency technical reviews, OCE maintains Technical Authority caucuses to ensure full integrity and to ensure all dissenting and divergent opinions are fully heard and appropriately considered. The 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.

Several activities underway in FY 2018 will be continued into FY 2019 including 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. In addition, work will continue on development of a Launch Vehicle Aerodynamic Buffet Flight Test to reduce uncertainties in SLS launch vehicle design loads. OCE will continue to provide leadership for a number of discipline-advancing assessments, improving the state of the art of foundational capabilities across the Agency.

OCHMO will continue to ensure that the Health and Medical Technical Authority (HMTA) is robust and will serve as an independent path for analysis; and, assure that health and medical standards are appropriately and efficiently administered by NASA programs.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

AITS has prioritized cybersecurity enhancements required to protect Agency data against the continuously evolving threat landscape. DHS is currently defining a common set of Dynamic and Evolving Federal Enterprise Network Defend (DEFEND) capabilities for NASA and other Federal agencies, filling in the existing gaps in the Agency's CDM solutions and improving overall cybersecurity reporting. NASA will work to implement the CDM Phase III DEFEND capabilities as defined by DHS.

SCAP will continue to support the development, testing, verification, and validation for NASA, Department of Defense (DoD), National Oceanic and Atmospheric Administration (NOAA), Federal Aviation Administration (FAA), and commercial companies. One of the areas included is the External Radiation Effects Testing. This pertains to the evaluation of natural space radiation environment impacts on electrical, electronic, electromechanical, and electro-optical components, systems, and related aerospace materials using ground-based high-energy particle accelerators and complementary radiation sources.

IV&V will continue to provide expert software analysis on NASA's safety and mission critical software. Analysis will be designed to help assure security, safety and mission success by identifying software problems as early as possible, minimize the cost of rework, and support key milestone decisions. IV&V Program also plans to continue to enhance its technical capabilities and focus on continuous improvement and best value.

OSMA plans to coordinate a joint effort with GSFC, Johnson Space Center, and Marshall Space Flight Center for a CapSat-DRAGONS mission to collect data on the millimeter-sized OD above 600 km altitude. FY2020 is year one of the effort, which aims to launch the mission in mid-2023.

OCE plans to continue to engage in collaborative efforts between OSMA, OCE, and OCHMO to strengthen the Agency's Technical Authority capability. The offices will work together, conducting safety reviews and independent technical assessments of NASA's missions (including ISS, Commercial Crew, Orion/SLS, scientific robotic missions, and Space Technology investments).

AGENCY MANAGEMENT AND OPERATIONS

OCHMO will continue to implement the HMTA as it pertains to all technical standards for research and technology (R&T) and human space flight (HSF) programs and projects; and, those related to occupational and / or environmental health requirements that are not established by the Occupational Safety and Health Administration (OSHA) or the Environment Protection Agency (EPA).

The Office of General Counsel (OGC) will deploy a new document and case management enterprise system across all NASA's geographic locations. This will enable a new concept of operations for the legal team as attorneys working at any geographic location can better support clients and activities in relevant practice areas at remote geographic locations.

Program Elements

AGENCY MANAGEMENT

AM provides functional and administrative management oversight for the Agency and operational support for NASA Headquarters. Agency Management governance and oversight activities include finance, protective services, general counsel, public affairs, external relations, legislative affairs, training, human capital management, procurement, real property and infrastructure, budget management, systems support, internal controls, diversity, equal opportunity, independent program and cost evaluation, and small business programs.

SAFETY AND MISSION SUCCESS

SMS programs protect the health and safety of the NASA workforce and improve the probability of safety and mission success for NASA's programs, projects, and operations. SMS includes NASA Headquarters programs, providing technical excellence, mission assurance, and technical authority. This includes the work managed by OSMA, IV&V, OCE, and OCHMO.

AGENCY INFORMATION TECHNOLOGY SERVICES

AITS provides critical technology capabilities and is dedicated to ensuring every mission can achieve success within NASA's complex environment. The AITS mission improves management and security of IT systems while improving the efficiency, collaboration capabilities, and streamlined service delivery and visibility into IT for the entire Agency.

STRATEGIC CAPABILITIES ASSETS PROGRAM

SCAP ensures the essential Agency test facilities are in a state of readiness, maintains the skilled workforce, and performs essential preventative maintenance to keep these facilities available to meet program requirements. Core capabilities supported within SCAP are thermal vacuum chambers, simulators, and the Arc Jet Facility.

AGENCY MANAGEMENT

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	363.7	--	390.4	397.0	402.3	336.9	343.0

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

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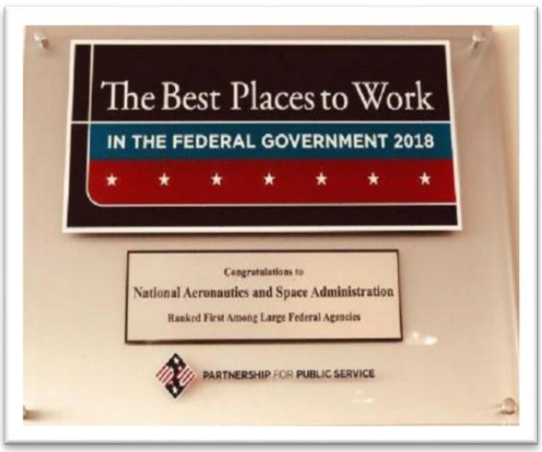

NASA Headquarters in Washington, DC provides overall planning and policy direction for HQ and the corporate management for all of its field Centers. NASA maintains its ranking, in Fiscal Year 2018, as the top large agency- Best Place to Work in the Federal Government.

The Agency Management Program (AM) provides functional and administrative management oversight Agency-wide; and, operational support for NASA Headquarters (HQ). AM delivers the competencies necessary to conduct business within the Federal government, delivers the capability to respond to legislative and other federal mandates, and supports over 35 discrete operations and mission support activities throughout the Agency.

The program provides policies, controls, and oversight across a range of functional and administrative management service areas. These include governance and oversight activities such as finance, protective services, general counsel, public affairs, and international and interagency relations. Further, AM provides legislative affairs, training, human capital management, procurement, communications, real property and infrastructure, budget management, systems support, internal controls, diversity, equal opportunity, and small business programs.

AM supports multiple HQ operational activities. These include building lease costs, facility operations costs (such as physical security, maintenance, logistics, IT hardware, and software costs), automated business systems implementation, and operations costs (such as internal control initiatives related to transparency and accountability in government).

AGENCY MANAGEMENT

EXPLANATION OF MAJOR CHANGES IN FY 2020

In 2020, The Mission Support Division (MSD) will initiate Phase 2 of the mission support transformation to realign Agency/enterprise resources and workforce management. As in Phase 1, the transition of specific management responsibilities to HQ will fundamentally enhance operations through improved integration, reduced redundancy, and asset sharing throughout the Agency.

ACHIEVEMENTS IN FY 2018

NASA continued in the rankings as the Best Place to Work in the Federal Government and continued to lead the federal government as the top large agency. In the Agency's FY 2017 and 2018 Federal Employee Viewpoint Survey (FEVS) analysis, NASA identified three agency themes for employee engagement and encouraged center-level action to address them. These three engagement levers included leadership excellence, superior communications, and employee involvement.

For the eighth consecutive year, the Agency received a “Clean” financial audit opinion. NASA received the Association of Government Accountants Certificate of Excellence in Accountability Reporting (CEAR).

NASA’s Office of Diversity and Equal Opportunity (ODEO), in partnership with an Agency level Working Group, updated the Agency’s Reasonable Accommodation Procedures to align with new EEOC disability regulations. ODEO conducted analyses and prepared the Affirmative Action Plan for Individuals with Disabilities and the Hispanic Barrier Analysis, and conducted an Anti-Harassment Forum at Johnson Space Center.

NASA's Office of Small Business Programs (OSBP) met the federally mandated requirements supported by the Agency-wide NASA Export Control Program consistent with internal and external audit recommendations to maximize the benefits of the Agency’s international efforts and ensure compliance with all mandatory U.S. export control laws, policies and regulations.

WORK IN PROGRESS IN FY 2019

Agency Management is supporting Phase 1 of NASA’s transition to a new mission support operating architecture (MAP) by providing resources, oversight and direction to ensure integration of overarching transition objectives.

The Office of General Counsel is working to identify a standard commercial legal operating system that all 10 NASA legal offices can utilize for legal document and case management in order to streamline diverse approaches and create greater efficiency for the legal enterprise.

The Office of Small Business Programs (OSBP) is planning the implementation of sustained, strategic engagement with international and interagency partners in support of growing partnership requirements for NASA programs and as part of the design and development of the Agency’s future exploration activities. In addition, OSBP will support senior NASA officials to advance cooperative activities, establish relationships with international partners and other foreign officials.

AGENCY MANAGEMENT

The Office of Communications will continue to identify opportunities and leverage public engagement capabilities across organizations and Centers and ensure effective collaboration among Center communications and/or public engagement offices to establish strong partnerships.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

Agency Management will support Phase 2 of NASA's mission support transformation by providing resources, oversight and direction to ensure integration of overarching transition objectives.

The Office of General Counsel will deploy a new document and case management enterprise system across all NASA's geographic locations. This will enable a new concept of operations for the legal team as attorneys working at any geographic location can better support clients and activities in relevant practice areas at remote geographic locations.

The Office of Procurement will implement a plan to manage the ongoing and increasing volume of contract closeouts in line with a continuing effort to develop quality reviews of the NASA FAR supplement.

Program Elements

HEADQUARTERS OPERATIONS

Headquarter Operations manages and sustains Headquarters employees and contractors, facilities, and operations required for program and institutional execution. Areas include:

- Facility operations support, including physical security, custodial, and maintenance services; equipment; expendable supplies; mail services; motor pool operations; logistics services; and emergency preparedness;
- Human resources (HR) staffing; employee payroll and benefits processing; retirement services; employee training; employee occupational health, fitness, and medical services; and grants awards processing; and,
- Headquarters operations, including support provided by Goddard Space Flight Center (GSFC) for accounting and procurement operations; configuration maintenance; automated business and administrative systems; contract close-out services; and payments to the NASA Shared Services Center (NSSC) for grants management.

MISSION SUPPORT

The Agency Management budget also provides for functional leadership of administrative and mission support activities at HQ and Centers performing this diverse set of activities on behalf of the Agency.

Mission Support activities include:

- Execution and management of the Agency's financial and budget processes and systems. This includes overseeing strategic planning, budget and financial management and accountability

AGENCY MANAGEMENT

practices while providing timely, accurate, and reliable information, and enhancing internal controls;

- Leadership and management of NASA protective services operations. This includes policy formulation; oversight, coordination and management of protective services operations, including security, fire, emergency management, and emergency preparedness; support for Agency counterintelligence and counter-terrorism activities; implementation of the Identity, Credential, and Access Management (ICAM) and other security systems, including communications; Continuity of Operations (COOP); and national intelligence community services;
- Technical expertise and oversight of Agency infrastructure and management systems for: aircraft, environmental, real property, logistics, and strategic capabilities programs; and,
- Leadership and management of the Agency’s Human Capital Resources and Equal Employment Offices (EEO). These offices engage the Agency in proactive equal opportunity and diversity and inclusion initiatives, workforce development and alternate dispute resolution services and complaint investigations.

SAFETY AND MISSION SUCCESS

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Safety and Mission Assurance	49.2	--	**57.0**	57.0	59.0	51.0	51.0
Chief Engineer	83.0	--	**91.5**	91.5	91.5	91.5	91.5
Chief Health and Medical Officer	4.4	--	**4.4**	4.4	4.6	4.6	4.6
Independent Verification and Validation	39.1	--	**39.1**	39.1	39.1	39.1	39.1
Total Budget	**175.7**	**--**	**192.0**	**192.0**	**194.2**	**186.2**	**186.2**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

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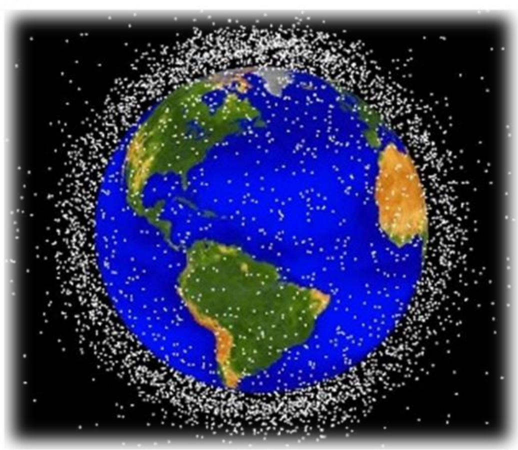


Micro-Meteoroid and Orbital Debris (MMOD)

Space Policy Directive-3 assigns efforts to characterize the small debris environment, mitigate the risk from orbital debris, and update the US Government Orbital Debris Mitigation Standard Practices.

Safety and Mission Success (SMS) programs protect the health and safety of the NASA workforce and increase the likelihood that Agency programs, projects, and operations will be completed safely and successfully. SMS includes programs that provide technical excellence, mission assurance, and technical authority Agency-wide.

The Program comprises of work managed by the Office of Mission Assurance (OSMA), including the NASA Safety Center (NSC) and the Independent Verification and Validation (IV&V); the Office of the Chief Engineer (OCE), including the NASA Engineering and Safety Center (NESC); and the Office of the Chief Medical Officer (OCHMO).

The elements of SMS reflect the recommendations outlined in many studies and by advisory boards and panels. These programs directly support NASA's core values and serve to improve the probability of safety and mission success of NASA's programs, projects, and operations, while protecting the health and safety of NASA's workforce.

SMS develops policy and procedural requirements. This program results in 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. SMS 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. SMS 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.

Programmatic resources are used to evaluate the implications on safety and mission success, including the 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 by the technical authorities to develop authoritative decisions related to the application of requirements on programs and projects.

EXPLANATION OF MAJOR CHANGES IN FY 2020

Space Policy Directive-3 (SPD-3) Goal 1 aims to advance Space Situational Awareness and Space Traffic Management Science and Technology to improve fundamental knowledge of the space environment, such as the characterization of small debris. Millimeter-sized orbital debris represents the highest penetration risk to spacecraft operating at 600-1000 km altitude (currently more than 400 spacecraft) but there is a lack of data on such small debris in the region. OSMA's plan in response to SPD-3 is to develop the Capsulation Satellite (CapSat) - Debris Resistive Acoustic Grid Orbital NASA-Navy Sensor (DRAGONS) mission to collect direct measurement data on millimeter-sized Orbital Debris at 600-1000 km altitude. The mission will address the critical data gap on small debris and improve the Agency’s ability to develop and implement cost-effective protective measures to ensure the safe operations of future missions. The data will be used to update NASA’s Orbital Debris Engineering Model (ORDEM). The model is developed and maintained by the NASA Orbital Debris Program Office (ODPO), funded by the OSMA, and used by all NASA missions and the aerospace community. OSMA proposes a joint effort with several NASA Centers - GSFC, JSC, and MSFC.

In FY 2020, new funding of $8 million will allow DRAGONS instrument and CapSat Bus development efforts to begin. With an authorization to proceed at the beginning of FY 2020, the OSMA-led CapSat-DRAGONS team will reach the Critical Design Review (CDR) phase by the end of FY 2020.

The Budget also provides $8 million for the OCE to support a new engineering research and analysis initiative. This initiative rebuilds NASA’s core engineering capability, under a unified structure, to support future missions.

ACHIEVEMENTS IN FY 2018

SMS conducted 11 formal, stringent Safety and Mission Success Reviews and seven Safety and Mission Success Assessments. These reviews represented the culmination of the identification and mitigation of all potential SMA problems for launches and high criticality events. Substantive participation in the Directorate Program Management Council (DPMC), Flight Planning Boards, Key Decision Point (KDP) reviews, and selected lower level reviews and assessments that collectively enabled effective governance and successful mission implementation.

OSMA updated nine Agency directives and seven NASA standards. Significant changes encompassed critical updates to range flight safety, Government-Industry Data Exchange Program (GIDEP) and NASA advisories, explosives safety, and metrology and calibration.

SAFETY AND MISSION SUCCESS

IV&V provided software expertise to 19 projects at eight NASA Centers. IV&V uses a rating system for issues identified in software artifacts. The issue ratings range from 1 to 5. A ‘one rating’ indicates that if the issue were to manifest itself during spacecraft or system operations, NASA could experience loss of life, physical injury, and/or mission failure. The IV&V Program identified and documented 27 issues with a "one rating".

The NASA Safety Center conducted 19 audits, assessments, and reviews at 8 separate NASA Centers and component facilities. The audit and assessment program categorized findings that provide NASA installations with opportunities to improve the safety and quality of their operations and activities. The Agency's programs and projects at these locations were reviewed to optimize and enhance their safety and quality assurance accomplishments. During the fiscal year, the NASA Safety Center also documented 157 findings that included potential systemic issues, critical concerns, non-compliances, observations, commendations, and best practices.

OCHMO, as NASA's Health and Medical Technical Authority (HMTA), created a Level One board to review and decided health and medical technical risks in a timely manner. An overhaul of the level one standards was undertaken, which streamlined the standards and placed them in an evidence-based context that would prove understandable to and implementable by engineering community. HMTA monthly board meetings made decisions on multiple program risks expeditiously, which helped NASA programs move forward from a cost and schedule standpoint. Seat angle, suit pressure, and additional memorandums of guidance helped expedite the decision process.

OCHMO updated several major Agency-level health and medical directives/standards; and continued collaborative efforts with OSMA, Health Physics Society, American Industrial Hygiene Association, and US Outdoor Laser Safety communities. During FY2018, additional achievements include the following:

- Conducted occupational health reviews at 5 NASA Centers to ensure that established requirements, sound principles, and recommended best practices used to accomplish NASA’s occupational health objectives.
- As the Agency's HMTA, ensured that risks to humans are communicated to, and addressed by, appropriate decision makers before spaceflight. With the passage of HR 6076 (To Research, Evaluate, Assess, and Treat Astronauts Act aka “TREAT”), OCHMO has led the Agency effort to provide former astronauts with diagnosis and treatment for spaceflight associated medical conditions.
- Ensured that new Common Rule for human research subjects reviewed by NASA's Institutional Review Board (IRB) and all stakeholders; and, incorporated into NASA policy.
- Converted the Flight Institutional Animal Care and Use Committee (IACUC) to an Agency asset and transitioned Intuitional Official (IO) responsibilities to NASA HQ for appropriate oversight.

SAFETY AND MISSION SUCCESS

WORK IN PROGRESS IN FY 2019

OSMA continues to assure the safety of all NASA activities through the development, implementation, and oversight of Agency-wide safety, reliability, maintainability, and quality assurance policies and procedures. Of particular importance is NASA efforts to implement to Space Policy Directive-3 (SPD-3), National Space Traffic Management Policy, and enhance SMA capabilities. Specific efforts include:

- Leading an interagency effort to update the United States Government (USG) Orbital Debris Mitigation Standard Practices. OSMA is further enhancing the OD environment definition via measurement activities and improving models used by NASA, other agencies, and commercial sector to assess the impact risk from small and large debris to satellites for the safe operations of current and future space missions.
- In collaboration with other agencies, expanding guidance for the use of commercial grade Electrical, Electronic and Electromechanical parts, with a focus on cubesat and smallsat missions, and addressing other issues related to the changing availability of parts and test facilities for high-reliability space applications.
- Investing in exploratory studies and pilots to integrate and transform assurance capabilities as part of digital engineering environments that are increasingly being adopted across the space industry.
- Investing in the development of methods to embed assurance capabilities into digital engineering
- Undertaking various policy and process development initiatives aimed at application of performance-based approaches to SMS to enable flexibility and innovation in space systems development.
- Evolving risk management policy and processes to provide for integrated management of mission, program, and institutional risks across the Agency, and explicit accountability for decisions affecting risk to SMS.

IV&V continues to provide software expertise to seventeen projects, including 14 NASA missions, Commercial Crew Program, two multi-agency missions, and across 8 NASA Centers. Additionally, IV&V continues to enhance its technical capabilities in the areas of cybersecurity and information assurance ensuring that NASA missions are secure.

OCE, including the NESC, continues to support the achievement of the Agency's major priorities. Through the Agency technical reviews, OCE maintains Technical Authority caucuses to ensure full integrity and to ensure all dissenting and divergent opinions are fully heard and appropriately considered. The 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.

Several activities underway in FY 2018 will be continued into FY 2019 including independent EDL modeling and simulation for the CCP and integrated ascent trajectory and separation analyses for the ESD SLS and Orion programs.

Work will continue on development of a Launch Vehicle Aerodynamic Buffet Flight Test to reduce uncertainties in SLS launch vehicle design loads. OCE continues to provide leadership for a number of discipline-advancing assessments, improving the state of the art of foundational capabilities across the Agency.

SAFETY AND MISSION SUCCESS

OCHMO will continue to establish health, medical, human performance policies, requirements, and standards for all human space flight programs and projects; technical standards levied on or supported by research and technology programs and projects; and NASA-unique occupational and environmental health requirements that are not mandated by OSHA or the EPA.

Currently, support is required for the Space Launch System Program (SLSP), the Orion Program, the Exploration Ground Systems (EGS) Program, the Exploration Systems Initiative (ESI), the Gateway Program, and 3 separate developments of experimental aircraft. This represents a volume of crewed vehicle development greater than at any other time in the Agency's history. Resources will be prioritized and provided to promote maximum capability.

OCHMO will continue to lead the Multilateral Medical Policy Board in addressing and resolving several critical issues dealing with crew health and medical operations support to the ISS operations.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

OSMA will coordinate a joint effort with GSFC, Johnson Space Center, and Marshall Space Flight Center for a CapSat-DRAGONS mission to collect data on the millimeter-sized OD above 600 km altitude. FY2020 is year one of the effort, which aims to launch the mission in mid-2023.

IV&V will provide expert software analysis on NASA’s safety and mission critical software. Analysis will be designed to help assure security, safety and mission success by identifying software problems as early as possible, minimize the cost of rework, and support key milestone decisions. IV&V Program also plans to continue to enhance its technical capabilities and focus on continuous improvement and best value.

OCE will engage in collaborative efforts between OSMA, OCE, and OCHMO to strengthen the Agency’s Technical Authority capability. The offices will work together, conducting safety reviews and independent technical assessments of NASA’s missions (including ISS, Commercial Crew, Orion/SLS, scientific robotic missions, and Space Technology investments).

OCHMO will implement the HMTA as it pertains to all technical standards for research and technology (R&T) and human space flight (HSF) programs and projects (including those to lunar and Mars surfaces); and, those related to occupational and/or environmental health requirements that are not established by OSHA or the EPA. International cooperation and integration are planned for the future with the new European Union General Data Protection Regulation (GDPR) signed into law in 2018, and more planning to conduct animal research on the International Space Station (ISS) by various countries.

Program Elements

SAFETY AND MISSION ASSURANCE

SMA establishes and maintains an acceptable level of technical excellence and competence in safety, reliability, maintainability, and quality engineering within the Agency. SMA assures that the risk presented by the lack of either safety requirements or compliance with safety requirements is analyzed, assessed, communicated, and used for proper decision-making and risk acceptance by the appropriate organizational leader.

Fundamental to these responsibilities are the definition and execution of a robust and well-understood methodology and process for the application of the safety, reliability, and quality in defining the level of risk. SMA conducts a schedule of reviews and assessments that focus on the life cycle decision milestones for crucial NASA programs and projects as well as for 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 is an important component of SMA and is responsible for consolidating Agency-wide SMA efforts in four key areas: SMA technical excellence, knowledge management, audits and assessments, and mishap investigation support.

INDEPENDENT VERIFICATION AND VALIDATION

Software, as an asset, on NASA's missions is extremely critical. IV&V is a proven means of making sure critical software works properly. IV&V can identify software problems as early as possible, and help minimize the cost of software development and potential rework.

The IV&V Program provides software expertise, services, and resources necessary to improve the likelihood for security, safety and mission success of programs, projects, and operations. The Program independently analyzes mission software on NASA's most critical software systems to assure security, safety and mission success of these systems.

In support of independent evaluations of software related approaches and processes, IV&V provides resources and software expertise to other SMA elements. The Program also supports the sustainment of software technical excellence within the Safety Mission Assurance (SMA) community, sustainment of software domain knowledge within the SMA organization, and formulation of software development improvement recommendations to the Agency.

IV&V Program's independent test capability enables advanced testing and simulations of NASA's mission and safety critical software; testing and evaluation of robotics and intelligent systems; capability development within the systems engineering disciplines; and training and education for workforce and students.

OFFICE OF THE CHIEF ENGINEER

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. As the Engineering Technical Authority, the 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. 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 the Agency's system of engineering standards.

SAFETY AND MISSION SUCCESS

The office 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.

OFFICE OF THE CHIEF HEALTH AND MEDICAL OFFICER

OCHMO is the technical authority which promulgates Agency health and medical policy, standards, and requirements, to support the medical technical capabilities of the Agency. It assures the physical and mental health and well-being of the NASA workforce, and assures 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, and oversees NASA's processes for reviewing the use of human and animal subjects in research.

International cooperation and integration are planned for the future with the new European Union General Data Protection Regulation (GDPR) being signed into law in 2018, and more animal research being planned on ISS by different countries. OCHMO administers the Health and Medical Technical Authority, which engages in all crewed programs from development through de-commissioning, providing health and medical direct technical support, and insight/oversight required to ensure properly Human-Rated spacecraft required to ensure mission success and the health of NASA personnel.

Annual certified continuing medical education activities and flight surgeon education support ongoing medical and health discipline professionalism and licensure. To maintain clinical currency, OCHMO sponsors university-based physician training programs. NASA's biomedical research programs, in support of human space flight, are guided by NASA-developed health and medical standards.

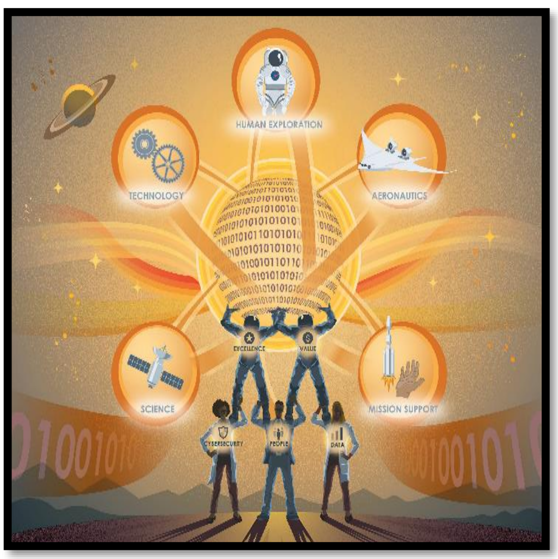
AGENCY IT SERVICES (AITS)

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
IT Management	29.4	--	**18.3**	18.3	19.2	20.6	19.1
Enterprise IT	247.9	--	**257.4**	257.4	244.7	250.5	241.0
Total Budget	**277.3**	**--**	**275.7**	**275.7**	**263.9**	**271.1**	**260.1**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



Graphic of an imagined Martian landscape and a symbolic atom with a data-filled nucleus driving NASA's five mission directorates shown as the orbiting electrons. The atom is supported by Agency personnel who represent NASA's IT Strategic Goals of Excellence, Data, Cybersecurity, Value, and People.

NASA's Agency IT Services (AITs) program provides information technologies and services to support the delivery of NASA's missions, safely and securely. AITs enables the management of information needed to fulfill NASA's mission. The program simultaneously works to secure a vast array of data and complex information technology (IT) infrastructure, from computers aboard the International Space Station (ISS) to mobile devices used Agency-wide. AITS ensures access to scientific data and promotes participation in NASA's activities. The Office of the Chief Information Officer (OCIO) provides leadership, planning, policy direction, and oversight for the management of AITS; and ensures that IT investments align to the NASA Strategic Plan and NASA IT Strategic Plan. The AITS strategy is documented in the NASA Information Technology (IT) Strategic Plan, through which NASA seeks to manage IT as a strategic resource to unleash the power of data throughout the Agency. The NASA IT Strategic Plan sets the goals and objectives for partnering with customers to deliver excellence, capitalize on data and innovation, safeguard National data and assets, maximize business value through optimization and unleash the power of NASA's data.

AGENCY IT SERVICES (AITS)

EXPLANATION OF MAJOR CHANGES IN FY 2020

Major changes in FY 2020 include $35 million for new initiatives including:

- IT Consolidation: NASA will transition IT to an enterprise operating model. The realignment will update IT business systems and enhance IT operational structures.
- Automated Segmentation Architecture: OCIO plans production deployment(s) for SD-A with NASA Automated Segmentation Architecture in FY 2020.
- End User Cloud Migration: NASA is moving its primary end user services including e-mail, instant messaging, large file transfer, and directory services to Office 365, a cloud-based solution.

ACHIEVEMENTS IN FY 2018

IT Governance and Oversight

- Identified opportunities for efficiencies, to facilitate collaboration, and to minimize redundancies, while enabling implementation of the Federal Information Technology Acquisition Reform Act (FITARA).
- Gained greater insight into IT spending for Mission Directorates by categorizing the IT portfolio into Technology Business Management (TBM) IT Towers and Cost Pools, and adopting the Office of Management and Budget (OMB) categories.

Safeguarding Data and IT Assets

- Established Office of Cybersecurity Services (OCSS) responsible to deliver and manage Agency-wide enterprise cybersecurity services. OCSS consolidated redundant cybersecurity services across NASA Centers including Identity, Credential, and Access Management (ICAM), Continuous Diagnostics and Mitigation (CDM), and Awareness and Training services.
- Completed deployment of Phase II of CDM and exceeded the FISMA 85% target score for mandatory Personal Identity Verification (PIV) card use.
- Finalized work on the Enterprise External Border Protection (EBPro), and implemented tools to secure and strengthen NASA's networks and IT infrastructure cybersecurity.

Applications Program

- Chartered Agency Software Management program and developed plan to effectively manage NASA's software licenses. Implemented e-Invoicing solution supporting the transition to electronic invoicing for federal procurements, resulting in more accurate expense reporting, increased efficiency, and transparency.
- Transitioned from virtual machine architecture to a container platform architecture. Lowered operating costs, improved cyber security compliancy, and better computing with hybrid cloud services.

Communication Program

- Provided voice, video, and network services to NASA Centers and Missions. Supported roughly 1.8 million minutes of video and 129 million minutes of voice conferencing.
- Implemented enterprise security infrastructure across the Agency that provided improved access management for assets connected to NASA's networks and enforced Agency security policies.

AGENCY IT SERVICES (AITS)

Computing Services Program (CSP)

- Migrated to the cloud in accordance with OMB guidance. Enhanced cloud portfolio by adding two additional Infrastructure as a Service (IaaS) providers:
- Closed the last of three data centers scheduled for closure. Reduced the number of data centers from 59 (FY 2010) to 20 (FY 2018).
- Continued expansion of SaaS offerings, issued five FIPS 199 Moderate Authority to Operates (ATOs) for SaaS offerings, and leveraged associated FedRAMP ATOs.

Information Management Program (IMP)

- Conducted analysis of the information flow of critical Agency information assets. Implemented advanced technology and capabilities for data hosting and concept tagging for data, and publication management.

End User Service (EUS) Program

- Refreshed over 8,500 computers, 5,200 mobile devices, and 370 printers Agency-wide.
- Expanded presence of Web Services Office elements into the enhanced service catalog.

WORK IN PROGRESS IN FY 2019

IT Governance and Oversight

- Continue using IT Portfolio Management processes and data to manage IT as a strategic resource, implement FITARA and meet OMB reporting requirements.
- Refine Capital Planning and Investment Control (CPIC) processes to better manage IT investments while linking resources to results and outcomes.

Safeguarding Data and IT Assets

- Complete CDM Phase I. Deploy cybersecurity tools on mission networks. Gain new levels of visibility into cybersecurity risks and vulnerabilities. Provide full identification of critical vulnerabilities within the mission environment available in FY 2019.
- Further solidify oversight of systems through the Enterprise Internal Border-Network Access Control (EIB-NAC) project. Manage user network access by placing users in appropriate network zones commensurate with cybersecurity policies by Q1 FY2019.

Applications Program

- Execute portfolio management strategy that results in an efficient set of applications for each business process area (i.e. deployment of Microsoft Office 365, consolidate SharePoint, review of platforms such as ServiceNow and Salesforce, and the like).
- Implement Phase 2 of Microsoft O365 (i.e. SharePoint and Teams, and Microsoft collaboration software). Consolidate multiple Center SharePoint instances and offer a centralized collaboration tool.

Communications Program

- Transition three of eleven NASA Centers to VoIP, and decommission one additional legacy TDM switch.

- Integrate multiple IP-based voice, video, and web conferencing services and transition to secure cloud-based technologies.

Computing Services Program

- Continue to prioritize migration to the cloud, complete technical integrations associated with second IaaS provide, and begin consumption of associated services. The cybersecurity assessment and technical integration work associated with the addition of third IaaS provider will continue throughout FY 2020.
- Integrate SaaS into the overall software management initiative. Sponsor several innovation initiatives to promote better understanding of developing software in clouds, including containerization, continuous integration and continuous deployment and automation.

Information Management Program

- Identify key digital assets and leverage existing and new standards to enable discovery and search across the enterprise. Expand availability of research and development (R&D) data and implement improvements to more easily reproduce publications through secure use of shared hosting and distributed metadata infrastructure.

End User Services Program

- Expand utilization of enterprise contract for end user services beyond the current utilization of 80 percent.
- Implement new information management modules including incident management, request fulfillment, problem management, change management, and a configuration management system (CMS) within enterprise service management tool.
- Complete migration of email capabilities to a cloud-based infrastructure with Office 365.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

IT Governance and Oversight

- Strengthen management and oversight of IT investments Agency-wide. Enhance IT investments in Centers and Missions. Key to governance and oversight are the efforts that will be undertaken to improve NASA's performance on the FITARA scorecard.
- Through enhanced IT data collection processes and associated analysis, drive smarter IT-related decision making. Automated IT Portfolio Management processes will provide accurate and efficient IT investment expenditure data that conform to OMB and FITARA requirements.

Safeguarding Data and IT Assets

- Implement the CDM Phase III DEFEND capabilities as defined by DHS.
- Make enhancements regarding data classification. The Agency plans to transition its current data classification standard (Sensitive but Unclassified 'SBU' Information) to the Federal 'Controlled Unclassified Information' (CUI) standard. NASA plans to publish its CUI policy, release its CUI training, and begin implementing its self-inspection program.
- Update the High Value Asset (HVA) inventory list, including the prioritized top 10 list, and provide to DHS and OMB on a quarterly basis to ensure appropriate cybersecurity protections are in place in accordance with DHS 18-02 and M-19-03.

AGENCY IT SERVICES (AITS)

Applications Program

- Conduct a phased implementation of centralized, standardized, and streamlined lifecycle processes for managing software licenses.
- Provide and mandate use of a hybrid cloud container platform to enable secure IT development. A hybrid cloud container platform enables NASA's containers to function on multiple cloud networks (e.g., NASA, Amazon, Google), giving vendor independence.
- Implement the SAP HANA platform, a modernized in-memory database for SAP – NASA's core financial system. By modernizing the financial management system, contract writing system, and business intelligence platform, the Agency will streamline financial management.

Communications Program

- Continue providing voice, video, and network services to Centers and Missions and anticipates further growth in service requests and support to missions and IT initiatives.
- Initiate a multi-year project for Agency-wide deployment of SDN to improve access management and reduce operating costs.
- Complete the transition of the final two of eleven Centers to VoIP, and decommissioning two additional legacy Tool Data Management (TDM) systems.

Computing Services Program

- Complete the on-boarding and integration of third IaaS cloud provider and begin working with customers in the new environment. Maturation of the offerings are also planned through enhancements to new vendor features and services to the authorization boundary.
- Facilitate additional Agency projects and programs in the cloud and continue promoting cloud adoption across Agency-wide, especially in innovative areas. Continue to ensure that cloud adoption is in compliance and integrated into the Agency application portfolio. In concert with cloud adoption, continue to identify opportunities for improving data center optimization efforts across the Agency.

Information Management Program

- Continue to develop and deploy solutions to improve information sharing. Invest in solutions for managing and analyzing large, complex, and growing volumes of Agency data. Planned activities include:
- Establish a system of registries that will enable loosely-coupled federations of digital assets to greatly enhance discoverability and re-use of agency information;

End User Services Program

- Use enterprise productivity applications and data storage solutions that are cloud based, device agnostic, virtual, user friendly, secure, and mobile.
- Develop an enhanced enterprise service catalog by expanding service offerings to include 85 percent of the OCIO services and revise the End User Services Service lifecycle management strategy guide (ordering, maintenance, and refreshes).

AGENCY IT SERVICES (AITS)

Program Elements

IT GOVERNANCE AND OVERSIGHT

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 laws, OMB's requirements and guidance, Executive Orders, laws, and regulations. These efforts also include the E-Government activities and Federal CIO Council Committees in which NASA participates and digital services for stakeholders who contribute to or support NASA scientific and technical research.

SAFEGUARDING NASA'S DATA AND IT ASSETS

The Cybersecurity Program is the organization responsible for Agency cybersecurity policy and implementation and management of enterprise cybersecurity services. This organization is responsible for protecting NASA from malicious actors and for ensuring the health of the Agency's cybersecurity posture. The Cybersecurity Program aligns its budget to the National Institute for Science and Technology's (NIST) Cybersecurity Framework, and assesses cybersecurity gaps and investments against the NIST cybersecurity functions: Identify, Detect, Protect, Respond, and Recover. This approach 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.

SERVICE DELIVERY EXCELLENCE

The Service Delivery Excellence program element includes a wide portfolio of activities to strengthen the delivery of IT services throughout the Agency. Specifically, the Applications Program has programmatic responsibility for enterprise service delivery and governance of applications and web sites. This program monitors the NASA applications ecosystem and identifies opportunities to simplify, eliminate and optimize applications usage.

The Communications Program is NASA's enterprise service provider for fully managed network and communications services. The program provides end-to-end enterprise services for NASA's users for voice, conferencing, video distribution, wide area, local area, and data center networks, and cybersecurity infrastructure.

The Computing Services Program provides key enterprise services to allow for Agency adoption of cloud computing technology, demonstrated by a healthy rate of adoption across all cloud services models. The program is also responsible for data center consolidation efforts and completed its final data center closure in FY18, and will continue to work on improving data center optimization metrics.

The Information Management Program delivers an Agency-wide information management framework and services for data and information assets, tools, and platforms to optimally and securely leverage NASA's information resources.

NASA's End User Services Program provides high-quality, reliable, cost-effective service desk, end user compute, collaboration, content management systems and services in support of all NASA Federal and

AGENCY IT SERVICES (AITS)

contractor employees. Specific service types supported by the program are laptops, desktops, mobile devices, print, enterprise email, SharePoint, instant messaging, help desk services, support, software patching and distribution, and other end user support capabilities

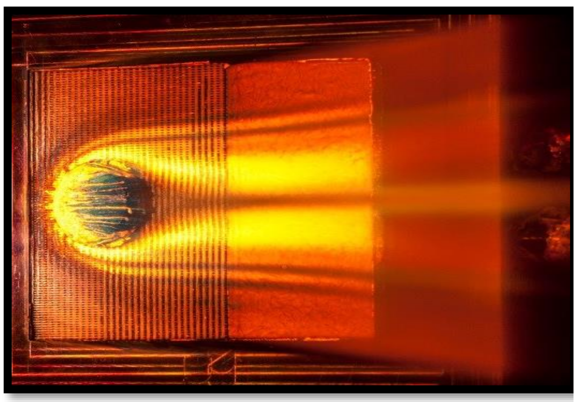
STRATEGIC CAPABILITIES ASSET PROGRAM

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**26.8**	**--**	**161.5**	**161.5**	**171.3**	**171.4**	**176.5**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



Scaled test article representing an Orion compression pad in the Interaction Heating Facility at the NASA Arc Jet Complex, Ames Research Center, Moffett Field, California. This is a test of the thermal protection material response to conditions anticipated during the entry of the Orion capsule upon return from cis-lunar space.

The Strategic Capabilities Assets Program (SCAP) ensures select critical test facilities are operationally ready to meet mission and program requirements by sustaining a skilled workforce and performing essential maintenance. The program supports essential core technical capabilities: arc jets, simulators, thermal vacuum chambers, wind tunnels, and space radiation environments.

The program strategically and centrally manages Agency assets, reviews assets and capabilities annually to ensure meeting mission requirements, identifies reinvestment and recapitalization needs, and recommends disposition of capabilities no longer needed.

SCAP ensures maximum benefit across the government by broadening alliances outside the Agency for capabilities (e.g., thermal vacuum chambers) and technical support. Facilitating this endeavor are the National Partnership for Aeronautical Testing (NPAT) and Space Environment Test Alliance Group, collaborative working groups consisting of NASA, the Department of Defense (DoD), and other partner entities. SCAP also collaborates with the Department of Energy’s Office of Nuclear Physics and Office of Science, the Air Force Space and Missiles Centers, and the Naval Research Office to support the National Academies of Science study on space radiation test infrastructure.

EXPLANATION OF MAJOR CHANGES IN FY 2020

In FY 2020, the Aerosciences Evaluation and Test Capabilities (AETC) portfolio transfers to SCAP. This transfer is intended to improve the overall efficiency and effectiveness of managing testing capabilities within the Agency. AETC's management and oversight functions will move from ARMD's Advanced Air Vehicles Program (AAVP), and funds ($117 million) will transfer from ARMD, HEOMD, SMD, and STMD.

STRATEGIC CAPABILITIES ASSET PROGRAM

AETC sets the strategic direction for NASA's versatile and comprehensive portfolio of ground test aeronautics research capabilities and assets. Among these assets are subsonic, transonic, supersonic, and hypersonic wind tunnels, propulsion test facilities, and icing simulation at Ames Research Center (ARC), Glenn Research Center (GRC), and Langley Research Center (LaRC). AETC's integrated approach to asset planning, use, and management includes the complementary high-end computing capabilities necessary for advanced analyses in conjunction with the ground experimentation capabilities.

AETC actively participates in the NPAT, a council co-chaired by NASA and the DoD. The council enables an integrated strategy for the management of national aeronautics test capabilities through cooperation and coordination. NPAT initiatives have led to an agreement on the guiding principles for facility pricing and access, the inventory and technical assessments of U.S. wind tunnels, the improved understanding and collaboration between government and industry operators and users, and the establishment of a national force measurement technology capability.

ACHIEVEMENTS IN FY 2018

In FY 2018, SCAP reviewed and assessed the condition and health of the Space Environments Testing capability components at GRC and identified high-risk areas which became the focus for out-year planning, additional studies, or engineering designs.

SCAP established a block buy purchase agreement for external radiation testing services to ensure continued Agency access to heavy ion and proton testing for current and future flight electronic parts qualification and radiation research and technology development .

SCAP managed capabilities provided risk mitigation and space vehicle assembly, integration, and testing to support NASA's mission. FY 2018 highlights included:

- NASA's Arc Jet Complex performed risk reduction activities in support of Orion Exploration Mission 1 development and the expansion of the thermal protection system (TPS) performance envelope. These risk reduction activities are critical to ensuring successful passage through the atmosphere upon Orion's return to Earth. The Arc Jet Complex also supported the development of NASA and commercial partner concepts and materials to improve TPS for extreme heating environments and replace solutions no longer available from legacy sources.
- ARC's Vertical Motion Simulator (VMS) investigated how different motion cueing strategies affect manual control behavior and performance during stall recovery maneuvers. This research is fundamental to understanding pilot reaction and performance in emergency conditions; and to developing mitigation techniques and training.
- GRC's Space Environments Complex (SEC) completed the reverberant acoustic testing for the Orion Ascent Abort 2 (AA-2) and reverberant acoustic and modal testing for the SpaceX Dragon 2 spacecraft. These tests are part of the certification needed before clearance for flight; and the test data validate the computational modeling and design of the spacecraft.
- Johnson Space Center's (JSC) Chamber A completed the vacuum and cold soak testing for the Optical Telescope Element/Integrated Science Instrument Module (OTIS) hardware for James Webb Space Telescope (JWST). This testing was required to validate performance in a space environment.
- JSC's Chamber B completed Capsule Parachute Assembly System Rapid Assent Test for Orion to validate the performance of the parachute assembly.

STRATEGIC CAPABILITIES ASSET PROGRAM

Further, SCAP removed the Goddard Space Flight Center (GSFC) Six-Degrees of Freedom vibration system and the LaRC Visual Motion Simulator from service due to equipment obsolescence and lack of future requirements. The estimated annual cost avoidance for preventative maintenance and repairs totals approximately $200K.

WORK IN PROGRESS IN FY 2019

During FY 2019, SCAP will complete the condition and health assessment of the space environments testing capability at LaRC to identify high-risk areas and to develop a corresponding five-year plan for investment. Additional work in progress includes:

- Initiating Arc Jet Modernization planning. Recent equipment failures and facility inspections raised concerns with reliability and availability and the unacceptable risk associated with an unplanned extended downtime of the Apollo-era facility of up to a total of two years. SCAP will engage in the planning necessary to sequence investment projects to minimize the impact to planned customer testing.
- Continuing AETC transition activities to support the seamless transfer from AAVP to SCAP.
- Removing the solar simulation capability from the GRC Vacuum Facility 6 and the LaRC Differential Maneuvering Simulator due to the lack of future requirements. The estimated annual cost avoidance for preventative maintenance and repairs totals approximately $150K, and the divestment avoids a deferred refurbishment cost of approximately $25M.

SCAP's technical capabilities are supporting NASA's missions by enabling:

- TPS development for Orion and for planetary science missions at the Arc Jet Complex.
- Thermal vacuum and electromagnetic interference testing of the Orion EM-1 vehicle at the GRC SEC.
- Mars Helicopter development testing and preparations for Mars 2020 at the Jet Propulsion Lab's (JPL) 25’ Space Simulator.
- Improved flight training and aviation safety using NASA’s synthetic vision technologies and simulators at the LaRC Flight Simulation Facilities (FSF).

KEY ACHIEVEMENTS PLANNED FOR FY 2020

In FY 2020, SCAP expects a successful transition of AETC in FY 2020. SCAP will assess the condition and health of the simulation testing capability at ARC and LaRC to identify high-risk areas and develop a five-year investment plan.

SCAP plans to sustain strategic technical capabilities required by NASA to achieve mission success and support the development, testing, verification, and validation for NASA, DoD, NOAA, FAA, and commercial companies in the following areas:

- TPS materials, system development, and qualification testing in the Arc Jet Complex.

- Air traffic management technology demonstration, Unmanned Aerial System airworthiness standards and guidelines, motion cueing, loss of control and recovery, and enhanced stall modeling in the ARC and LaRC Simulators.
- Orion, JWST, Mars 2020, Europa, and Commercial Crew and Crew Cargo launch program testing in thermal vacuum and acoustic chambers.
- Accuracy, efficiency, and sufficiency reliance on only computational analysis for supersonic wind tunnel testing in AETC.
- Space radiation environment impacts on electronic and related aerospace materials systems using external, ground-based, high-energy radiation sources.

Planned testing in SCAP managed assets include:

- Orion thermal vacuum and acoustics and vibrations testing at the GRC SEC.
- Orion heat shield development and TPS testing at the NASA Arc Jet Complex.
- Supersonic testing in the LaRC Unitary Plan Wind Tunnel to assess the viability of reliance on computational fluid dynamics analyses.

Program Elements

HIGH ENTHALPY TEST CAPABILITY

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. To do this, a gas (typically air) is heated using a continuous electrical arc and accelerated to supersonic/hypersonic speeds. This high-temperature gas passes over a test sample and produces an approximation of the surface temperature and pressure environments experienced by a vehicle during atmospheric entry.

SIMULATORS

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 missions operations. The capability includes an array of simulator components used in the research and development of flight and crewed operations:

- The Vertical Motion Simulator and its associated laboratories at ARC; and,
- The Flight Simulation Facilities and supporting suite of simulators (the Differential Maneuvering Simulator, the Test and Evaluation Simulator, and the Development and Test Simulator) and associated laboratories at LaRC.

SPACE ENVIRONMENTS TEST CAPABILITY

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, this capability simulates the ultra-low pressures and low temperatures experienced in deep space; and, the noise and vibration levels experienced during launch. Testing performed with these capabilities ensures the equipment, sub-systems, and assembled spacecraft will meet the strict requirements of harsh launch and space environments.

EXTERNAL RADIATION TESTING CAPABILITY

This capability procures the necessary testing time and facility support at external facilities to meet the requirements of NASA 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.

AEROSCIENCES EVALUATION AND TEST CAPABILITIES

Starting in FY 2020, the ground test capabilities necessary to develop future air and space vehicles. Among these capabilities are subsonic, transonic, supersonic, and hypersonic wind tunnels, propulsion test facilities, and icing simulation at ARC, GRC, and LaRC. NASA's integrated approach to test capability includes the complementary computational tools, software, and related systems to effectively acquire and process research data. These test facilities and capabilities also serve the needs of non-NASA users.

HEADQUARTERS WORKFORCE BY OFFICE

AGENCY MANAGEMENT BUDGET BY HEADQUARTERS OFFICE

	Actual	Current	Request		
($ in millions in full cost)	**FY 2018**	**FY 2019**	**FY 2020**	**FY 2021**	**FY 2022**
Aeronautics Research	7.0	6.9	7.3	7.4	7.6
Human Exploration and Operations	28.1	27.4	29.1	29.8	30.3
Science	29.2	28.4	30.2	30.9	31.4
Space Technology	5.8	5.8	6.2	6.3	6.4
Mission Directorates	**70.1**	**68.5**	**72.7**	**74.5**	**75.7**
Office of the Administrator	5.2	5.0	5.3	5.4	5.4
Office of Strategy and Plans	1.2	2.4	2.1	2.1	2.1
Chief Engineer	4.0	3.9	4.1	4.2	4.3
Chief Financial Office	35.4	35.6	39.6	40.5	41.2
Chief Health and Medical Office	2.2	2.1	2.2	2.3	2.3
Chief Information Office	9.0	8.9	9.4	9.6	9.8
Chief Scientist	1.5	1.4	1.4	1.5	1.5
Chief Technologist	0.8	0.8	0.8	0.8	0.9
Communications	14.9	14.3	15.2	15.5	15.6
Diversity and Equal Opportunity	4.2	4.0	4.2	4.2	4.3
STEM Engagement	2.6	2.5	2.7	2.7	2.8
General Counsel	10.3	9.9	10.4	10.7	10.8
International and Interagency Relations	13.5	12.9	13.9	14.1	14.3
Legislative and Intergovernmental Affairs	4.0	3.9	5.1	5.3	5.4
Safety and Mission Assurance	7.7	7.4	7.9	8.1	8.2
Small Business Programs	2.1	1.9	2.2	2.2	2.2
Staff Offices	**118.5**	**116.9**	**126.6**	**129.3**	**131.2**
NASA Management Office at JPL	9.4	9.7	9.6	9.7	9.8
Human Capital Management	9.3	12.4	14.9	15.4	17.2
Headquarters Operations	100.1	98.4	109.9	110.7	110.5
Strategic Infrastructure	15.9	15.6	16.8	17.1	17.3
Procurement	11.0	10.6	11.3	11.4	11.5
Mission Support Directorate Front Office	4.3	4.1	4.2	4.3	4.3
NASA Shared Services Center	4.8	4.9	4.9	4.9	4.9
Protective Services	20.3	19.0	19.5	19.8	19.9
Mission Support	**175.1**	**174.8**	**191.1**	**193.2**	**195.5**
Total Agency Management	**363.7**	**360.2**	**390.4**	**397.0**	**402.3**

HEADQUARTERS WORKFORCE BY OFFICE

HEADQUARTERS WORKFORCE BY OFFICE

	Actual				Current				Request			
	FY 2018				FY 2019				FY 2020			
Headquarters	**FTE**	**SES**	**Non-Career**	**WYE**	**FTE**	**SES**	**Non-Career**	**WYE**	**FTE**	**SES**	**Non-Career**	**WYE**
Aeronautics Research	34	6		11	33	8		11	33	8		11
Human Exploration and Operations	130	21		57	130	17		58	130	17		58
Science	146	7		64	146	22		64	146	22		64
Space Technology	33	3		13	33	2	1	12	33	2	1	12
Mission Directorates	343	37	0	145	343	49	1	145	343	49	1	145
Office of the Administrator	20	4	4	2	20	6	2	2	20	6	2	2
Office of Strategy and Plans	3	17	1	2	3	0		2	3	0		2
Chief Engineer	18	3			18	3			18	3		
Chief Financial Officer	107	4		42	114	10	1	42	114	10	1	42
Chief Health and Medical Officer	11	2		2	10	2		3	10	2		3
Chief Information Officer	42	3		77	42	5		77	42	5		77
Chief Scientist	5	1			5	1			5	1		
Chief Technologist	3	1			3	1			3	1		
Communications	49	0	2	27	48	2	4	27	48	2	4	27
Diversity and Equal Opportunity	14	2		1	13	3		1	13	3		1
STEM Engagement	12	10		0	12	4		0	12	4		0
General Counsel	41	2			42	6			42	6		
International and Interagency Relations	50	7		7	51	7		7	51	7		7
Legislative and Intergovernmental Affairs	23	1	2		23	1	3		23	1	3	
Safety and Mission Assurance	35	2		7	35	6		7	35	6		7
Small Business Programs	5	1		4	5	1		4	5	1		4
Staff Offices	438	60	9	171	443	58	10	172	443	58	10	172
NASA Management Office at JPL	25	2		0	26	2		0	26	2		0
Human Capital Management	34	3		15	34	8		15	34	8		15
Headquarters Operations	91	4		340	91	3		333	91	3		333
Infrastructure	52	5		2	52	6		2	52	6		2
Procurement	40	3			40	5			40	5		
Mission Support Directorate Front Office	15	6		1	15	3		1	15	3		1
Protective Services	39	6		6	39	4		6	39	4		6
Mission Support	296	29	0	364	298	31	0	357	298	31	0	357
Total Agency Management	**1,077**	**126**	**9**	**680**	**1,084**	**138**	**11**	**674**	**1,084**	**138**	**11**	**674**

**NC is Non-Career*

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Construction of Facilities	483.1	--	**517.5**	385.9	385.9	385.9	304.9
Environmental Compliance and Restoration	86.4	--	**82.9**	82.9	82.9	82.9	82.9
Total Budget	**569.5**	**348.2**	**600.4**	**468.8**	**468.8**	**468.8**	**387.8**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Construction of Facilities	483.1	--	**517.5**	385.9	385.9	385.9	304.9
Environmental Compliance and Restoration	86.4	--	**82.9**	82.9	82.9	82.9	82.9
Total Budget	**569.5**	**348.2**	**600.4**	**468.8**	**468.8**	**468.8**	**387.8**
Change from FY 2019			**252.2**				
Percentage change from FY 2019			**72.4%**				

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.
The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

The Katherine G. Johnson Computational Research Facility (CRF) at the Langley Research Center (LaRC) earned a Leadership in Energy and Environmental Design (LEED) Silver certified in FY 2018. Multiple data centers from various locations across LaRC were relocated and consolidated at the CRF. NASA's inventory of high-performance facilities that reduce energy consumption for similar facilities per ASHRAE standards and improves indoor work quality now exceeds 3.4 million square feet.

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) makes capital repairs and improvements to NASA's infrastructure and provides NASA programs and projects with the research, development, test and evaluation (RDT&E) facilities required to accomplish their missions. Over 80 percent of NASA's infrastructure and facilities are beyond their constructed design life, requiring strong risk management programs to mitigate risk to current and future missions. Apollo-era legacy infrastructure is especially inefficient and costly to maintain and operate. NASA's Office of Inspector General continues to note in its annual NASA's Top Management and Performance Challenges (Nov 2017): "While NASA strives to keep these facilities operational - and when not operational, in sufficient condition so they do not pose a safety hazard - NASA estimates its deferred maintenance costs at $2.4 billion in 2016." To address these challenges, NASA's CoF programs focuses on reducing and modernizing NASA's infrastructure into fewer, more efficient sustainable facilities and repairing failing infrastructure to reduce overall maintenance costs. The CoF Program strives to repair equipment and facilities that can no longer effectively be maintained and that have either suffered continuous degradations, recent failures or deterioration from reduced maintenance over time. This has resulted in increasing number of construction projects that have evolved from backlogged maintenance projects rather than focusing more on revitalization or new construction to solely replace obsolete facilities.

The CoF Program supports goals within NASA's Annual Performance Plan. Specifically, the Demolition Program eliminates obsolete and unneeded facilities. It supports goals within the annual Sustainability Plan through replacing inefficient, obsolete facilities, such as outdated laboratories, with more efficient sustainable facilities. Also, the Energy Savings Investment funds projects that reduce energy intensity consumption, and renewable energy projects that increase energy reliability and resiliency.

Environmental Compliance and Restoration (ECR) projects clean up pollutants released into the environment 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. NASA prioritizes these cleanup activities to protect human health and the environment, and preserve natural resources for future needs.

Together, these construction and remediation activities help ensure that NASA’s assets are ready, available, and appropriately sized to conduct NASA’s missions, and that NASA facilities are compliant with current environmental regulations.

EXPLANATION OF MAJOR CHANGES IN FY 2020

NASA will invest more heavily in the repair of obsolete and deteriorated distribution systems, and will reduce mission and safety risk through repair of facilities or structures that have unreliable equipment and building systems. These investments will improve reliability of equipment such as aging electrical and water systems to support basic day-to-day function of Centers as well as ongoing research, testing and exploration. Additionally, NASA will initiate two new Institutional CoF projects in FY 2020. The two new projects are the Flight Electronics Integration Facility (FEIF) at the Jet Propulsion Laboratory (JPL) and the Flight Dynamics Research Facility (FDRF) at the Langley Research Center (LaRC). The FEIF consolidates space from multiple facilities into a single facility reducing risk to flight hardware and enabling more efficient operations and maintenance. The FDRF replaces an aging test facility that requires enhanced capabilities such as increased flow capability within the vertical spin tunnel to meet future testing needs. The Budget does not fund projects that support the Block 1B of the SLS, which is deferred so the agency can focus on getting the SLS flying and operating at an annual flight cadence.

Construction and Environmental Compliance and Restoration

Achievements in FY 2018

NASA completed several significant Institutional CoF infrastructure projects, including the Katherine G. Johnson Computational Research Facility, which consists of a consolidated data center and high-density office space. This facility is U.S. Green Building Council (USGBC) Leadership in Energy and Environmental Design (LEED) Silver certified and incorporates adaptability, flexibility, and expandability to accommodate both current needs and anticipated future growth over the multi-decade life of the facility. In addition, this facility consolidated multiple data centers from various locations across LaRC into a single facility.

Other significant Institutional CoF projects completed include:

- Construction of the Mission Operations Control Center (Wallops Flight Facility (WFF)/Goddard Space Flight Center (GSFC)), which serves as the hub for interfacing with, and controlling rockets, their payloads and associated launch pad support systems during flight operations at WFF;
- Renovation of Building 1230, a research facility (LaRC), which supports cutting-edge research that produces innovative concepts, tools, and technologies to improve the safety of current and future aircraft;
- Renovation of Building 230, Data Center Phase 2 (Jet Propulsion Laboratory), which created server rack infrastructure and protection in a mission critical operations facility, increasing data processing capacity and reducing computing footprint;
- Completed construction of the Central Campus Phase 1 Construct Replacement Shared Services and Office Building and Kennedy Data Center office project (Kennedy Space Center), which will reduce the Agency's footprint and maintenance costs. Central Campus is planned as a multi-phase project which will enable deconstruction of approximately 900,000 square feet of physical plant that is between 50 to 60 years old by the time it is deactivated and deconstructed;
- Rehab of the site-wide high-pressure gas helium, gaseous nitrogen and air distribution Phase 1 (Stennis Space Center), which refurbished the high-pressure gas piping system that supplies gaseous nitrogen (GN), gaseous helium (GHe), and high-pressure missile-grade air (HPA) to the end user locations. This project addressed primarily adressed aging infrastructure, however also resulted in avoided maintenance costs and decreasing operational issues.

NASA continues to construct new facilities and major renovations to meet the Guiding Principles for Sustainable Federal Buildings, issued January 2006 and updated February 2016 by the Council on Environmental Quality. Furthermore, NASA continues to reduce the footprint of its portfolio of constructed assets through strategic demolition and consolidation efforts. The design of new construction or major renovations minimizes long-term infrastructure energy, water, and maintenance costs. In FY 2018, NASA added four new high-performance facilities (with a total area of nearly 190,000 square feet (SF)), thereby increasing the inventory of sustainable facilities to more than 3.4 million SF. All four buildings also achieved the U.S. Green Building Council (USGBC) LEED Silver rating certification.

NASA initiated multiple significant discrete Institutional CoF projects to repair and revitalize its infrastructure. Two key recapitalization projects include the Instrument Development Facility (GSFC), which will provide technical capabilities to execute increased NASA work in astrobiology, and robotic and crewed space missions; and the Research Support Building (Glenn Research Center), which enables consolidation of research laboratories and offices, reduced maintenance costs, and enabled significant footprint reduction of approximately 40,000 square feet. Other significant projects include: Restore KSC Coastal Shoreline, Phase 1 (KSC), Steam Distribution Replacement, Phase 2 (MSFC), and Sanitary Sewage Recapitalization (SSC).

To reduce the Agency’s footprint, NASA disposed of over 4.63 million square feet since 2013. Over this time period, NASA eliminated more than 800 structures. In 2018, the net reduction amounted to over 460,000 square feet, double the amount planned. The combined reduction in NASA's real property portfolio reduced deferred maintenance by $71.4 million.

In the Energy Savings Investments program, NASA completed construction of a project to replace the window walls of the mall area buildings at Johnson Space Center (JSC). The result of this project is a reduction in the energy intensity by decreasing solar heat gain and outdoor air infiltration. Also, NASA initiated an HVAC improvement project at GSFC, which includes the installation of two waterside economizers on 200-ton and 300-ton chillers, and a geothermal heat pump. When completed, this project is estimated to result in an annual energy cost avoidance of $220K.

Programmatic funded construction of specialized capabilities for testing and development that directly support specific NASA missions. Programmatic CoF continued to make significant progress on transitioning the legacy Space Shuttle and Constellation infrastructure to accommodate the Space Launch System (SLS) and Orion programs for Human Exploration Missions. Progress also continued on the construction of the Deep Space Network Aperture Enhancement Project (DAEP). Other specific acheivements include:

- At KSC, the Exploration Ground Systems (EGS) program began the final phases of construction and activation of the Vehicle Assembly Building (VAB) platforms and the Launch Complex 39B (LC-39B) needed for the first Exploration Mission (EM-1). Additionally, the recent solicitation and award of a 1.25 million-gallon liquid helium (LH2) storage sphere scheduled for installation at LC-39B, ensures liquid hydrogen capacity necessary to accommodate SLS propellant requirements;
- At SSC, the SLS Program completed major activation of the B-2 Test Stand in preparation for the SLS Green Run Testing. The activation of the B-2 Stand included the Liquid Oxygen System, Liquid Hydrogen System, Gaseous Nitrogen Systems, High Pressure Air Systems, Nitrogen Heaters Systems, Test Control Center, NASA Data Acquisition System, LOX Dock, and LH2 Dock;
- Remaining work should be completed by the 3rd quarter of FY19, and the B-2 Test Stand will be ready for Core Stage 1;
- For the Deep Space Network Aperture Enhancement project, construction continued in Madrid, Spain with construction of both antenna pedestal structures nearing completion; and
- At Ames Research Center (ARC), Science CoF began construction of the Modular Supercomputing Facility (MSF), 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.

Within the ECR program:

- Santa Susana Field Laboratory (SSFL) continued demolition of structures in areas not associated with the Test Stands. The site submitted initial cleanup plans for groundwater to the State of California regulators. A Record of Decision for groundwater cleanup under the National Environmental Policy Act was also prepared.
- SSFL continued operations of groundwater treatment systems, long-term monitoring of groundwater, and Cultural Resource actions per the Programmatic Agreement with the State Historic Preservation Office, Native Americans, and consulting parties;

- JPL, in conjunction with the State of California and the U.S. Environmental Protection Agency, completed a Record of Decision for onsite and offsite groundwater contamination remediation;
- GRC completed decontamination and decommission of the cyclotron building under Nuclear Regulatory Commission license termination, the site also continued cleanup operations of abandoned wastewater treatment facility and lead contaminated range at Plum Brook Station;
- KSC continued investigation and cleanup of groundwater and soil contamination. Activities included the installation of new groundwater treatment systems, removal of contaminated soils, investigation of additional sites for potential contamination, continued sampling of over 400 monitoring wells, and continued operations of existing groundwater cleanup systems;
- ARC began a major landfill remediation project and final closure per its Federal Facilities Agreement;
- Marshall Space Flight Center (MSFC) began cleanup of the Industrial Sewer operable unit and monitoring/characterization of groundwater;
- White Sands Test Facility (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 of the sewage lagoon; and
- The Agency continued operations of treatment systems and monitoring at Armstrong Flight Resarch Center (AFRC), GSFC, JPL, LaRC, MAF, SSC, and WFF.

Facilities at MAF sustained significant damage from an EF-3 tornado on February 2, 2017. Damage included major impacts to multiple buildings within the facility and SLS Ground Support Equipment. NASA received $109 million in supplemental funding in FY2017 to repair major and minor damages to fifteen (15) MAF facilities, demolish three (3) totally damage buildings and emergency response and cleanup.

NASA received $59 million in supplemental funding in FY 2018 to repair the facilities damaged at JSC by Hurricane Harvey and $22.3M to repair the facilities damaged at KSC by Hurricane Irma. Emergency repair and recovery to numerous facilities is underway at JSC, including repairs at The Sonny Carter Training Facility, Mission Control Center, and the Space Environment and Simulation Laboratory. Emergency repair and recovery to numerous facilities is underway at KSC, including repairs at the Payload Support Facility, roof repairs at the Vertical Assembly Building Complex and the KSC shoreline.

WORK IN PROGRESS IN FY 2019

NASA's planned FY 2019 Institutional CoF projects will protect the Agency’s critical assets, improve mission assurance, reduce mission risk, and maintain mission essential capabilities. Planned projects include utility system repairs and replacement of obsolete buildings. Work continues on the following significant projects:

- Construction of the Aerospace Communications Facility (GRC). This facility, which will consolidate and modernize existing technical capabilities, which supports the Space Communications and Navigation (SCaN) Phase 3 Next Generation Architecture planetary network program for human exploration of Mars; Advanced Exploration Systems EVA Project supporting HEOMD’S Evolvable

Mars Campaign (EMC); integration of Unmanned Aerial Systems (UAS) into the National Airspace (NAS) project. This facility also supports the International Space Station (ISS), SLS and MPCV/Orion.

- Repair Lewis Field Storm Sewer System, Phase 2. This project consists of replacing storm sewer piping across the Center. Frequent storm water intrusion into buildings has caused evacuation and damage to structures and infrastructure. Also, storm water intrusion has also led to unhealthy work areas, impacting employee productivity and mission readiness for personnel.
- Shoreline Protection (GSFC). This project will restore the Wallops Island shoreline to the 100-year storm floodplain in order to provide protection for the constructed assets. Currently, segments of the beach dune and beach berm have been reduced to near sea-level elevations, with an increased risk for inundation during storms. Missions supported include Commercial Orbital Transportation Services (COTS) and numerous sounding rocket campaigns that are ongoing.
- Restore KSC Coastal Shoreline, Phase 2. This project is the second of two phases to construct a new sand dune along approximately the 4.5+ miles of KSC shoreline. These coastal dunes protect KSC's facilities and infrastructure including Launch Complex 39A and B from the impact of storm surge and inundation. Storm activities have resulted in significant loss of beach and sand dunes, increasing significantly the risk of inland flooding, infrastructure loss and salt water intrusion.
- Revitalize Pressure and Propellant Distribution Systems, Phase 2 of 3 (MSFC). This project replaces sections of the high-pressure gas distribution piping system that have experienced corrosion-related failures. This project is critical for support of on-going missions including the International Space Station Payload operations Center and the Environmental Control and Life Support Systems (ECLSS) onboard ISS, Space Launch Systems, and the Multipurpose Crew Vehicle.

Programmatic funded construction of specialized capabilities for testing and development that directly support specific NASA missions.

- At Michoud Assembly Facility (MAF), the SLS Program will continue construction work that supports SLS Core Stage manufacturing with structural, mechanical electrical, and steam system repairs.
- Within Space Operations programmatic construction, SCaN will continue the DAEP project, a multi-year funded discrete project to construct the two new 34-meter BWG DSS Antennas, DSS-56 and DSS-53, at the Madrid Deep Space Communications Complex.

NASA's planned FY 2019 ECR projects will investigate and mitigate releases of chemicals into the environment from past activities and work to restore soil and water to protect human health and the environment and preserve natural and cultural resources for future missions. Work include continuation of the following projects:

- SSFL is expecting to complete demolition activities for structures and implement abatement activities for the remaining Test Stands; complete cleanup plans for soils and groundwater and begin implementation for groundwater cleanup. The site will continue operation of groundwater treatment systems and long-term monitoring of groundwater. Cultural Resource actions will continue per the Programmatic Agreement with the State Historic Preservation Office, Native Americans, and consulting parties.
- KSC will continue investigation and cleanup 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 over 400 monitoring wells, and continued operations of existing groundwater cleanup systems;
- ARC will continue landfill remediation and final closure per its Federal Facilities Agreement;
- MSFC will complete cleanup of the Industrial Sewer operable unit and begin removing contaminated soil from the Test Areas as well as begin contaminant source removal for the groundwater 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 of the sewage lagoon;
- GRC will continue cleanup operations of 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;
- The Agency will continue operations of treatment systems and groundwater and soil monitoring at AFRC, ARC, GSFC, JPL, LaRC, MAF, SSC, and WFF.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

NASA planned construction and environmental activities include:
- Initiate the Flight Electronics Integration Facility (JPL). This project is jointly funded with Institutional and Science funding;
- Initiate the Flight Dynamics Research Facility (LaRC);
- Initiated the High-Pressure Industrial Water System repairs (SSC). This repair project is jointly funded with Institutional, Exploration, and Space Operations funding;
- Repairs and upgrades at the Centers to mitigate near-term risk to missions by revitalizing electrical, mechanical, life safety, sanitary sewer and water systems;
- Investments to reduce energy cost and consumption to increase progress toward Federal energy requirements;
- Demolition to eliminate obsolete facilities and reduce footprint;
- Continued demolition, cleanup of contaminated soils, operation of groundwater treatment systems, and long-term monitoring of groundwater at SSFL in accordance with the State of California. Cultural Resource actions will continue per the Programmatic Agreement with the State Historic Preservation Office, Native Americans, and consulting parties;
- Continued investigation and cleanup 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 over 400 monitoring wells, and continued operations of existing groundwater cleanup systems;
- Continued cleanup of ground water contamination and investigation of soil contamination at WSTF, to include 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; and
- Operation and maintenance of systems to clean up contaminated groundwater emanating from JPL and the Lincoln Avenue and Monk Hill drinking water treatment systems.

CONSTRUCTION OF FACILITIES

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Institutional CoF	348.3	--	**430.6**	385.9	385.9	385.9	304.9
Exploration CoF	95.9	--	**52.1**	0.0	0.0	0.0	0.0
Space Operations CoF	23.9	--	**19.5**	0.0	0.0	0.0	0.0
Science CoF	15.0	--	**15.3**	0.0	0.0	0.0	0.0
Total Budget	**483.1**	**--**	**517.5**	**385.9**	**385.9**	**385.9**	**304.9**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

Rendering of the Flight Electronics Integration Facility at the Jet Propulsion Laboratory. This building will support multiple NASA missions such as the Europa Clipper, Wide-Field Infrared Survey Telescope (WFIRST) Coronagraph, the NASA-Indian Space Research Organization (ISRO) Synthetic Aperture Radar (NISAR) mission, the Surface Water and Ocean Topography (SWOT) mission, and a host of future Earth Science instruments.

NASA’s Construction of Facilities (CoF) program includes programmatic and institutional construction projects that reduce facility-related risk to mission success and increase sustainability.

The Institutional CoF program provides for the design and construction of facilities projects that enable NASA’s infrastructure to meet mission needs. Utility system repairs and replacements improve the reliability of NASA’s systems and reduce operational consumption of energy. Refurbishment or repair-by-replacement projects replace inefficient, deteriorated buildings with efficient high-performance facilities. 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 provides specialized capabilities in testing and development that directly support NASA’s missions. These projects enable NASA to provide critical technical capabilities to manufacture, test, process, or operate hardware for NASA programs.

CONSTRUCTION OF FACILITIES

Discrete projects refer to those with initial cost estimates of $10 million or greater. Minor projects are those with initial cost estimates between $1 and $10 million and are subject to change according to priorities. Centers accomplish routine day-to-day facility maintenance and repair activities with estimates of $1 million or less within program and Center Management and Operations budgets.

EXPLANATION OF MAJOR CHANGES IN FY 2020

NASA will initiate two new Institutional CoF projects in FY 2020. The two new projects are the Flight Electronics Integration Facility (FEIF) at the Jet Propulsion Laboratory, and the Flight Dynamics Research Facility (FDRF) at the Langley Research Center. The FEIF consolidates space from multiple facilities into a single facility reducing risk to flight hardware and enabling more efficient operations and maintenance. The FDRF replaces an aging test facility that requires enhanced capabilities such as increased flow capability within the vertical spin tunnel to meet future testing needs.

INSTITUTIONAL COF

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**348.3**	**--**	**430.6**	**385.9**	**385.9**	**385.9**	**304.9**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

View of corrosion and water intrusion in the High-Pressure Industrial Water (HPIW) system at the Stennis Space Center. The HPIW system delivers the water that is required for rocket engine test stand fire suppression, deflector cooling, and diffuser operations. In its current degraded condition this critical system poses a risk to the Space Launch System and other programs, and needs repair.

NASA's Institutional CoF program includes projects to reduce risks, increase efficiency, and reduce operational costs.

Institutional CoF projects predominantly repair or replace aging equipment, infrastructure or facilities in order to minimize facility-related risks to mission success, property, and personnel. NASA prioritizes these projects using a risk-informed process that evaluates risks to mission schedules, cost, safety, and operations. This year's budget includes projects such as risk reduction to personnel safety from arcflash injuries, reliability improvement of key systems such as electrical distribution and high-pressure industrial water systems, and projects that address deficiencies with electrical substations, potable water systems and emergency power for critical facilities.

Institutional CoF projects also include the replacement of old, obsolete and costly facilities with new, smaller high-performance facilities that aim to consolidate core functions, reduce operating costs and improve flexibility over the life of the facilities. NASA is focusing its Minor Construction Program on repairing infrastructure and facilities that are near failure, have suffered failures that affect reliability and operability or which will reduce risk to Center personnel or missions.

NASA's demolition program eliminates obsolete, unneeded infrastructure to improve efficiency and eliminate safety and environmental risks. Energy Savings projects reduce operational costs by improving energy efficiency and reducing energy usage through improvement projects.

INSTITUTIONAL COF

EXPLANATION OF MAJOR CHANGES IN FY 2020

NASA will initiate two new Institutional CoF projects in FY 2020 that replace aging facilities. The two new projects are the Flight Electronics Integration Facility (FEIF) at Jet Propulsion Laboratory (JPL) and the Flight Dynamics Research Facility (FDRF) at Langley Research Center (LaRC). The FEIF consolidates space from multiple facilities into a single facility reducing risk to flight hardware and enabling more efficient operations and maintenance. The FDRF replaces an aging test facility that requires enhanced capabilities such as increased flow capacity within the vertical spin tunnel to meet future testing needs.

ACHIEVEMENTS IN FY 2018

NASA initiated multiple significant CoF projects, including the construction of two new sustainable-rated facilities that replace obsolete and inefficient facilities. These projects are the Research Support Building (GRC) and the Instrument Development Facility at GSFC. Other key achievements include execution of a critical shoreline restoration project "Restore Coastal Shoreline, Phase 1" (KSC), and execution of multiple critical infrastructure projects "Steam Distribution Replacement Phase 2 of 2" (MSFC), Replace/Revitalize Fire Protection & Alarm Node System (Site Wide) (MSFC), and "Sanitary Sewer System Rehabilitation" (SSC).

Also, during FY 2018, NASA disposed of approximately 460,000 square feet of buildings, double the amount planned. Demolition of inactive and obsolete facilities allow the Agency to avoid operating cost of maintaining old, and abandoned facilities in a safe and secure condition. Furthermore, demolition is the most cost-effective way to reduce the Agency's deferred maintenance. Finally, demolition promotes environmental responsibility and community planning through the recycling of old construction materials and creating green space for future development. There are many benefits from these efforts such as supporting the Agency's mission to reduce the footprint and staying consistent with the facility master planning process.

NASA initiated and/or began construction of the following critical minor construction projects:

- Repair Mechanical Systems B4840 (AFRC)
- Modular Supercomputing Facility (ARC)
- Replace Unitary Plan Wind Tunnel Three Stage Compressor Rotor Blades (ARC)
- Restore Reliability of 150 MW Arc Jet Rectifier Module 6 and Digital Control (ARC)
- Repair Exterior of Engine Research Building West Wing, Building 23 (GRC)
- Repair Water Intrusion and Institutional Plumbing, ERB (GRC)
- Integration and Test Complex Electrical/Mechanical Repairs (GSFC)
- Replace Chillers, Building 31 (GSFC)
- Airfield Repairs (WFF/GSFC)

NASA continued the Energy Savings Investments program by initiating the following projects:

- Implement HVAC Efficiency Improvements, Various Buildings (WFF/GSFC)
- Repair and Replace Chilled Water and Steam Piping Insulation (JSC)
- Install Solar Photovoltaic Systems with Energy Storage (WSTF/JSC & WSC/GSFC)

Significantly, in FY 2018 NASA completed construction of multiple infrastructure projects. Highlights of the accomplishments include:

- New Mission Operations Control Center at WFF
- New Katherine G. Johnson Computational Research Facility at LARC
- Pilot Modular Supercomputer at ARC
- Arcjet repairs to the IHF Diffuser and Aerodynamic Heating Facility
- Repair Aircraft Hangar B4802, HVAC Systems (AFRC)
- Continued water system repairs at GRC, JSC, LARC and KSC
- Continued electrical system repairs at buildings at MSFC
- Rehab Site-wide High-Pressure Helium, Gaseous Nitrogen and Air Distribution, Phase 1 (SSC)
- Repair Bascule Bridge (SSC)
- Refurbish and Replace Helium Compressors (SSC)
- Renovation of Building 1230 (LARC)

WORK IN PROGRESS IN FY 2019

In addition to the projects with ongoing construction that were initiated in FY 2018 and prior years, NASA is planning to initiate the following projects in FY 2019:

- Repair Flight Loads Lab Mechanical Systems (AFRC)
- Reduce Seismic Risk to Buildings N226, N244, and N245 (ARC)
- Restore Reliability of Main Switch Board for Telecom Gateway N254 (ARC)
- Repair by Replacement, Aerospace Communications Facility (GRC)
- Repair Facility Horizontal Communications Infrastructure, Plum Brook Station (GRC)
- Repair Electrical Distribution System, Phase 3 of 5 (GRC)
- Repair North and South Chilled Water Plant (GRC)
- Repair Lewis Field Storm Sewer System, Phase 2 of 3 (GRC)
- Replace Electrical Feeders and Systems (GSFC)
- Shoreline Protection (WFF/GSFC)
- Replace Substation Switchgear (JSC)
- Electrical Safety and Reliability Upgrades, Phase 4 of 5 (KSC)
- Electrical Distribution System Upgrades, Langley Boulevard (LARC)
- Revitalize Pressure and Propellant Distribution Systems (Site Wide, Phase 2 of 3) (MSFC)
- Refurbish Potable Water System, Water Wells and Towers (SSC)

KEY ACHIEVEMENTS PLANNED FOR FY 2020

NASA is planning to initiate numerous Discrete and Minor Revitalization and Construction of Facilities projects in FY 2020 to repair and revitalize its infrastructure. Planned Discrete projects include the High-

Pressure Industrial Water System Repair at SSC, construction of the FIEF at JPL, and construction of the FDRF at LARC. The FIEF replaces inadequate, inefficient, and failing facilities. In addition it provides consolidation, efficiency improvements, and long-term opportunity for other facility deconstruction. Likewise the FDRF replaces existing facilities that cannot support the complex technology of many currently planned, as well as projected, NASA missions due to poor flow quality and low dynamic pressure range.

In addition to awarding the planned FY 2020 projects, NASA anticipates completing several significant infrastructure projects under construction. Highlights include:

- Steam distribution replacement (MSFC)
- Site wide Fire detection system upgrades (SSC)
- Continued Utility tunnel repairs (LARC)
- Continued Electrical Distribution System Upgrades (LARC)
- Central Steam Plant Repairs (LARC)
- Replacement of 4 Liquid Nitrogen Tanks (Tank Nos. 23, 26, 27, 30)(JPL)
- Repair Water Intrusion and Institutional Plumbing, Engine Research Building No. 5 (GRC)
- Refurbish High Pressure Air (HPA) Dryer System (SSC)
- Rehabilitate E-Complex Deluge System (SSC)
- Electrical Repairs to Navigational Lock and Canal Water Replenishment System (SSC)

NASA also plans to continue Energy Savings Investments that reduce energy cost and consumption in support of NASA's mission.

Institutional Discrete Construction of Facility Projects

Discrete Construction of Facilities 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 recapitalization projects that replace outdated facilities or buildings that are impeding mission success.

NASA's FY 2020 Institutional CoF budget includes three discrete recapitalization projects required to meet laboratory and testing needs; these include the Flight Electronics Integration Facility, the Flight Dynamics Research Facility, and an infrastructure improvement project that continues a FY 2013 project to replace deteriorated high-pressure water piping in support of rocket engine testing.

Jet Propulsion Laboratory

Flight Electronics Integration Facility

FY 2020 Estimate: $75.0 million; $63.0 million (Institutional Construction of Facilities),

$12.0 million (Science Mission Directorate)

Over the next two decades, pursuit of the challenging questions identified as priorities by the National Academies of Sciences Decadal Surveys will require NASA to conduct a series of ever more complex planetary, astrophysics, and Earth science missions. Key attributes of these missions include significantly increased autonomy; tolerance to extreme environments; increased reliability requirements; and tight mass, power, and volume constraints. Advances in avionics technology and engineering practices are therefore crucial enablers for these missions. Future exoplanet-detection missions and Earth science instruments will have even more challenging performance requirements to support high levels of onboard data-filtering.

Development of robust, next-generation avionics requires a multidisciplinary team consisting of analog and digital electronics designers, packaging and manufacturing engineers, parts and reliability analysis specialists, and electronics test engineers. Collocation with the technical facilities will allow this team to rapidly develop design solutions, conduct detailed analyses of designs, prototype new concepts, and conduct early validation tests. Additionally, collocation will significantly reduce risk by minimizing transportation of flight hardware between facilities. Currently electronic components are moved in and around multiple laboratories and testing facilities spread across JPL during development and testing, increasing risk of damage to the equipment, as has been seen in some previous missions. By co-locating the facilities into one vertically stacked facility, the risk of damage and resulting time delays associated with necessary repairs will be greatly reduced. The elimination of unnecessary transportation and related packing will streamline operations, resulting in significant mission cost and schedule savings. This single integrated facility will handle the electronic components generated for flight hardware for all of the NASA missions led by JPL.

FEIF is a 95,000 SF, five-story concrete building with two-way concrete floor and roof slabs designed for the high seismic region. It is joint funded between the Science Mission Directorate and Institutional CoF to 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 exterior envelope will be an energy-efficient, high-performance exterior wall system and a single-ply membrane roof. Mechanical and electrical equipment and components will be modern, high-efficiency units in integrated, digitally controlled systems. Building infrastructure will provide the necessary redundancy to ensure faultless support for mission critical operations. The facility will consist of class 1K, 10K and 100K cleanrooms and facilities for parts storage, fabrication, integration and testing. More than 115,000 SF of existing buildings will be demolished as a footprint offset.

In particular, 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.

Langley Research Center

Flight Dynamics Research Facility

FY2020 Construction Estimate: $51.0 million

The FDRF project includes the design, construction, and commissioning of a new state-of-the-art flight dynamics experimental testing facility. This facility will be 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). To meet these objectives, the facility will use a COTS free-fall simulator facility with minor 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, and increased flexibility and cost effectiveness, and optimization of systems for operational and maintenance efficiency. The FDRF shall be located on the West Area, adjacent to Building 1200. Upon commissioning of the new facility, four existing NASA-owned buildings in the Langley East Area (Langley Air Force Base) can be demolished.

The existing flight dynamics facilities cannot support the complex technology needs for many 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). For example, tests supporting planetary sample return missions, crewed entry vehicles like Orion, and the Commercial Crew program require dynamic pressures (i.e., airspeed) to simulate the dynamics of a vehicle in the atmosphere at various altitudes. Higher altitudes or heavier vehicles require higher dynamic pressures. As a result, tests for the Stardust comet sample return mission and the follow-on OSIRIS-REx asteroid sample return mission were limited in simulated altitude during tests in the VST which resulted in data that was less useful for mission risk reduction than was desirable. Neither the VST nor 12-Foot are amenable to having dynamic pressure capability increased (e.g., through repowering) or flow quality improved due to compromises in the original designs and the age of the facilities. Conversely, an experimental facility that combines rapid, low-cost access with significantly greater capability than current assets will be an enabler for several planned research, development and science thrusts. For example, high-fidelity flight mechanics predictions using CFD will be enabled through experimental validation by these new capabilities, furthering the goals of NASA's CFD Vision 2030. VST and 12-Foot were both constructed by The National Advisory Committee for Aeronautics (NACA) and have been in continual operational since prior to World War II (1941 for the VST and 1939 for 12-Foot) and are long past their design life. The facilities are experiencing accelerated corrosion due to their proximity to the water on the East Area (Langley Air Force Base) which is continually affected by saltwater flooding during storm events. Currently, major investments are needed to maintain these crucial facilities. As a key element in LaRC 20-Year Revitalization Plan, the Flight Dynamics Research Facility enables LaRC to continue the drive towards satisfying Agency-established goals for reducing cost of ownership, facility total square footage and current replacement value (CRV).

Stennis Space Center

High Pressure Industrial Water System Repair

FY 2020 Estimate: $16.5 million; $12.3 million (Institutional Construction of Facilities),

$3.1 million (HEO/Exploration Construction of Facilities), $1.1 million (HEO/Space Operations Construction of Facilities)

The project will repair the 66-inch diameter water pipe and ancillary equipment within the Test Complex that runs from the A2 Valve Vault to the A1 Test Stand of the High-Pressure Industrial Water (HPIW) System at Stennis. The HPIW system, which provides the water required for fire suppression, cooling the test stand deflector, and diffuser operations, is critical during rocket engine testing.

The existing piping is severely corroded and cannot operate as designed. A systematic planned repair by replacement is more economically beneficial than an emergency repair or repairs. Repairing and/or replacing the existing pipe will dramatically reduce the risk of failure which will impact all engine testing and, in turn, may affect future launches.

The HPIW pipe from A1/A3 Valve Vault to the A1 Test Stand can no longer operate at full design pressure and has been de-rated to the lowest recommended operating pressure. A pressure variance has been issued due to the severe corrosion and wall thickness of the HPIW pipe.

If a leak is discovered, severity of the failure would be determined and the system would be down approximately three weeks for inspection alone. For a minor leak (pin hole, etc.), the repair would take approximately one month if repaired from inside; 4-12 months if repaired from outside. For a major leak (sinkhole develops, etc.), downtime and cost would elevate with complexity of environment – ground stabilization required, potential concrete excavation, complexity of utilities, etc. In the event of failure, all testing would be affected in the A complex and would affect any schedule launch whose engines are in the critical path for delivering payloads.

INSTITUTIONAL COF

This project supports all rocket engine testing programs, including the Space Launch System (SLS) and the RS-25.

Minor Revitalization and Construction of Facilities

FY 2020 Estimate: $229.3 million

Minor revitalization and construction of facilities projects have initial cost estimates between

$1 million and $10 million. These projects consist of revitalizing and constructing facilities at various NASA center installations and government-owned industrial plants. Revitalization and modernization projects provide for the repair, modernization, and/or upgrade of facilities and collateral equipment. Repair projects restore facilities and components to a condition equivalent to the originally intended and designed capability. Repair and modernization work include the equivalent replacement of utility systems and collateral equipment necessitated by incipient or actual breakdown. Modernization and upgrade projects include restoration of current functional capability and enhancement of the condition of a facility so it can accomplish its designated purpose, increase its functional capability, or meet new building, fire, and accessibility codes.

The minor revitalization and construction projects that comprise this request are of the highest priority, based on relative urgency, and expected return on investment. The focus is on projects that reduce building square footage or eliminate excess building systems, provide long-term savings, and reduce the Agency's maintenance backlog. During the year, planned projects may change to accommodate changing priorities.

The minor projects listed below provide critical upgrades and repairs at ten NASA centers. Not funding these projects would cause direct cost, schedule, and personnel impacts to major NASA programs, such as Orion and SLS, with direct impacts to NASA's commercial partners.

Ames Research Center:

- Reduce Seismic Risk to Buildings N204A, N206A, and N239
- Repair UPWT Underground Cooling Water Pipes
- Restore Reliability of UPWT 11-foot Model Support
- Restore Reliability of VMS OTW Cockpit Visual Infrastructure
- Reduce Electrical Arc-Flash Risk to Personnel, Phase 1 of 4

INSTITUTIONAL COF

Armstrong Flight Research Center:

- Repair Fire Suppression Systems
- Repair Electrical Substation 1
- Repair Center-wide Electrical Systems

Glenn Research Center:

- Repair Central Process Systems
- Repair Steam Distribution System, Phase 4

Goddard Space Flight Center:

- Wallops Island Causeway Bridge Repairs
- Upgrade Electrical Feeders, Phase 2
- Repair Airfield, Phase 2 (WFF)

Jet Propulsion Laboratory:

- Replace 16.5 kV Oil Impregnated, Paper Insulated Underground Distribution Cables
- Replace and Upgrade Substation H

Johnson Space Center:

- Safety Upgrades to the Public Water System, WSTF Phase 2
- Replace Potable Water Storage and Elevated Tanks (339 and 341)
- Upgrade Mission Control Center Infrastructure
- Repair Roads and Drainage (WSTF)

Kennedy Space Center:

- Repair Primary Roads
- Replace Mechanical Systems, Various Buildings

Langley Research Center:

- Utility Tunnels 1 and 2 Repairs, Phase 2
- Utility Tunnels 3 and 4 Repairs
- Central Steam Plant Repairs
- Replace Emergency Battery Bank

Marshall Space Flight Center:

- Emergency Egress Lighting Compliance Upgrade
- Replace Water Systems, Building 4708
- Electrical Safety Repairs

Stennis Space Center:

- Potable Water Supply Line Replacement - Test Complex
- Repair SSC Canal Impoundment System - Tainter Valves
- Repairs to Critical Tet Complex Power Generation System
- Upgrade Emergency Management Control Systems
- Replace Roofs, Various Buildings
- Repair Bascule Bridge Infrastructure

Energy Savings Investments

FY 2020 Estimate: $12.0 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 8.5-year simple payback period – the time required to recover the initial investment through annual energy cost avoidances. These projects allow NASA to meet Federal statutory and executive order energy requirements, and will result in an estimated annual $1.5 million in utilities expenditures avoided by implementing these projects.

Jet Propulsion Laboratory:

- Improve Energy Efficiency, Various Buildings

Johnson Space Center:

- Implement Energy Conservation Measures and Retro-commissioning, Various Buildings, Phase 3

Marshall Space Flight Center:

- Implement Energy Upgrades, Various Buildings

Demolition of Facilities

FY 2020 Estimate: $25.0 million

NASA continues to increase the functionality of Agency retained assets 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 and are eyesores at the Centers. The Agency continues to 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 way to reduce the Agency deferred maintenance.

NASA identifies facilities for demolition through special studies that determine if the 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.

Facility Planning and Design

FY 2020 Estimate: $38.0 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 associated cost estimates associated with non-programmatic construction projects. This includes master planning, value engineering studies, design and construction management studies, facility operation and maintenance studies, condition-based maintenance studies, facilities utilization analyses, engineering support for facilities management systems, and capital leveraging research activities. Funding also supports participation in facilities-related professional engineering associations and organizations.

The facilities planning and design activity is crucial to implementing NASA's recapitalization strategy. These projects are necessary to make progress toward required sustainability, energy, and stewardship goals.

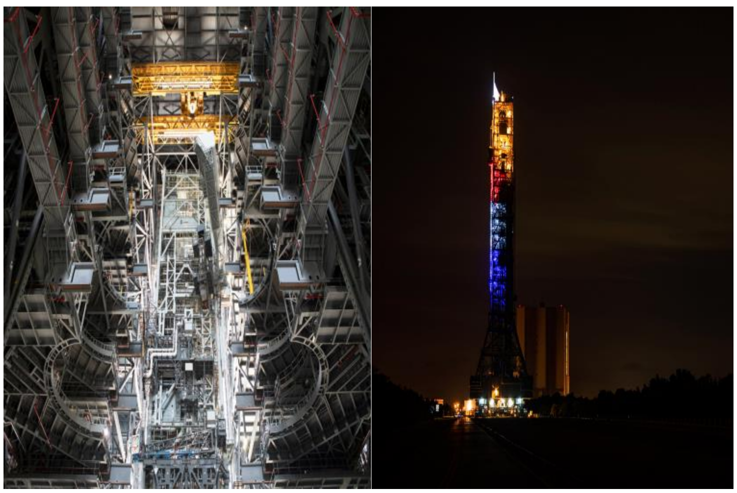
EXPLORATION COF

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**95.9**	**--**	**52.1**	**0.0**	**0.0**	**0.0**	**0.0**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



At left, a view of High Bay 3 inside the KSC Vertical Assembly Building (VAB) showing platform halves installed. Note in the background the Mobile Launch Tower (MLT) undergoing preliminary fit-checks assessment. On the right is a view of the MLT undergoing final preparation just prior to being transported by the Crawler to LC-39B and VAB.

Exploration CoF provides construction required to support the Space Launch System (SLS), Orion, and Exploration Ground Systems 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 2020

None.

ACHIEVEMENTS IN FY 2018

During FY 2018, 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 Exploration Missions.

At the Kennedy Space Center (KSC), the Exploration Ground Systems (EGS) program began the final phases of construction and activation of the Vehicle Assembly Building (VAB) platforms and the Launch Complex 39B (LC-39B) needed for the first Exploration Mission (EM-1). This included finishing the installation of the 20 adjustable platforms within the high bay 3 of the VAB with the preliminary fit-checks with the Mobile Launch Tower (MLT). These new VAB platforms will provide critical access during SLS processing. LC-39B is undergoing final installation of flame deflector components, as well as the revitalization of the flame trench surface. Additionally, the recent solicitation and award of a

1.25 million gallon liquid helium (LH2) storage sphere scheduled for installation at LC-39B, ensures liquid hydrogen capacity necessary to accommodate SLS propellant requirements.

EXPLORATION COF

Exploration Upper Stage (EUS) mission objectives at KSC include the LC-39B Emergency Egress System (EES), which will provide an emergency evacuation of flight crew to a safe haven via a slide wire system. Preliminary engineering development of the EES is ongoing. Design of a new environmental control system (ECS) and high bay platforms within the VAB are under engineering review to accommodate Orion access and processing.

KSC EGS continues to rehabilitate and maintain infrastructure to support SLS and Orion flight hardware processing operations. Recent achievements include completion of a new roof and HVAC system for the Launch Equipment Shop (LES); solicitation and award to replace the Logistic facility roof; studies associated with Logistics HVAC upgrades and design to refurbish the Rotational Surge Processing Facility (RPSF) Firex system.

At Stennis Space Center, the SLS Program completed major activation of the B-2 Test Stand in preparation for the SLS Green Run Testing. The activation of the B-2 Stand included the Liquid Oxygen System, Liquid Hydrogen System, Gaseous Nitrogen Systems, High Pressure Air Systems, Nitrogen Heaters Systems, Test Control Center, NASA Data Acquisition System, LOX Dock, and LH2 Dock. Work in FY 2019 will include activation of the FireX System, Stage Controller Integration and Activation, and Special Test Equipment Activation. All of these are on track to be completed by the 3rd quarter of FY 2019, and the B-2 Test Stand will be ready for Core Stage 1.

At Michoud Assembly Facility (MAF), modifications continue to tooling and manufacturing in support of SLS Core Stage Production. During FY 2018, the SLS Program replaced a chiller and associated piping and valves in Building 207 to ensure reliable chilled water was provided to manufacturing areas in Building 103. The program also replaced wood roof purlins in Building 103 that are essential in maintaining the structural integrity of the roofing system. In addition, transformers and switchgear of substations 20A, 43, 63 and 64 that supporting manufacturing operations were replaced upgrading the overall reliability and capability at the facility. Other accomplishments included rehabilitating the chiller water and steam distribution system by removing and replacing the return and supply lines between Building 207 and Building 103, and the upgrading of the south steam reducing station. Structural repairs of selected fan houses on the roof surface of Building 103 were also necessary to ensure the environmental control of manufacturing spaces was maintained.

WORK IN PROGRESS IN FY 2019

KSC EGS initiates two construction projects to upgrade and modify KSC infrastructure in support of SLS and EUS launch processing requirements. At LC-39B, a fabricated 1.25M gallon (est.) LH2 Dewar sphere, along with a vaporizer, flare stack and associated piping/valve system will be installed. Within the VAB, construction of a new Environmental Control System (ECS) along with design commencement of high bay platforms to support Orion processing requirements.

At MAF, the SLS Program will continue construction work that supports SLS Core Stage manufacturing by completing the second phase of the fan house structural repairs in Building 103 and commence numerous construction projects to include replacing the north 50psi steam piping in Building 103, the first phase to rehabilitate the site –wide storm drainage system, replacing electrical substation 21, rehabilitating the east master substation, and the first phase to rehabilitate the tank and process components of the industrial water tank farm (IWTF). Additionally, numerous design efforts will also commence this fiscal year, to include the second phase to rehabilitate of critical fan house components in

Building 103; upgrading the 100 and 200 Series Fire Alarm Panels at various locations; and upgrading elevators in Buildings 103, 110 and 114.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

KSC will focus on SLS infrastructure requirements. The solicitation and award of two major construction projects as part of the overall of an EGS discrete implementation strategy. At LC-39B EGS will commence upgrades to the enhance the environmental contol system (ECS). Additionally, EGS will begin the multiphase construction of the Component Converter Facility (CCF) starts in FY 2020. CCF upgrades increase operational efficiency and augment delivery of Helium and Nitrogen to the launch site.

At KSC, EGS plans to rehabilitate the water distribution system in the VAB and replace the HVAC system in the Logistics Facility. The Orion Program plans to repair the south wall of the high bay in the Operations and Checkout Building (O&C).

At MAF, the SLS Program will initiate the second phase to rehabilitate components of critical fan houses in Building 103; upgrade the 100 and 200 Series fire alarm panels in numerous buildings; begin elevator upgrades in buildings 103, 110 and 114; rehabilitate the tanks and process components of the IWTF and, replace the roofs on Building 110 and Building 101; and second phase to rehabilitate the site-wide drainage system.

In FY 2020 Exploration CoF will provide support for the Discrete project "High-Pressure Industrial Water System Repair" at SSC, since this project is critical to the SLS program. This project is jointly funded with Institutional, Exploration and Space Operations COF funding.

Exploration Discrete Construction of Facilities Projects

Kennedy Space Center

Modifications to Convertor Compressor Facility and Environmental Control Systems:
FY 2020 Estimate: $24.3M

This project will upgrading the helium and gaseous nitrogen assemblies within the Convertor Compressor Facility to support all NASA launch complexes at Kennedy and Cape Canaveral replacing aging "Apollo " era infrastructure within the facility. The project will increase the GN2 and GHe flow rates to the launch complexes. These modifications are needed to support EM-2. In addition to the higher flow rates required, the age of the existing facility and equipment introduces significant reliability and maintainability risk for all future missions.

NASA will require $10.6M to support planned upgrades to the Environmental Control System at LC-39B. This is required to meet the current manifest and minimal modification windows for EM-2. Additionally it replaces heritage equipment including the Apollo era air intake filters and piping and Shuttle era cooling towers and modifications to the GN2 supply line to improve performance and for long term maintainability and reliability of the system. These modifications are required regardless of vehicle configuration.

EXPLORATION COF

NASA requires $13.7M of Construction of Facility funding in FY 2020 to support the first work package for the Converter Compressor Facility (CCF) Project. The project will increase the GN2 and GHe flow rates to the Pad. These modifications are needed to support EM-2. In addition to the higher flow rates required, the age of the existing facility and equipment introduces significant reliability and maintainability risk for all future missions.

Stennis Space Center

High Pressure Industrial Water System Repair

FY 2020 Estimate: $16.5 million; $12.3M (Institutional Construction of Facilities), $3.1M (HEO/Exploration Construction of Facilities), $1.1M (HEO/Space Operations Construction of Facilities)

The project will repair the 66-inch diameter water pipe and ancillary equipment within the Test Complex that runs from the A2 Valve Vault to the A1 Test Stand of the High-Pressure Industrial Water (HPIW) System at Stennis. The HPIW system, which provides the water required for fire suppression, cooling the test stand deflector, and diffuser operations, is critical during rocket engine testing.

The existing piping is severely corroded and cannot operate as designed. A systematic planned repair by replacement is more economically beneficial than an emergency repair or repairs. Repairing and/or replacing the existing pipe will dramatically reduce the risk of failure which will impact all engine testing and, in turn, may affect future launches.

The HPIW pipe from A1/A3 Valve Vault to the A1 Test Stand can no longer operate at full design pressure and has been de-rated to the lowest recommended operating pressure. A pressure variance has been issued due to the severe corrosion and wall thickness of the HPIW pipe.

If a leak is discovered, severity of the failure would be determined and the system would be down approximately three weeks for inspection alone. For a minor leak (pin hole, etc.), the repair would take approximately one month if repaired from inside; 4-12 months if repaired from outside. For a major leak (sinkhole develops, etc.), downtime and cost would elevate with complexity of environment – ground stabilization required, potential concrete excavation, complexity of utilities, etc. In the event of failure, all testing would be affected in the A complex and would affect any schedule launch whose engines are in the critical path for delivering payloads.

This project supports all rocket engine testing programs, including the SLS and the RS-25.

Minor Revitalization and Construction of Facilities

FY 2020 Estimate: $24.7 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. 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, or so that it can meet new building, fire, and accessibility codes.

The minor project below provides critical investments to support refurbishment of infrastructure and to ensure National Fire Protection Association (NFPA) compliance at KSC. During the year, rearrangement of prio rities may be necessary, which may cause a change in some of the items to be accomplished.

Kennedy Space Center

- VAB Water Distribution Rehabilitation
- Logistics Facilities HVAC
- Repair the South Wall in the O&C Building High Bay

Michoud Assembly Facility

- Elevator Upgrades in Buildings 103,110 and 114
- Replace Roof, Building 110
- Replace Roof, Building 101
- Upgrade Fire alarm Panels 100 and 200 Series
- Rehabilitate Critical Fan Houses in Building 103 (Phase 2)
- Rehabilitate IWTF Tank and Processing System
- Rehabilitate Drainage System (Phase 2)

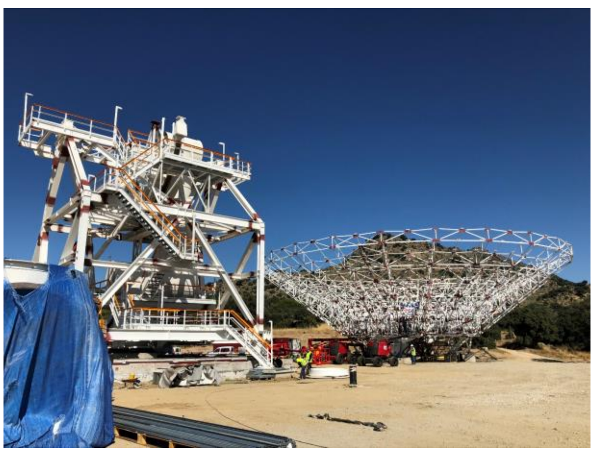
SPACE OPERATIONS COF

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**23.9**	**--**	**19.5**	**0.0**	**0.0**	**0.0**	**0.0**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.



View of NASA's Deep Space Network (DSN) Aperture Enhancement Project (DAEP) under construction in Madrid.

Space Operations Construction of Facilities (CoF) provides construction to support Space Communication and Navigation (SCaN), the International Space Station (ISS) program and 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 2020

In continuing with NASA's goal for improving the communications capabilities of its Deep Space Network (DSN), the Jet propulsion Laboratory (JPL) is proceeding with the DSN Aperture Enhancement Project (DAEP). The DAEP addresses the concern of the aging 70-m antennas located at each of the communication sites. The three strategically located sites (120 degrees apart in Goldstone, Madrid, and Canberra) ensure the DSN's ability to provide optimal support of NASA's vital space assets.

Recently, SCaN has directed JPL to pursue the development of Optical Communications in the DSN. Under the management of the DAEP, this development will be introduced with a new hybrid Radio Frequency (RF)-Optical antenna at the Goldstone complex, identified as Deep Space Station-23 (DSS-23). DSS-23 will include the new deep space Optical Communications capability, which will also provide traditional RF deep space support for NASA missions. The DSS-23 antenna will be the first ever built hybrid aperture of this type capable of providing both RF and Optical Communications for deep space missions.

ACHIEVEMENTS IN FY 2018

FY 2018 was a dynamic year for the DAEP that brought about the near completion of both antenna pedestal structures in Madrid. Minor rework and repair efforts of the pedestals was completed in October of 2018. With the completion of the pedestals, the on-site assembly and erection of the antenna steel structure for DSS-56 and DSS-53 has been actively progressing. The steel fabricator is aggressively working to meet the construction schedule.

At Goldstone, the DAEP has been working to identify the next site for DSS-23 antenna. The DSS-23 will complete the array of four, 34-m Beam Wave Guide antennas at Goldstone, and will introduce optical capabilities for the DSN.

Throughout the Network, each complex also experienced improvements at their facilities. The 34-m BWG Antenna HVAC Chiller Replacement project is near completion with the installation of the first water purification, cooling, and storage subsystem for protecting and increasing the reliability of the new chiller systems.

Furthermore, the 34-m Subnet Replace Beam Wave Guide Azimuth Tracks project witnessed the installation of the Azimuth track at both DSS-25 and DSS-13. These much-needed improvements will ensure the reliability and provide life-extension of the antennas.

LSP also completed the modifications at VAFB that added a new Pre-Engineered Metal Building (PEMB) system of approximately 6,050 square feet. The project enabled the consolidation of dispersed storage areas. Prior to this building addition, mission support equipment was stored in the weather due to Building 836 explosive siting requirements when flight hardware was being processed.

WORK IN PROGRESS IN FY 2019

In Madrid, with the completion of the antenna pedestals, reflector RF panels and mirrors, and sub-reflector, the focus is on completing the on-site assembly and erection of both antennas, DSS-56 and DSS-53. In parallel, significant work will take place for implementing the necessary interface between new and existing support-facilities and infrastructure. The DAEP is also looking to begin the integration of electronics as soon as possible. Additionally, at Goldstone, DAEP will continue with the site determination, design, and contracting efforts for DSS-23.

Four new Minor-projects are scheduled to begin in 2019. In Canberra two projects, the Operational Buildings HVAC Upgrade and the DSS-43 US-1, US-2, Servo Starter Replacement, are commencing. While in Madrid, the Upgrade Switchgear and Protection Integration project will commence. Additionally in the network, the Replacement of the 70-m Antenna Cooling Towers for XMTR Support will begin.

Progress will continue for existing projects. The Antenna Apron and Subsoil Remediation project continues to progress. The Beam Wave Guide (BWG) Azimuth Track replacement project will continue to address the need for track replacements. Lastly, the BWG Antenna Chiller Replacement project and the Site Wide UPS in Canberra will finalize.

LSP will continue replacing Chillers and boilers in Hangar AE and the Payload Hazardous Servicing Facility (PHSF) at the Kennedy Space Center. This project will provide functional replacement of chilled water systems and other heating, ventilation, and air conditioning (HVAC) components at Hangar AF and the Payload Hazardous Servicing Facility (PHSF) by replacing: three Chillers, two cooling Towers and one boiler at Hangar AE; and two Chillers and four Ventilation Units at the PHSF. Other system components are also being repaired or replaced in order to improve overall system performance.

LSP will also commence an energy efficiency upgrade to Building 840 at Vandenberg Air Force Base. This project will install an integrated HVAC system for the entire 25,000 sq. ft. building, and update the lighting to the entire facility by installing Light Emitting Diode (LED).

KEY ACHIEVEMENTS PLANNED FOR FY 2020

The DAEP completion of DSS-56 in Madrid is planned in FY 2020. At Goldstone, the antenna pedestal build is expected to complete by the end of FY 2020 and enable the next phase of the project. Concurrently, the design and build of the optical hybrid design will be in full-force. FY 2020 will include completion of the prototype Optical subsystem field tests at Goldstone, and the start of the development of the operational Optical subsystem for DSS-23.

In FY 2020, support for the Discrete project, "High-Pressure Industrial Water System Repair" at SSC, will continue, since this project is critical to the Rocket Propulsion Test program. This project is jointly funded with Institutional, Exploration and Space Operations CoF funding.

In FY 2020, one Minor CoF project for the replacement of the US1, US2, Servo Starter at DSS-14 is planned. This project will replace an antiquated system with modern and maintainable distribution equipment for greater safety and reliability.

Space Operations Discrete Construction of Facility Projects

Jet Propulsion Laboratory

DAEP: Construction of 34-m Beam Wave Guide Antennas – Goldstone/Canberra

Location: Deep Space Communications Complex, Goldstone and Canberra

FY 2020 Construction Estimate: $14.6 million, Total Project is $113.4million (FY 19 $4.5 million, FY 2020 14.6 million, FY 2021 $21.0 million, FY 2022 $23.1 million, FY 2023 $21.5 million, FY 2024 $3.8 million, FY 2025 $12.6 million and FY 2026 $12.3 million).

This project will result in four, 34-m BWG Antennas operating at each of the DSN’s communications complexes. DSS-23 will become a fourth Goldstone operating 34-meter BWG antenna, initially utilized as a traditional DSN RF aperture and shortly thereafter providing both RF and Optical Communications for deep space. Because of its location and optimal weather conditions, Goldstone has been identified as the best site for this initial hybrid RF-Optical aperture in the DSN.

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, as well as all facilities in and around the antennas, including the 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.

The new DAEP 34-meter beam waveguide antennas are essential for providing needed capabilities in the DSN, based on current projections for NASA missions in the 2020s.

The new DAEP 34-meter beam waveguide antennas are essential for providing needed capabilities in the DSN, based on current projections for NASA missions in the 2020s.

NASA is currently developing a number of interplanetary spacecrafts, including planetary robotic missions and pre-cursor robotic missions for Human Exploration. Additionally, NASA's ability to support crewed missions will also be enhanced by these expanded capabilities. The newly developed Optical Communications capability will provide data rates for both robotic and crewed missions. At present, the existing DSN antennas are operating at capacity and are oversubscribed, with demand exceeding supply by about 50%.

Stennis Space Center

High Pressure Industrial Water System Repair

FY 2020 Estimate: $16.5 million; $12.3M (Institutional Construction of Facilities), $3.1M (HEO/Exploration Construction of Facilities), $1.1M (HEO/Space Operations Construction of Facilities)

The project will repair the 66-inch diameter water pipe and ancillary equipment within the Test Complex that runs from the A2 Valve Vault to the A1 Test Stand of the High-Pressure Industrial Water (HPIW) System at Stennis. The HPIW system, which provides the water required for fire suppression, cooling the test stand deflector, and diffuser operations, is critical during rocket engine testing.

The existing piping is severely corroded and cannot operate as designed. A systematic planned repair by replacement is more economically beneficial than an emergency repair or repairs. Repairing and/or replacing the existing pipe will dramatically reduce the risk of failure which will impact all engine testing and, in turn, may affect future launches.

The HPIW pipe from A1/A3 Valve Vault to the A1 Test Stand can no longer operate at full design pressure and has been de-rated to the lowest recommended operating pressure. A pressure variance has been issued due to the severe corrosion and wall thickness of the HPIW pipe.

If a leak is discovered, severity of the failure would be determined and the system would be down approximately 3 weeks for inspection alone. For a minor leak (pin hole, etc.), the repair would take approximately 1 month if repaired from inside; 4-12 months if repaired from outside. For a major leak (sinkhole develops, etc.), downtime and cost would elevate with complexity of environment – ground stabilization required, potential concrete excavation, complexity of utilities, etc. In the event of failure, all testing would be affected in the A complex and would affect any schedule launch whose engines are in the critical path for delivering payloads.

This project supports all rocket engine testing programs, including the SLS and the RS-25.

Minor Revitalization and Construction of Facilities

FY 2020 Estimate: $3.8 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 include 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, or so that it can meet new building, fire, and accessibility codes.

The FY 2020 request includes one minor construction project for the SCaN program to upgrade various pre-1970 vintage substation equipment with new modern and maintainable distribution equipment.

Jet Propulsion Laboratory:

- DSS-14, US-1, US-2 Servo Starter Replacement, Goldstone

SCIENCE COF

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**15.0**	**--**	**15.3**	**0.0**	**0.0**	**0.0**	**0.0**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

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Artist's rendering of the fully populated modular computing facility, which will house energy efficient supercomputing modules.

Science Construction of Facilites (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, as the biggest user, manages for the Agency. Construction for HECC directly supports the Aeronautics, Human Exploration and Operations, 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 2020

In support of modernizing capabilities and NASA infrastructure, Science is contributing to the new Flight Electronics Integration Facility at the Jet Propulsion Laboratory, which is an important revitalization project that will integrate multiple flight hardware assembly and fabrication facilities into a single location, thereby reducing risk to mission flight hardware by collocating multiple personnel and functions into this important integrated facility.

ACHIEVEMENTS IN FY 2018

In FY 2018, NASA began construction of the Modular Supercomputing Facility (MSF) at Ames Research Center, 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.

The prototype demonstrated the feasibility of new energy efficient and water-conserving modular computing technology, enabling the increase of NASA’s supercomputing capability with minimal impact on limited energy and water resources. The FY 2018 work provides the infrastructure and utilities required to support the modular container-based capability. When complete, the project will ensure flexibility to adjust for fast-changing technology with minimal risk, and will provide the supercomputing capability necessary to meet NASA's mission requirements.

WORK IN PROGRESS IN FY 2019

In FY 2019, NASA will proceed with three minor revitalization and construction efforts: the Asteroid Sample and Advanced Curation Facility at Johnson Space Center, the Replace/Refurbish Laboratory Infrastructure (Bldg. N239) Project at the Ames Research Center, and work to facilitate the processing of large balloon payloads at Wanaka, New Zealand.

NASA also continues work on the Modular Supercomputing Facility at Ames Research Center, anticipating a spring 2019 completion.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

NASA's FY 2020 Science CoF budget includes one Discrete and one Minor construction project required to meet laboratory needs. These projects include the Flight Electronics Integration Facility (split funded with Institutional Construction of Facilities), and additional work to Replace/Refurbish Laboratory Infrastructure (Bldg. N239) at the Ames Research Center. (See "Minor Revitalization and Construction of Facilities" below.)

Discrete Construction of Facility Projects

Discrete Construction of Facilities 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 recapitalization projects that replace outdated facilities or buildings that are impeding mission success.

Jet Propulsion Laboratory

Flight Electronics Integration Facility

FY 2020 Estimate: $75.0 million; $63.0M (Institutional Construction of Facilities), $12.0M (Science Mission Directorate)

Science Mission Directorate funding is provided to support Institutional CoF. This important repair by replacement project will consolidate multiple locations across the center and reduce risk to flight hardware by integrating multiple flight hardware fabrication, testing, and assembly functions into a single location. This will eliminate transportation risks of flight hardware between multiple facilities across JPL. (Please refer to a full description of the project in Institutional COF Discrete projects.)

Minor Revitalization and Construction of Facilities

FY 2020 Estimate: $3.3 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, or so that it can meet new building, fire, and accessibility codes.

The FY 2020 request includes a minor construction project that will modernize outdated and non-compliant laboratories on the fourth floor of Building N239 at ARC.

ENVIRONMENTAL COMPLIANCE AND RESTORATION

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**86.4**	**--**	**82.9**	**82.9**	**82.9**	**82.9**	**82.9**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

The FY 2019 Operating Plan was not approved at the time the budget was prepared. Therefore, only specific marks from Public Law 116-006, Consolidated Appropriations Act, 2019, as well as projects in development, are included in the FY 2019 column.

Remediation of contamination in the groundwater at MAFElectrical current is applied through electrodes driven into the ground and the contaminated soils and groundwater are heated. The volatilized contaminants are removed through vacuum extraction.

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 sites as part of remediation and cleanup measures. For additional information about NASA's ECR program, go to: http://www.nasa.gov/offices/emd/home/ecr.html.

EXPLANATION OF MAJOR CHANGES IN FY 2020

None.

ENVIRONMENTAL COMPLIANCE AND RESTORATION

ACHIEVEMENTS IN FY 2018

NASA's ECR program includes cleanup activities at all NASA centers, with priority given to protecting human health and the environment in conformance with Environmental Protection Agency and state regulatory agreements and requirements. NASA accomplished the following notable restoration activities in FY 2018:

- The Santa Susana Field Laboratory (SSFL) continued demolition of structures in areas not associated with the Test Stands. The site submitted initial cleanup plans for groundwater to the State of California regulators. A Record of Decision for groundwater cleanup under the National Environmental Policy Act was also prepared. SSFL continued operations of groundwater treatment systems, long-term monitoring of groundwater, and Cultural Resource actions 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 the U.S. Environmental Protection Agency, completed a Record of Decision for onsite and offsite groundwater contamination remediation.
- The Glenn Research Center completed decontamination and decommission of the cyclotron building under the National Resource Center license termination.
- The Kennedy Space Center (KSC) continued investigation and cleanup of groundwater and soil contamination. Activities included the installation of new groundwater treatment systems, removal of contaminated soils, investigation of additional sites for potential contamination, continued sampling of over 400 monitoring wells, and continued operations of existing groundwater cleanup systems.
- The Ames Research Center (ARC) began a major landfill remediation project and final closure per its Federal Facilities Agreement.
- The Marshall Space Flights Center (MSFC) began cleanup of the Industrial Sewer operable unit and monitoring/characterization of groundwater.
- The White Sands Test Facility (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 of the sewage lagoon.
- The Agency continued operations of treatment systems and monitoring at the Armstrong Flight Research Center (AFRC), Goddard Space Flight Center (GSFC), JPL, Langley Research Center (LaRC), Michoud Assembly Facility (MAF), Stennis Space Center (SSC), and the Wallops Flight Facility (WFF).

WORK IN PROGRESS IN FY 2019

NASA is continuing its commitment to restoration by executing the following activities in FY 2019:

- SSFL is expecting to complete demolition activities for structures and implement abatement activities for the remaining Test Stands; complete cleanup plans for soils and groundwater and begin implementation for groundwater cleanup. The site will continue operation of groundwater treatment systems and long term monitoring of groundwater. Cultural Resource actions will continue per the Programmatic Agreement with the State Historic Preservation Office, Native Americans, and consulting parties.

ENVIRONMENTAL COMPLIANCE AND RESTORATION

- KSC will continue investigation and cleanup 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 over 400 monitoring wells, and continued operations of existing groundwater cleanup systems.
- ARC will continue landfill remediation and final closure per its Federal Facilities Agreement.
- MSFC will complete cleanup of the Industrial Sewer operable unit and begin removing contaminated soil from the Test Areas as well as begin contaminant source removal for the groundwater 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 of the sewage lagoon.
- GRC will continue cleanup operations of abandoned wastewater treatment facility and lead contaminated range at Plum Brook Station;
- WFF will begin operation of a groundwater treatment system to adress specific perfluorinated compounds.
- The Agency will continue operations of treatment systems and groundwater and soil monitoring at AFRC, ARC, GSFC, JPL, LaRC, MAF, SSC, and WFF.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

Key projects and achievements planned for the FY 2020 include:

- $39.2 million for demolition, cleanup of contaminated soils, continued operation of groundwater treatment systems, and continued long term monitoring of groundwater at SSFL in accordance with the State of California. Cultural Resource actions will continue per the Programmatic Agreement with the State Historic Preservation Office, Native Americans, and consulting parties;
- $11.0 million for the continued investigation and cleanup 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 over 400 monitoring wells, and continued operations of existing groundwater cleanup systems;
- $8.6 million for the continued cleanup of ground water contamination and investigation of soil contamination at WSTF, to include 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; and
- $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.

Program Elements

RESTORATION

Restoration projects address cleanup liabilities at all NASA centers and component facilities. As of the start of FY 2019, known liabilities totaled $1.3 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

ENVIRONMENTAL COMPLIANCE AND RESTORATION

“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 may 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)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**39.0**	**39.3**	**41.7**	**42.1**	**42.5**	**43.0**	**43.4**

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

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INSPECTOR GENERAL

FY 2020 Budget

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Total Budget	**39.0**	**39.3**	**41.7**	**42.1**	**42.5**	**43.0**	**43.4**
Change from FY 2019			**2.4**				
Percentage change from FY 2019			**6.1%**				

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million.

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For FY 2020, the NASA Office of Inspector General (OIG) requests $41.7 million to support the work of auditors, investigators, analysts, specialists, lawyers, and support staff located at NASA Headquarters in Washington, DC, and 12 locations throughout the United States.

The OIG conducts audits, investigations, and reviews of NASA programs to prevent and detect fraud, waste, abuse, and mismanagement. OIG also assists NASA leadership in promoting economy, efficiency, and effectiveness in its programs and operations and independently reports to the Administrator, Congress, and the public to further the Agency's accomplishment of its mission. Our 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 high-risk areas and NASA's top management challenges. OIG audits provide independent assessments with actionable recommendations that help NASA achieve its space exploration, scientific, and aeronautics research missions 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 leadership 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 77 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.

EXPLANATION OF MAJOR CHANGES IN FY 2020

For FY 2020, we are requesting $41.7 million, or $2.4 million more than the $39.3 million baseline. Salaries and benefits for our employees and the contract with a private accounting firm to conduct the statutorily required audit of NASA's financial statements consume 91 percent of our annual budget. The change from baseline primarily reflects an upwards adjustment for salaries and benefits needed to carry out our mission. Unlike most of NASA, the OIG is almost exclusively a personnel-driven organization. It is critical that adequate staffing is maintained to provide needed audit and investigative oversight. NASA OIG supportable direct Full-Time Equivalent (FTE) has decreased substantially because of budget reductions and increased personnel costs. For example, over the last 5 years, the appropriations provided to NASA OIG have increased 4 percent from $37.5 million in FY 2014 to $39.0 million in FY 2018. During this same timeframe, the average cost of salaries and benefits has increased 12 percent. The impact of the disparity between the increase in appropriations versus the increase in salaries and benefits, is a loss of 15 FTE for NASA OIG. This request includes an additional $1.9 million to allow NASA OIG to maintain its supportable FTE at FY 2019 levels.

Additionally, in January 2020, the 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 reduced price (compared to similar previous contracts), a reduction not expected to be repeated by firms competing for the new 5-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 2019. The request includes $500,000 more for the contract to be awarded in FY 2020.

ACHIEVEMENTS IN FY 2018

In FY 2018, the OIG issued 16 audit products containing 103 recommendations for improvement and identifying approximately $13.9 million in potential savings for NASA. Audit products included reports examining NASA's:

- Progress in Maximizing Utilization of the International Space Station;
- Efforts to Eliminate Risk in its Information Technology Supply Chain;
- Ability to Address Cybersecurity Threats Through the Security Operations Center;
- Success in Controlling Cost and Mitigating Risks in Commercial Cargo Resupply Missions;
- Management of the Surface Water and Ocean Topography Mission;
- Oversight of the National Space Biomedical Research Institute; and
- Actions to Improve the Agency's Information Technology Governance.

In FY 2018, 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 $11.7 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 2018 resulted in 39 indictments, 30 convictions, 5 civil settlements, 73 administrative actions, and 12 suspensions or debarments.

Examples of OI's work over the past year include:

- As a result of an investigation by the NASA OIG, Defense Criminal Investigative Service (DCIS), and Naval Criminal Investigative Service, a small business owner was convicted of six counts of wire fraud related to five NASA research contracts and one Navy research contract valued at over $2 million.
- As the result of a joint investigation by NASA OIG, the Department of Commerce OIG, DCIS, the Defense Contract Management Agency, and the U.S. Air Force Office of Special Investigations, a Yreka, California, company agreed to pay $300,000 in a civil settlement to

resolve allegations that it fraudulently obtained multiple government contracts by misrepresenting itself as a small business.

- Following a joint investigation by NASA OIG, DCIS, and Naval Criminal Investigative Service, the owner of a Wilmington, Delaware, company was sentenced to three years imprisonment, three years supervised release, and ordered to pay more than $1.4 million in restitution for falsifying information on NASA and U.S. Navy research contracts.
- Following a joint investigation by NASA OIG, the Department of Homeland Security OIG, and GSA OIG, a Peoria, Illinois, grand jury returned a seven-count indictment charging an Athens, Alabama, computer store owner with mail fraud, wire fraud, theft, and interstate transportation of stolen property. Over a decade-long scheme, the subject allegedly made false representations to GSA in order to obtain computer systems intended to support the Computers for Learning program, then diverted the computers for retail sale. The program facilitates the transfer of computers and related equipment owned and excessed by the Federal Government directly to schools and educational nonprofit organizations at no cost. Over an eight year period, the store owner received approximately 830 computer-related items from NASA valued at $929,791.
- Following a joint investigation by NASA OIG and National Science Foundation (NSF) OIG, a contractor pled guilty to theft relating to SBIR program fraud. The investigation revealed the contractor knowingly converted $200,000 in grant funds from NASA and NSF to his personal use and attempted to obtain additional grant funds via fraudulent claims regarding the financial condition of his company. Pursuant to his plea agreement in May 2018, the contractor was ordered to pay the Federal Government $200,000 in restitution.
- As a result of an investigation by the NASA OIG, NSF OIG, Department of Health and Human Services OIG, and the Federal Bureau of Investigation, a small business owner was sentenced to 12 months of probation and ordered to forfeit $185,000 for making false statements. The owner was previously charged with multiple counts of identity theft and wire fraud related to proposals totaling over $1.8 million.
- A former Johnson Space Center contractor employee damaged NASA databases after gaining unauthorized access to the systems following his termination. In November 2017, the subject pled guilty to fraud and was sentenced to 12 months imprisonment, three years supervised release, and ordered to pay $10,000 in restitution.

WORK IN PROGRESS IN FY 2019

In the first six months of FY 2019, the OIG has issued audit reports examining NASA's efforts to oversee Boeing's Space Launch System core stages contract; implement processes to identify and account for Agency historic real and personal property; control waste and abuse by employees on extended travel duty; and manage costs while remediating environmental contaminants at the Santa Susana Field Laboratory. During the remainder of the fiscal year, OIG will work on examining the SETI Institute; Heliophysics portfolio of projects and missions; network security at NASA's Jet Propulsion Laboratory; and the Mobile Launcher Program.

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.

KEY ACHIEVEMENTS PLANNED FOR FY 2020

Going forward, the OIG will continue to focus its audit work on NASA's top management and performance challenges. In a November 2018 report, OIG listed those challenges as:

- Space Flight Operations in Low Earth Orbit;
- Deep Space Exploration;
- NASA's Science Portfolio;
- Information Technology Governance and Security;
- Infrastructure and Facilities; and
- Contracting and Grants.

The OIG's FY 2020 request is $41.7 million, and includes the following:

- $35.1M (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 and increased rates for retirement contributions. Salaries include the required additional 25 percent law enforcement availability pay for criminal investigators. The request assumes no pay raise is enacted for 2019 and no pay raise for 2020.
- $2.9M (7 percent) to fund the statutorily required annual audit of the Agency's financial statements.
- $0.9M (2 percent) to fund travel, per diem, and related expenses.
- $2.8M (7 percent) to fund equipment, training, government vehicles, special equipment for criminal investigators, transit subsidies, and information technology equipment unique to the OIG.[1]

In Public Law 115-141, Consolidated Appropriations Act, 2018, the OIG received $500,000 of 2-year funding to execute the budget in alignment with NASA's end-of-year close-out procedures. For FY 2020, OIG requests that Congress provide 2-year availability for all OIG funding. This change will make OIG funding consistent with NASA's other appropriations 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.

[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.*

SUPPORTING DATA

Supporting Data

FUNDS DISTRIBUTION BY INSTALLATION

FUNDS BY MISSION BY NASA CENTER

Budget Authority ($ in millions)	FY 2020*
Deep Space Exploration Systems	35.7
Exploration Technology	38.5
LEO and Spaceflight Operations	27.9
Science	173.5
Aeronautics	111.0
STEM Engagement	0.0
Safety, Security, and Mission Services	235.1
Construction and Environmental Compliance and Restoration	36.9
Ames Research Center (ARC) Total	**658.6**
Deep Space Exploration Systems	0.8
Exploration Technology	3.9
LEO and Spaceflight Operations	0.3
Science	77.6
Aeronautics	129.8
STEM Engagement	0.0
Safety, Security, and Mission Services	69.0
Construction and Environmental Compliance and Restoration	27.4
Armstrong Flight Research Center (AFRC) Total	**308.7**
Deep Space Exploration Systems	277.4
Exploration Technology	90.7
LEO and Spaceflight Operations	56.5
Science	35.5
Aeronautics	125.3
STEM Engagement	0.0
Safety, Security, and Mission Services	276.9
Construction and Environmental Compliance and Restoration	19.6
Glenn Research Center (GRC) Total	**881.9**
Deep Space Exploration Systems	7.7
Exploration Technology	56.1
LEO and Spaceflight Operations	165.6
Science	2,241.4
Aeronautics	18.9
STEM Engagement	0.0
Safety, Security, and Mission Services	409.3
Construction and Environmental Compliance and Restoration	18.7
Goddard Space Flight Center (GSFC) Total	**2,917.7**

FUNDS DISTRIBUTION BY INSTALLATION

Budget Authority ($ in millions)	**FY 2020***
Deep Space Exploration Systems	2.8
Exploration Technology	30.2
LEO and Spaceflight Operations	183.1
Science	1,729.4
STEM Engagement	0.0
Safety, Security, and Mission Services	13.6
Construction and Environmental Compliance and Restoration	114.1
Jet Propulsion Laboratory (JPL/NMO) Total	**2,073.2**
Deep Space Exploration Systems	1,521.3
Exploration Technology	42.9
LEO and Spaceflight Operations	3,168.4
Science	37.1
STEM Engagement	0.0
Safety, Security, and Mission Services	369.6
Construction and Environmental Compliance and Restoration	39.6
Johnson Space Center (JSC) Total	**5,178.9**
Deep Space Exploration Systems	427.9
Exploration Technology	11.6
LEO and Spaceflight Operations	189.9
Science	345.0
Aeronautics	0.0
STEM Engagement	0.0
Safety, Security, and Mission Services	379.1
Construction and Environmental Compliance and Restoration	57.4
Kennedy Space Center (KSC) Total	**1,410.9**
Deep Space Exploration Systems	28.4
Exploration Technology	43.7
LEO and Spaceflight Operations	1.2
Science	208.0
Aeronautics	155.4
STEM Engagement	0.0
Safety, Security, and Mission Services	334.8
Construction and Environmental Compliance and Restoration	73.7
Langley Research Center (LaRC) Total	**845.3**
Deep Space Exploration Systems	1,638.6
Exploration Technology	33.2
LEO and Spaceflight Operations	210.5
Science	181.7
STEM Engagement	0.0
Safety, Security, and Mission Services	430.5
Construction and Environmental Compliance and Restoration	82.1
Marshall Space Flight Center (MSFC) Total	**2,576.6**

FUNDS DISTRIBUTION BY INSTALLATION

Budget Authority ($ in millions)	**FY 2020***
Deep Space Exploration Systems	1042.7
Exploration Technology	661.7
LEO and Spaceflight Operations	249.6
Science	1,274.5
Aeronautics	126.5
STEM Engagement	0.0
Safety, Security, and Mission Services	505.2
Construction and Environmental Compliance and Restoration	82.1
Office of Inspector General	41.7
NASA Headquarters (HQ) and Inspector General (IG) Total	**3,984.1**
Deep Space Exploration Systems	38.4
Exploration Technology	1.8
LEO and Spaceflight Operations	32.7
Science	0.1
STEM Engagement	0.0
Safety, Security, and Mission Services	61.5
Construction and Environmental Compliance and Restoration	48.9
Stennis Space Center (SSC) Total	**18.5**
	21,019.0

* Totals may not add due to rounding.

NOTE: Funds will not be fully distributed to Centers until after final acquisition decisions are made. Thus, Center FY 2019 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 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 2020 Budget support NASA's scientists, engineers, researchers, managers, technicians, and business operations workforce. It includes civil service personnel at NASA Centers, Headquarters, and NASA-operated facilities.

NASA continually assesses and adjusts the mix of skills in its workforce to address changing mission priorities, leveraging industry and 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 will explore cross-mission retraining opportunities for employees whenever possible, offer targeted buyouts in selected surplus skill areas, and continue to identify, recruit, and retain a multi-generational workforce of employees who possess skills critical to the Agency.

CIVIL SERVICE FULL-TIME EQUIVALENT DISTRIBUTION BY CENTER

DIRECT FUNDED

	Actual	Estimate	Request				
	FY 2018	**FY 2019**	**FY 2020**	**FY 2021**	**FY 2022**	**FY 2023**	**FY 2024**
ARC	1,129	1,145	1,143	1,143	1,143	1,143	1,143
AFRC	512	531	513	513	513	513	513
GRC	1,513	1,531	1,525	1,525	1,525	1,525	1,525
GSFC	3,011	3,011	3,010	3,010	3,010	3,010	3,010
JSC	2,918	2,945	2,939	2,939	2,939	2,939	2,939
KSC	1,906	1,925	1,922	1,922	1,922	1,922	1,922
LaRC	1,757	1,773	1,769	1,769	1,769	1,769	1,769
MSFC	2,267	2,301	2,292	2,292	2,292	2,292	2,292
SSC	252	270	274	274	274	274	274
HQ	1,067	1,113	1,113	1,113	1,113	1,113	1,113
NSSC	-	-	-	-	-	-	-
NASA Total*	**16,332**	**16,545**	**16,500**	**16,500**	**16,500**	**16,500**	**16,500**
OIG	176	207	207	207	207	207	207

**Totals may not add due to rounding.*

NOTE: Funds will not be fully distributed to Centers until after final acquisition decisions are made. Thus, Center FY 2020 allocations should not be considered final or directly comparable to prior year allocations.

CIVIL SERVICE FULL-TIME EQUIVALENT DISTRIBUTION

CIVIL SERVICE FULL-TIME EQUIVALENT DISTRIBUTION BY CENTER

REIMBURSABLE FUNDED

	Actual	Estimate	Request				
	FY 2018	**FY 2019**	**FY 2020**	**FY 2021**	**FY 2022**	**FY 2023**	**FY 2024**
ARC	14	22	22	22	22	22	22
AFRC	14	-	15	15	15	15	15
GRC	8	3	3	3	3	3	3
GSFC	162	224	232	232	232	232	232
JSC	31	-	-	-	-	-	-
KSC	17	1	1	1	1	1	1
LaRC	16	15	15	15	15	15	15
MSFC	22	-	-	-	-	-	-
SSC	39	27	19	19	19	19	19
HQ	10	-	-	-	-	-	-
NSSC	135	148	148	148	148	148	148
NASA Total*	**468**	**440**	**455**	**455**	**455**	**455**	**455**
OIG	6	6	6	6	6	6	6

**Totals may not add due to rounding.*

NOTE: Funds will not be fully distributed to Centers until after final acquisition decisions are made. Thus, Center FY 2020 allocations should not be considered final or directly comparable to prior year allocations.

CIVIL SERVICE FULL-TIME EQUIVALENT DISTRIBUTION

FY 2020 FTE DISTRIBUTION BY ACCOUNT BY CENTER

	Science	Aeronautics	Explortion Technology	Deep Space Exploration Systems	LEO and Spaceflight Operations	STEM Enagagement	Safety, Security, and Mission Services	Reimbursable / Working Capital Fund**	OIG	NASA-Funded Total	Agency TOTAL
ARC	137	221	90	98	28	-	569	22	-	1,143	1,165
AFRC	95	186	16	6	1	-	209	15	-	513	528
GRC	74	324	122	218	126	-	661	3	-	1,525	1,528
GSFC	1,176	-	109	36	132	-	1,557	232	-	3,010	3,242
JSC	31	-	55	784	1,212	-	857	-	-	2,939	2,939
KSC	9	-	49	588	427	-	849	1	-	1,922	1,923
LaRC	191	441	118	118	4	-	897	15	-	1,769	1,784
MSFC	132	-	100	845	206	-	1,009	-	-	2,292	2,292
SSC	-	-	6	65	39	-	164	19	-	274	293
HQ	20	-	7	-	-	-	1,086	-	-	1,113	1,113
NSSC	-	-	-	-	-	-	-	148	-	-	148
NASA Total*	**1,865**	**1,172**	**672**	**2,758**	**2,175**	**-**	**7,858**	**455**	**-**	**16,500**	**16,955**
OIG								6	207	207	213

**Totals may not add due to rounding*

***Includes 156 FTE funded by Working Capital Fund; and 305 FTE funded by reimbursable customers*

NOTE: Funds will not be fully distributed to Centers until after final acquisition decisions are made. Thus, Center FY 2020 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; and
- Information Technology (IT) Infrastructure Integration Program (I3P).
- National Center for Critical Information Processing and Storage (NCCIPS)

WORKING CAPITAL FUNDS BUDGET SUMMARY

	Actual	Estimate	Request
Spending Authority from Offsetting Collections ($ millions)	**FY 2018**	**FY 2019**	**FY 2020**
NSSC	72	74	84
SEWP	18	25	27
I3P	340	390	387
NCCIPS	18	30	25
Total Spending Authority	**448**	**519**	**523**
Unobligated Brought Forward, Oct. 1	14	14	15
Recoveries of Prior Yr. Unpaid Obligations	1	5	5
Total Budgetary Resources	**463**	**538**	**543**
NSSC	73	75	86
SEWP	19	25	27
I3P	340	392	388
NCCIPS	17	31	26
Total Obligations	**449**	**523**	**527**
Unobligated Balance (end-of-year)*	**14**	**15**	**16**

**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 SSC 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 2019, NSSC will continue to offer similar services as in FY 2018 with no significant scope changes anticipated. During FY 2020, NSSC will continue to offer similar services as in FY 2019 expanding the scope to include two additional services, Staffing and Classification and Training Administration. In addition to expanding the scope, NSSC will also be making minor expansions to existing services.

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 2018, SEWP quotes have a 21-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 0.375 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 2018, the Federal Government is projected to save about $21.3 million in fees, based on the difference between General Services Administration (GSA) and SEWP surcharge fees.

Solutions Enterprise-Wide Procurement (SEWP) office is forecasting an increase of around 20% in FY 2020 for usage of the NASA SEWP. NASA is looking to make SEWP their first line of usage when making Information Technology and Communication (ITC) purchases because of the proactive way that SEWP has setup the Supply Chain Risk Management (SCRM) within the online tools and a couple of DoD agencies are looking to move a major part of their ITC purchase through SEWP toward the second half of FY 2019 and will continue through FY 2020. The percent in Government saving will increase as well with the usage increasing as SEWP will continue to keep the fee percent at 0.375%, with the possibility of a decrease in fee within FY 2020.

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 2019 anticipated funding level, the I3P WCF will continue to offer similar services as in FY 2018. During FY 2020 NSSC will continue to offer similar services as in FY 2019 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 2019, NCCIPS will continue to offer similar services as in FY 2018 with no significant scope changes anticipated. During FY 2020, NCCIPS customer base will be increasing which drives the rate per square footage as well as implementation and utilities costs.

BUDGET BY OBJECT CLASS

FY 2020 Estimated Direct Discretionary Obligations
($ millions)

Code	Object Class	Deep Space Exploration Systems	Exploration Research and Technology	LEO and Spaceflight Operations	Science	Aeronautics	STEM Engagement	Safety, Security, and Mission Services	Construction & Environmental Compliance & Restoration	Office of Inspector General	NASA Total
11.1	Full-time permanent	370	90	265	249	158		961	-	25	2,118
11.3	Other than full-time permanent	2	3	2	3	3		20	-	-	33
11.5	Other personnel compensation	2		2	1			36	-	-	41
11.8	Special Personal Services Payments	1									
11.9	*Subtotal Personnel Compensation*	*375*	*93*	*269*	*253*	*161*	-	*1,017*	-	*25*	*2,192*
12.1	Civilian personnel benefits	122	38	86	80	51		311	-	9	697
13	Benefits to former personnel	-	-	-	-	-	-	1	-	-	1
	Total Personnel Compensation & Benefits	**497**	**131**	**355**	**333**	**212**	-	**1,329**	-	**34**	**2,890**
21	Travel & transport. of persons	16	7	15	26	7		25		1	97
22	Transportation of things	1	1	1,483	7			2			1,494
23.1	Rental payments to GSA										-
23.2	Rental payments to others			2	3			42			47
23.3	Communications, utilities & misc.	29		5	5	3		84	1		127
24	Printing & reproduction							3			3
25.1	Advisory & assistance services	397	32	101	78	10		275	29		922
25.2	Other services	53	46	132	212	25		252	72	4	796
25.3	Other purchases of goods & services from Government accounts	57	26	26	223	8		66	31	1	438
25.4	Operation & maintenance. of facilities	132	8	54	18	23		272	72		579
25.5	Research & development contracts	3,536	654	1,839	4,414	245		184	39		10,911
25.6	Medical care							9			9
25.7	Operation & maintenance of equipment	127	18	203	116	38		434	30	2	968
26	Supplies & materials	32	12	17	30	20		24			135
31	Equipment	41	11	16	45	25		41	1		180
32	Land & structures	50		5	2	1		18	325		401
41	Grants, subsidies, & contributions	54	68	33	791	50		25			1,021
	Other Object Classes	**4,525**	**883**	**3,931**	**5,970**	**455**	-	**1,756**	**600**	**8**	**18,128**
	NASA Total, Direct	**5,022**	**1,014**	**4,286**	**6,303**	**667**	-	**3,085**	**600**	**42**	**21,019**

**Totals may not add due to rounding*

NOTE: The table only reflects the FY 2020 request and does not include remaining funding from previous direct or supplemental appropriations.

STATUS OF UNOBLIGATED FUNDS

UNOBLIGATED FUNDS SUMMARY BY APPROPRIATIONS ACCOUNT

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 2018 or FY 2019 amounts to make them comparable to the budget structure underlying the FY 2020 request.

UNOBLIGATED FUNDS SUMMARY BY APPROPRIATIONS ACCOUNT

Budget Authority ($ millions)	Unobligated Balances Sept. 30, 2018	Estimated Unobligated Balances Sept. 30, 2019	Estimated Unobligated Balances Sept. 30, 2020
Deep Space Exploration Systems	**416**	**516**	**616**
Exploration Technology	**40**	**54**	**68**
LEO and Spaceflight Operations	**118**	**251**	**384**
Science	**400**	**455**	**510**
Aeronautics	**25**	**35**	**45**
STEM Engagement	**7**	**12**	**17**
Safety, Security, and Mission Services	**551**	**647**	**743**
Construction and Environmental Compliance and Restoration	**370**	**445**	**520**
Office of Inspector General	**1**	**0**	**0**
Working Capital Fund	**14**	**15**	**16**
Science, Space, and Technology Education Trust Fund	**2**	**2**	**2**
Total NASA	**1,944**	**2,432**	**2,921**
**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) canceled 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. As most reimbursable requests to NASA do not occur until the year of execution, the FY 2019 to FY 2020 estimates are based on an annual survey of Centers' anticipated reimbursable agreements. NASA separately budgets for and executes the four categories of reimbursable agreements listed below. Within the non-EUL amounts, reimbursable agreements are used for a range of activities; for example, use of NASA operated wind tunnel test facilities or rocket test stand facilities by other government agencies and private sector users. NASA also serves as the acquisition agent for NOAA's GOES series of satellites, under a reimbursable agreement between the two agencies. Reimbursable agreements are managed by individual Mission Directorates: Aeronautics, Deep Space Exploration Systems, LEO and Spaceflight Operations, Science, and Exploration Technology at the NASA centers under Safety, Security, and Mission Services (SSMS) fund appropriation using authorities including Space Act, Economy Act, Commercial Space Launch Act, and Commercial Space Competitiveness Act. Additional data for Enhanced Use Leasing (EUL) and National Historic Preservation Act (NHPA) is provided in the respective sections following the table below.

REIMBURSABLE ESTIMATES BY APPROPRIATIONS ACCOUNT

($ millions)	Actual	Request	Estimate
	FY 2018	**FY 2019**	**FY 2020**
Safety, Security, and Mission Services (non-EUL)	2,623.2	2,520.8	2,328.2
Aeronautics	*114.8*	*140.9*	*127.8*
Safety, Security, Mission Services	*52.9*	*122.1*	*104.2*
Deep Space Exploration Systems	*192.2*	*191.5*	*256.7*
LEO and Spaceflight Operations	*261.3*	*394.9*	*370.6*
Science	*1,997.8*	*1,573.0*	*1,468.1*
Exploration Technology	*4.2*	*98.4*	*0.8*
Construction and Environmental Compliance and Restoration (EUL)	18.4	25.0	20.5
Safety, Security, and Mission Services (NHPA)	20.6	24.3	26.4
Office of Inspector General	1.0	1.5	1.5
Total	**2,663.2**	**2,571.6**	**2,376.6**

ENHANCED USE LEASING

In 2003, Congress authorized NASA to demonstrate leasing authority and collections at two Centers. In 2007 and 2008, Congress amended that authority such that NASA may enter into leasing arrangements at all Centers. The EUL authority originally included a sunset provision (enacted as part of the FY 2009 Omnibus Appropriations Act (P.L. 110-161)) under which NASA's authority would expire on December 26, 2017. The NASA Transition Authorization Act of 2017 amended Section 20145(g) of title 51, United States Code, by striking "10 years after December 26, 2007" and inserting "December 31, 2018", thereby extending the authority through 2018. The NASA Enhanced Use Leasing Extension Act of 2018 (P.L. 115-403) extended the authority through December 31, 2019. The EUL authority provides NASA the ability to 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 then permitted to retain 65 percent of net receipt revenue, and the balance is made available Agency-wide for NASA. These funds are in addition to annual appropriations. To ensure annual oversight and review, the 2010 Consolidated Appropriations Act, P.L. 111-117 contains a provision that requires NASA to submit an estimate of gross receipts and collections and proposed use of all funds collected in the annual budget justification submission to Congress. The table below depicts the estimated FY 2020 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 2020 EUL ACTIVITY

FY2020 EUL Expenses and Revenues ($ Thousands)	ARC	GSFC	JPL(NMO)	MSFC	SSC	KSC	Agency	Total
Base Rent	12,680.4	67.6	101.8	551.5	89.5	921.8	18.3	14,430.9
Institutional Support Income	1,034.9	8.7			5.2	57.2		1,106.0
Additional Reimbursable Demand Services Requested by Lessees (including overhead)	4,133.2				16.0	37.8	776.1	4,963.1
Total Lease Income (EULX52020L)	**17,848.5**	**76.3**	**101.8**	**551.5**	**110.7**	**1,016.8**	**794.4**	**20,500.0**
Institutional Support Costs	-1,034.9	-8.7		0.0	-0.3	-57.2	0.0	-1,101.1
Lease Management and Administration	-851.5			-15.1	-1.5		0.0	-868.1
Tenant Building Maintenance and Repair	-1,064.9			-291.7	-8.4		0.0	-1,365.0
Cost to Fulfill Reimbursable Demand Services (including overhead)	-4,133.2	0.0	0.0	0.0	-16.0	-37.8	-776.1	-4,963.1
Total Cost Associated with Leases	**-7,084.5**	**-8.7**	**0.0**	**-306.8**	**-26.2**	**-95.0**	**-776.1**	**-8,297.3**
Net Revenue from Lease Activity	**10,764.0**	**67.6**	**101.8**	**244.7**	**84.5**	**921.8**	**18.3**	**12,202.7**
Beginning Balance, Capital Asset Account (2019 Ending Balance)	**0.0**	**5.1**	**64.4**	**182.9**	**113.0**	**490.2**	**1,841.7**	**2,697.3**
Net Revenue from Lease Activity Retained at Center (EULX52020E)	**6,996.6**	**43.9**	**66.2**	**159.1**	**54.9**	**599.2**	**4,282.8**	**12,202.7**
Total Available, Capital Assest Account	**6,996.6**	**49.0**	**130.6**	**342.0**	**167.9**	**1,089.4**	**6,124.5**	**14,900.0**
Planned Maintenance, Various Buildings	-2,180.8	-49.0						-2,229.8
Replace Roofs on Varous Buildings	-4,815.8							-4,815.8
Misc. Renewable Solar Energy Expansion								
Replace Bldg 1 main steam condensate piping						-210.6		-210.6
Upgrade Lighting Systems (Green Project)				-98.0				-98.0
Energy and Sustainability Upgrades, Various Buildings (Stennis)					-54.9			-54.9
Energy and Sustainability Upgrades, Various Buildings (Various Centers)							-6,124.5	-6,124.5
Capital Asset Account Expenditures	**-6,996.6**	**-49.0**	**0.0**	**-98.0**	**-54.9**	**-210.6**	**-6,124.5**	**-13,533.6**
Capital Asset Account Ending Balance	**0.0**	**0.0**	**130.6**	**244.0**	**113.0**	**878.8**	**0.0**	**1,366.4**
In Kind Activity	**175.0**	**0.0**	**0.0**	**0.0**	**0.0**	**8,310.3**	**0.0**	**8,485.3**

DEFINITIONS

Base Rent

Revenue collected from the tenant for rent of land or buildings.

ENHANCED USE LEASING

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 EUL activities for expenses due to renting NASA property.

In-Kind

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

In FY 2014, NASA established a new fund based upon the National Historic Preservation Act (NHPA) of 1966. The Act provides the authority to administer, operate, manage, lease and maintain property, and demolish or remove buildings or space in buildings owned by NASA. It also allows any funds received from leasing the properties, buildings, or space in buildings to be deposited to the credit of a special receipt account and expended for purposes of operating, maintaining, and managing the properties and demolishing or removing the buildings. Agreements or contracts with public or private agencies, corporations, or persons, upon such terms and conditions, are allowed. There are no civil servants funded from the NHPA Fund. The NHPA activities will be maintained under NHPA authority under Section 111. These funds are in addition to annual appropriations.

The table below depicts the estimated amounts of anticipated NHPA expenses and revenues for FY 2020. NASA currently expects total rental income of $26.4 million. Of the total rental income of $26.4 million, $11.7 million represents net revenue from lease activities. The net revenue amount of $11.7 million will be used for historic building maintenance and repairs for historic properties at ARC, as well as for other properties throughout the Agency.

FY2020 NHPA Expenses and Revenues ($ thousands)	**ARC**
Base Rent	15,500.0
Security Deposit (Reissue)	2,000.0
Institutional Support Income	3,199.5
Cost to Fuflill Reimbursable Demand Services	5,727.7
Total Rental Income	**26,427.2**
Institutional Support Costs	(8,829.9)
Security Deposit (Reissue)	(2,000.0)
Lease Management and Administration	(283.2)
Reimbursable Demand Services Requested by Leasees	(3,611.1)
Total Cost Associated with Leases	**(14,724.2)**
Net Revenue from Lease Activity	**11,703.0**
Unobligated Proceeds Prior Years (as of 9/30/2018)	
Deferred Maintenance for Buildings 2, 10, 15, 16, 17, 19, 20, 25, 26, N200, N226, N227, N234, N238 & N243	(1,615.2)
Improve VMS Video Distribution Infrastructure Reliability, N243	(6,050.0)
Restore Reliability of UPWT Underground Water Piping, Phase 2 of 2	(1,259.0)
Capital Asset Account Expenditures	**(8,924.2)**
Capital Asset Account Ending Balance	**2,778.8**
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:

$ in millions	FY 2018 Actual	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Exploration ISS Research	$256	$264	$284	$266	$259	$248	$234
Non- Exploration ISS Research	$129	$133	$145	$135	$133	$127	$125
Total	**$385**	**$397**	**$428**	**$400**	**$391**	**$376**	**$360**
% of Non-Exploration to Total	34%	33%	34%	34%	34%	34%	35%

The amounts included for FY 2018 reflect actuals, FY 2019 through FY 2024 are reflective of the NASA outyear planning.

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 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 applicable MUSS funding is included in the table above.

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 with broad national benefits, supporting research that can be advanced significantly through the use of the microgravity environment. This budget supports basic ISS research in fields including, 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

BUDGET FOR MICROGRAVITY SCIENCE

other government agencies. The Non-Exploration ISS Research line in the previous table also includes the Center for the Advancement of Science in Space (CASIS), and the applicable MUSS funding. CASIS is the organization selected by NASA to manage non-NASA use of the ISS National Laboratory.

BUDGET FOR SAFETY OVERSIGHT

The following table provides the safety and mission assurance budget request. This includes the agency-wide safety oversight 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 2018**	**FY 2019**	**FY 2020**	**FY 2021**	**FY 2022**	**FY 2023**	**FY 2024**
Safety and Mission Assurance (AMO)	49.2	49.5	57.0	57.0	59.0	51.0	51.0
Institutional Operational Safety (CMO)	38.0	38.0	38.0	38.5	38.2	38.1	38.5
SMA Technical Authority (CMO)	49.5	51.0	51.6	52.3	53.3	54.2	55.2
Agency-wide Safety Oversight	**136.7**	**138.5**	**146.6**	**147.8**	**150.6**	**143.2**	**144.7**
Program Specific*	**300.0**	**300.0**	**300.0**	**300.0**	**300.0**	**300.0**	**300.0**
NASA Total, Safety	**436.7**	**438.5**	**446.6**	**447.8**	**450.6**	**443.2**	**444.7**

* 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 program administers and refines the pertinent policies, procedural requirements, and technical safety standards. The program participate 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 responsibility include, among other activities, managing NASA’s Orbital Debris program, NASA’s Electronic Parts program, and the NASA Safety Center.

Institutional Operational Safety - NASA’s institutional operational safety program is driven by OSHA 29 CFR 1960, OSHA Standards, NPR 8715.1A, NASA Occupational Safety and Health Programs, NPR 8715.3D, and NASA’s General Safety Program Requirements. The program includes construction safety, mishap prevention program including reporting and investigations, safety training, safety awareness, the voluntary protection program, safety metrics and trend analysis, contractor insight/oversight, support to safety boards and committees, support to emergency preparedness and fire safety program, aviation safety, explosives and propellants safety, nuclear safety requirements, radiation safety protection, 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, risk management, institutional safety policy development, visitor and public safety, and institutional safety engineering. The institutional operational safety program requires significant federal state and local coordination.

S&MA Technical Authority and S&MA Support - 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

BUDGET FOR SAFETY OVERSIGHT

authoritative decisions on S&MA requirements matters relating to the design or operation of a program or project, that person's salary is included. These positions often are the lead S&MA manager positions for large programs where the decision making process is nearly a full time demand. This category does not include salary for those whose work only occasionally falls as an authority task. This includes travel funds in direct support of these individuals.

S&MA is mission support, including administrative support, which cannot be directly charged to a program. This budget includes policy development across the programs, range safety, payload safety (ground processing), independent assessments, metrology and calibration (for center), reliability and maintainability policy, center wide S&MA program integration and analysis, business and administrative support to S&MA Directorates, and quality assurance for facilities and ground support hardware.

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 systems, mission operations, and payload(s) meet performance requirements and function for their intended lifetimes.

Physicians' Comparability Allowance (PCA) Worksheet

1) Department and component:

National Aeronautics and Space Administration

2) Explain the recruitment and retention problem(s) justifying the need for the PCA pay authority.

NASA currently has 25 civil servant physicians. Goddard Space Flight Center (GSFC) in Greenbelt, Maryland has 1 physician with the remaining 24 at Johnson Space Center (JSC) in Houston, Texas. There are 22 operational physicians, one pathologist, and two management physicians including the Chief Medical Officer and Deputy Chief Medical Officer at JSC. There are a number of recruitment and retention challenges for NASA.

- The Houston area has world-renowned medical facilities. Physician salaries in the Houston area and across the country continue to rise and compensation at JSC must remain competitive in order to attract and retain high quality physicians. Further, since the majority of the physicians are at the GS-15 step 10 level, their compensation is frozen by federal pay statute and has not changed even while private sector pay has continued to increase.
- JSC's clinical resources focus on multiple programs: International Space Station crew (operating 24/7), Commercial Crew Program, Orion Program, the new Gateway Program, planning for future Mars missions, support of the active astronaut corps, the operation of the Lifetime Surveillance of Astronaut Health program (which includes all retired astronauts), and the newly established program to provide care under the TREAT Act for former astronauts. Physicians at JSC also provide expertise to inform human system risks and support Human Research Program efforts.
- 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; the same physicians are being actively recruited by commercial space companies, other government and military organizations. In the past year, we lost one physician to SpaceX, and other commercial space companies are courting the physician cadre. It takes approximately one year for a new surgeon to complete the certification necessary to support mission operations. This represents a significant investment for NASA. As a result, retaining the trained and certified physicians we have is critical.
- Many of the JSC physicians are dual boarded with a primary residency in a clinical specialty such as internal medicine, emergency medicine, or psychiatry. Double board-certified physicians are especially rare 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. PCA plays a key part in retaining them.
- At GSFC, competition for physicians is also high with many opportunities for private practice in the DC, Maryland and Virginia metropolitan area. Physician salaries in the Washington, DC area are much higher than NASA is currently able to pay without PCA.

PCA is an important tool in recruiting new physicians since the GS salary offered is consistently lower than salaries in the private sector. Prior to hiring the current physician at GSFC, the previous incumbent left after 18 months for a civil service position in the Department of Defense that offered a $40,000 salary increase. In the past two years, four surgeons have resigned from JSC to accept positions outside the Federal Government. Currently, more than a third of JSC's physicians are retirement eligible and in the next five years, 50% will become eligible. JSC is facing a challenge in retaining physicians and having the capability to fill positions that become vacant due to resignations and/or retirements. JSC is also facing challenges recruiting physicians who are willing and able to serve in leadership roles. Being able to offer PCA has become increasingly critical to NASA in competing with the private sector for the most qualified physicians.

3-4) Please complete the table below with details of the PCA agreement for the following years:

	PY 2018 (Actual)	CY 2019 (Estimates)	BY* 2020 (Estimates)
3a) Number of Physicians Receiving PCAs	25	26	24
3b) Number of Physicians with One-Year PCA Agreements	22	25	24
3c) Number of Physicians with Multi-Year PCA Agreements	3	1	0
4a) Average Annual PCA Physician Pay (without PCA payment)	$164,200	$164,200	$164,200**
4b) Average Annual PCA Payment	$21,595	$22,566	$22,598

*BY data will be approved during the BY Budget cycle. Please ensure each column is completed.
**Estimated salary increase in FY 2020 is 0%.

5) Explain the degree to which recruitment and retention problems were alleviated in your agency through the use of PCAs in the prior fiscal year.

- PCA remains a very effective tool for NASA in both recruiting and retaining physicians. It has been used successfully at JSC and GSFC to recruit and retain highly qualified physicians over the last several years. PCA is used successfully to bridge the widening gap between the compensation that such uniquely qualified physicians can earn in the private sector versus Federal Government service.
- In FY17, JSC has had three resignations and was able to fill those vacancies with new hires because of the PCA. With PCA, we have been able to retain the hires that we have made. PCA closed the pay gap between NASA and contractors providing similar services, though it did not close the gap between private practice pay and GS-15 salaries. PCA is a way to lessen the gap with private sector compensation and allow NASA to continue attracting and retaining qualified physicians.
- PCA allows continuity of knowledge and personnel in overseeing the occupational health of GSFC employees and compliance with regulatory requirements and allows for medical continuity across the various GSFC geographical locations (Greenbelt, WFF, IV&V and GISS).

6) Provide any additional information that may be useful in planning PCA staffing levels and amounts in your agency.

- With decreasing procurement funds in FY18, which is expected to continue, retaining essential civil service physicians will become increasingly critical to maintaining core competencies and fulfilling mission objectives. For example, the International Space Station (ISS) program has proposed significant cuts to procurement budgets that could shrink the number of contractor flight surgeons available for ISS support. Fluctuations in program funding make it difficult to maintain the critical skills necessary to support current and future programs if there are not enough civil service physicians. Increased competition with new commercial space providers for skilled, experienced physicians is also making it more difficult to retain top talent.
- The multi-year Federal pay freeze caused the gap between Federal and private physician salaries to widen and become more evident. The 2013, 2018 and 2019 Federal government furloughs call into question the stability of Federal service. Significantly higher physician pay scales under Title 38 in the Veterans Administration and Department of Defense provide a potential incentive for NASA physicians to continue their government service and receive higher pay by transferring to those agencies. All of these factors

affect NASA's ability to attract and retain qualified physicians. PCA is a means to lessen the impact of these factors and provide NASA the ability to continue attracting and retaining qualified physicians.

Physicians' Comparability Allowance (PCA) Plan

Department and component:

National Aeronautics and Space Administration

Purpose: The purpose of this document is to describe the agency's plan for implementing the Physicians' Comparability Allowance (PCA) program. Per 5 CFR 959.107, 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 the Office of Management and Budget (OMB) in accordance with 5 CFR 959.107.

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 OPM will use this data for Budget development and congressional reporting.

Plan for Implementing the PCA program:

1a) 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.

	Category of Physician Position	**Covered by Agency** (mark "x" if covered)	**Basis for Category**
Number of Physicians Receiving PCAs by Category (non-add)	Category I Clinical Position	X	Difficulty recruiting and retaining
	Category II Research Position	X	Difficulty recruiting and retaining
	Category III Occupational Health	X	Difficulty recruiting and retaining
	Category IV-A Disability Evaluation	X	Difficulty recruiting and retaining
	Category IV-B Health and Medical Admin.	X	Difficulty recruiting and retaining
Additional category (if applicable)	N/A		
Additional category (if applicable)			

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.

	Category of Physician Position	**Recruitment and retention problem**
Number of Physicians Receiving PCAs by Category (non-add)	Category I Clinical Position	Most NASA physicians who receive PCA are all located at Johnson Space Center (JSC) in Houston, Texas. 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. According to the 2017 Medscape Physician Compensation Report, the average physician compensation in the South Central geographical area was $300,000. In 2018, the maximum GS salary payable in Houston is $164,200. Significantly higher physician pay scales under Title 38 in the Veterans Administration and Department of Defense 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. JSC's physicians are supporting more critical program activities simultaneously than at any time in the past. This includes support the International Space Station crew (operating 24/7), Commercial Crew, Orion, and Gateway activities, the active astronaut corps, and the operation of the Lifetime Surveillance of Astronaut Health program, which includes all retired astronauts. The recent passage 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.

		Goddard Space Flight Center (GSFC) in Greenbelt, Maryland currently has 1 physician. Physician salaries in the Washington, DC area are, on average, $262,591 per year. In addition, competition is high with many opportunities for private practice in the DC, Maryland and Virginia metropolitan area. Prior to hiring the current physician, the previous incumbent left after 18 months for a civil service position with the Department of Defense that offered a $40,000 salary increase. This position had been advertised twice before being filled. One selectee declined due to the salary offered (GS-15, Step 10 without PCA). All of these factors affect NASA's ability to be competitive and to attract and retain qualified physicians. Without offering PCA, NASA would not be able to recruit and retain qualified physicians.
	Category II Research Position	Currently no physician positions in this category
	Category III Occupational Health	Currently no physician positions in this category
	Category IV-A Disability Evaluation	Currently no physician positions in this category
	Category IV-B Health and Medical Admin.	NASA has difficulty attracting skilled and qualified physicians to leadership positions, in part because, in the absence of different PCA scales, it cannot provide meaningful pay differentials between individual contributor physicians and management physicians who have greater responsibility and authority.
Additional category (if applicable)	N/A	
Additional category (if applicable)		

3) . Explain how the agency determines the amounts to be used for each category of physicians.

	Category of Physician Position	**Basis of comparability allowance amount**
Number of Physicians Receiving PCAs by Category (non-add)	Category I Clinical Position	The amounts are determined by taking into account current difficulties in recruiting qualified physicians and anticipated retention problems. The amounts paid are the minimum needed to deal with the recruitment and retention problems and are reviewed each year.
	Category II Research Position	Currently no physician positions in this category
	Category III Occupational Health	Currently no physician positions in this category
	Category IV-A Disability Evaluation	Currently no physician positions in this category

	Category IV-B Health and Medical Admin.	The amounts are determined by taking into account current difficulties in recruiting qualified physicians to these demanding leadership positions. In 2018, only two qualified physicians applied for the Deputy Branch Chief position at JSC. The amounts paid are the minimum needed to deal with the recruitment and retention problems and are reviewed each year.
Additional category (if applicable)	N/A	
Additional category (if applicable)		

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 5CFR Ch. 1?

Yes

IT STATEMENT OF AFFIRMATION

National Aeronautics and Space Administration

Headquarters
Washington, DC 20546-0001

FEB 1 9 2019

Office of the Chief Information Officer

TO: Science and Space Branch, Office of Management and Budget

FROM: Chief Information Officer
THRU: Chief Financial Officer

SUBJECT: Fiscal Year 2020 NASA IT Budget Justifications Statement of Affirmation

As required by the Office of Management and Budget (0MB) 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 objectives;
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. Agency budget request funding levels will include expected contributions to the E-Gov/Line-of-Business initiatives;
6. The CIO collaborated with all Center CIOs and the CFO on the IT Budget submission;
7. The IT Portfolio (0MB Circular A-11, Section 55.6 and as described herein) includes appropriate estimates of all IT resources included in the President's Budget; and

8.

included in the President's Budget.

The CIO has reviewed and had significant input in approving all IT Investments

Chief Information Officer
Renee P. Wynn

Signed Electronically by

Chief Financial Officer

Jeff DeWit

BUDGET FOR PUBLIC RELATIONS

The NASA budget for Public Affairs is funded within Safety, Security, and Mission Services under Center Management and Operations and Agency Management and Operations. All the Installations listed below, except for Headquarters, are in the Center Management and Operations account and the Headquarters budget is in the Agency Management and Operations account.

These budgets include dissemination of information to the news media and the general 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 http://www.nasa.gov portal, and other multimedia support.

NASA PAO BUDGET SUMMARY, BY CENTER

	Actual	Estimate	Request				
Budget Authority ($ millions)	**FY 2018**	**FY 2019**	**FY 2020**	**FY 2021**	**FY 2022**	**FY 2023**	**FY 2024**
ARC	4.0	4.0	4.0	4.0	4.0	4.0	4.0
AFRC	1.4	1.2	1.2	1.2	1.2	1.2	1.2
GRC	2.6	2.9	3.0	3.1	3.2	3.3	3.3
GSFC	5.9	5.8	5.9	6.0	6.0	6.1	6.1
HQ	14.9	14.3	15.2	15.5	15.6	15.8	16.0
JSC	9.1	8.5	8.5	8.7	8.7	8.7	8.7
KSC	7.5	8.8	8.8	9.2	9.3	9.8	9.9
LaRC	2.6	2.4	2.5	2.5	2.5	2.6	2.6
MSFC	5.7	4.9	4.8	4.8	4.8	4.8	4.8
SSC	1.2	1.2	1.3	1.3	1.3	1.3	1.3
NASA Total	**54.9**	**54.0**	**55.2**	**56.3**	**56.5**	**57.5**	**57.9**

Public Affairs per baseline service level definition as part of the Safety, Security, and Mission Services Budget

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 assures the selection of experiments likely to have the greatest scientific merit. Other individuals provide independent views of technical and functional problems in order to provide senior management with the widest possible 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 FY 2018	Estimate FY 2019	Request FY 2020
Number of Paid Experts and Consultants	30	30	30
Annual FTE Usage	6.7	6.7	6.7
Salaries	$0.8M	$0.8M	$0.8M
Total Salary and Benefits Costs	$0.9M	$0.9M	$0.9M
Travel Costs	$0.2M	$0.2M	$0.2M
Total Costs	**$1.1M**	**$1.1M**	**$1.1M**

FY 2018 are actual obligations. FY 2019 and FY 2020 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" include 1) Management and Professional Support Services, 2) Studies, Analysis, and Evaluations, and 3) Engineering and Technical Services.

(Cost in $ millions)	Actual FY 2018	Estimate FY 2019	Request FY 2020
Quality Control, Testing & Inspection Svc	34.5	35.7	36.8
Mgmt and Professional Support Services	663.7	680.8	709.9
Studies, Analysis, & Evaluations	86.2	92.0	92.2
Engineering and Technical Services	8.6	7.0	9.2
IT Services	68.9	68.9	73.8
Total Costs, Advisory & Assistance Ser.	862.0	884.4	922.0

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 is providing funding contributions in FY 2020 for each of the following E-Government initiatives:

Initiative	2020 Contributions (Includes In-Kind)	2020 Service Fees*
E-Rulemaking	0	10,000
Grants.gov	74,000	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	500,000
Geospatial LoB	225,000	0
Budget Formulation and Execution LoB**	130,000	0
Federal PKI Bridge		153,299
NASA Total	**621,714**	**7,493,038**

**Service fees are estimates as provided by the E-Government initiative managing partners*

***Final FY 2020 commitments have yet to be finalized by Managing Partners (OMB MAX)*

After submission of the budget, NASA will post FY 2020 Exhibit 300 IT business cases on the IT Dashboard, located at https://www.itdashboard.gov.

E-GOV INITIATIVES AND BENEFITS

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 reduced cost, thereby making resources available for higher priority needs. Benefits realized through the use of these initiatives for NASA in FY 2019 are described in the following.

eRulemaking (Managing Partner EPA) FY 2020 Benefits

NASA’s benefits from the eRulemaking initiative are largely focused on providing the public benefits by providing one-stop access to the Agency’s information on rulemakings and non-rulemaking activities via the Regulations.gov Web site.

NASA uses the Federal Docket Management System (FDMS) to post its rulemakings in order for the public to 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 as this use increases public participation in the regulatory process. Direct budget cost savings and cost avoidance result from NASA’s transition to FDMS and Regulations.gov, enabling the Agency to discontinue efforts to develop, deploy, and operate specific individual online docket and public comment systems. Over a five-year period, NASA is estimated to save over $700,000 over alternative options that would provide similar services.

Grants.gov (Managing Partner HHS) FY 2020 Benefits

The Grants.gov initiative benefits NASA and its grant programs by providing a single location with broader exposure to publish grant (funding) opportunities and application packages, making the process easier for applicants to apply to multiple agencies. All 26 major Federal grant making agencies posted 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 giving greater access and ability to apply for Federal funding. Through the use of Grants.gov, NASA is able to reduce operating costs associated with online posting and application of grants. 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 2020 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 80,000 civil servants and contractors. This centralized approach allows NASA to reduce and leverage training costs by eliminating unique systems, standardizing training processes, and valid data. In 2018 NASA migrated SATERN to a software as a service 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 2020 Benefits

USAJOBS simplifies the Federal Job Search Process for Job Seekers and Agencies. The USAJOBS.gov Web site 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;
- 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.

NASA adopted the USAJOBS resume as the basic application document for all NASA positions, except for astronaut positions (in 2005). 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. However, 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 2020 Benefits

The Enterprise HR Integration (EHRI) Program supports the strategic management of human capital by providing agency customers with 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.

E-GOV INITIATIVES AND BENEFITS

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. When fully implemented, the eOPF will cover the entire Executive Branch as well as other Federal and Local Governments with a total user population of more than 1.9 million. The system will replace the existing manual process by automating the Federal Government's HR processes and thereby creating a streamlined Federal HR system for all Federal Employees. The initiative is achieving cost savings that are recognized on a per-folder basis. The total cost avoidance per folder is estimated at $55.56.

Specific EHRI/eOPF benefits to NASA include improved convenience in searching, better security and safety to electronic files, more economical, streamlined business processes, and the ability to have a central repository of OPF records for the Agency. During FY 2010, NASA also deployed the eOPF capability of electronic transfer of eOPFs between agencies. 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 2020 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. Prior to beginning the initiative, 26 federal agencies provided payroll services. Four providers were selected to furnish payroll services for the Executive branch. Since 2004, the Department of Interior (DOI) has served as NASA's payroll provider, using their system, the Federal Personnel and Payroll System (FPPS), to process NASA's HR and Payroll transactions and supply 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 2020 Benefits

NASA completed migration of its travel services to ETS2 - Concur Government Edition (CGE) (formerly HP Enterprise Services (FedTraveler)). Completing this migration after implementation the summer of 2014 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.

ETS2 builds on the success of the first generation ETS, and will continue to take advantage of advances to help the government further consolidate online travel booking services and expense management platforms, driving additional cost savings and efficiencies while delivering a transparent service for improved accountability and reduced waste. ETS2 serves as the gateway to optimize the government's scale and full market leverage to lower travel costs. ETS has served as the backbone of GSA's managed travel programs, providing access to air, car and lodging, as well as the foundation for implementing a shared service for civilian agency travel management.

ETS2's new benefits and features include:

- Improved usability and optimized online travel planning;
- Increased navigation and ease-of-use, enabling informed cost and sustainability decisions at point-of-sale; and
- Strengthened operational environment, improving management by adopting commercial best practices in software development, data transparency and improved security controls.

ETS2 will enable the government to further consolidate travel services, platforms, and channels, improve the leverage of government travel spending, increase transparency for improved accountability, and reduce waste. This directly aligns and supports the recent Office of Management and Budget Memo M-12-12 regarding *Promoting Efficient Spending to Support Agency Operations* with respect to travel.

Integrated Award Environment (Managing Partner GSA) FY 2020 Benefits

The Integrated Award Environment (IAE) initiative is designed to streamline the process of reporting on subcontracting plans and provide agencies with access to analytical data on subcontracting performance. Use of the IAE common services allows agencies to focus on agency-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.

IAE facilitates and supports cost-effective acquisition of goods and services by agencies. The IAE initiative provides common acquisition functions and shared services that benefit all agencies, such as the maintenance of information about business-partner organizations (e.g., banking, certifications, business types, capabilities, performance). IAE provides benefits to the government and business-partner organizations by improving cross-agency coordination that helps to improve the government's buying power, while providing business partners maximum visibility and transparency into the process. IAE provides various services, tools, and capabilities that can be leveraged by the acquisition community including buyers, sellers, and the public to conduct business across the federal government space.

Government buyers can:

- Search for commercial and government sources
- Post synopses and solicitations
- Securely post sensitive solicitation documents
- Access reports on vendors' performance
- Retrieve vendor data validated by SBA and Internal Revenue Service (IRS)
- Identify excluded parties
- Report contract awards

Business suppliers can:

- Search business opportunities by product, service, agency, or location
- Receive e-mail notification of solicitations based on specific criteria
- Register to do business with the federal government
- Enter representations and certifications one time
- Revalidate registration data annually
- Report subcontracting accomplishments

Citizens can:

- Retrieve data on contract awards
- Track federal spending
- Search to find registered businesses
- Monitor business opportunities

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 2020 Benefits

All agencies participating in the posting and/or awarding of Contracts and Grants & Loans 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 Web site. FFATA requires OMB to lead the development of a single, searchable Web site through which the public can readily access information about grants and contracts provided by Federal government agencies[1].

Based on the recommendations of the Transparency Act Taskforce, the Web site leverages functionality provided by the IAE initiative to provide Data Universal Numbering System (DUNS) numbers as the unique identifier. An existing IAE Dun and Bradstreet (D&B) transaction-based contract for the contract community was expanded to provide government-wide D&B services for the Grants & Loans community. These services include parent linkage, help desk support, world database lookup, business validation and linkage monitoring, matching services, as well as the use of DUNS numbers. The enterprise D&B contract provides substantial savings to the participating agencies over their previous agency transaction-based D&B contracts.

[1] More information on the development of this Web site can be found at: https://www.usaspending.gov/Pages/Default.aspx

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E-GOV INITIATIVES AND BENEFITS

On December 14, 2007, OMB launched www.USASpending.gov to meet the Federal Funding Accountability and Transparency Act (FFATA) statutory requirements, ahead of schedule. Since that launch, OMB has and will continue to work with agencies to improve the quality, timeliness, and accuracy of their data submissions and has released a series of enhancements to the site. USASpending.gov complements other Web sites providing the public Federal program performance information (e.g., USA.gov, Results.gov and ExpectMore.gov).

USASpending.gov provides:

- The name of the entity receiving the award;
- The amount of the award;
- Information on the award including transaction type, funding agency, etc.;
- The location of the entity receiving the award; and
- A unique identifier of the entity receiving the award.

Cross-government cooperation with OMB's Integrated Acquisition Environment initiative allows agencies and contributing bureaus to meet the requirements of the FFATA by assigning a unique identifier, determining corporate hierarchy, and validating and cleaning up incorrect or incomplete data.

The FY 2019 funding requirements as it relates to the IAE – Loans and Grants funding line supports the FFATA and DATA Act for the relationship with D&B and DUNS support services. In addition to provision of DUNS numbers, D&B is now providing business and linkage data seamlessly, and the business arrangement supports the quality of data by real-time updates. NASA and other agencies will leverage the linkages to corporate organizational rollups based on parental and subsidiary relationships.

Federal PKI Bridge - FY 2020 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 secur

The physical and logical access through the use of strong credentials such as the PIV card, and allows federal 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 use of the FPKI.

The FPKI Policy Authority (managed by GSA) is the CIO Council PKI action agent responsible for the governance of the FPKI Ecosystem.

LINES OF BUSINESS

Financial Management LoB (Managing Partners DOE and DOL) FY 2020 Benefits

Treasury's Office of Financial Innovation and Transformation (FIT) served as Managing Partner and the Program Management Office (PMO) for the FMLoB. In accordance with OMB's guidance on shared services (the Federal IT Shared Services Strategy), the Treasury's FIT will lead 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. Under the guidance of the CFOC and COFAR, partner agencies will work with the FMLOB's support to standardize core financial business processes (including financial assistance) and data elements across the Federal Government to provide: (1) reliable and accessible financial data to the public; (2) adequate training and development resources to agency workforces; and (3) strong oversight of Federal programs using tools such as the Single Audit. The FMLoB will also play a role in implementing OMB's Memorandum M-13-08, *Improving Financial Systems Through Shared Services*. 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 (for example, shared services).

Human Resources Management LoB (Managing Partner OPM) FY 2020 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). Driven from a business perspective, the solutions will address distinct business improvements enhancing the government's performance of HR and payroll services in support of agency missions delivering services to citizens. The HR LoB concept of operations calls for agencies to receive core services from an HR LoB provider. These core services are defined as personnel action processing, compensation management (payroll) and benefits management. Leveraging shared services solutions will allow the HR LoB to significantly improve HR and payroll service delivery, save taxpayer dollars, and reduce administrative burdens.

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 Interior Business Center (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 2020 Benefits

The Geospatial LoB will better serve the agencies' missions and the Nation's interests developing a more strategic, coordinated, and leveraged approach to producing, maintaining, and using geospatial data and services across the Federal government. Specific goals of the Geospatial LoB include establishing a collaborative governance mechanism, coordinating a government-wide planning and investment strategy, and optimizing and standardizing geospatial data and services.

E-GOV INITIATIVES AND BENEFITS

Contributing agencies and bureaus will receive value from the development of the LoB primarily through improved business performance and cost savings. Enhanced governance processes, improved business planning and investment strategies, and optimization and standardization of geospatial business data and services will produce the following results:

- Collaborative management of geospatial investments will be made more adaptable, proactive and inclusive;
- Enterprise business needs and agency core mission requirements will be identified, planned, budgeted, and exploited in a geospatial context;
- Long-term costs of geo-information delivery and access will be reduced while minimizing duplicative development efforts;
- Effective, yet less costly commercial off the shelf systems and contractual business support operations will replace legacy geospatial applications; and
- Business processes will be optimized and knowledge management capabilities will exist for locating geospatial data and obtaining services.

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 rather than a central focus of data dissemination. Scientific inquiry often leads scientist 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 2020 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 moving forward.

BFELoB's "MAX Federal Community," a secure government-only collaborative Web site, provides significant benefits for collaboration across and within agencies, as well as knowledge management. The Community site is commonly used for sharing information, collaboratively drafting documents (including the direct-editing of documents posted on the site).

COMPARABILITY ADJUSTMENT TABLES

FY 2018 Budget Structure Crosswalk to FY 2020 Budget Structure

Budget Authority ($ millions)

NASA TOTAL	**$19,092.2**	**$19,092.2**
Science	**$5,711.8**	**$5,711.8**
Earth Science	**$1,754.1**	**$1,754.1**
Earth Science Research	$406.7	$406.7
Earth Systematic Missions	$778.0	$778.0
Surface Water and Ocean Topography	*$90.9*	*$90.9*
Sentinel-6	*$53.4*	*$53.4*
Landsat 9	*$175.8*	*$175.8*
Ice, Cloud, and land Elevation Satellite (ICESat-II)	*$92.3*	
GRACE FO	*$20.5*	
NASA-ISRO SAR	*$55.4*	*$55.4*
Other Missions and Data Analysis	*$289.7*	*$289.7*
ICESat-2		$92.3
GRACE Follow-On		$20.5
Earth System Science Pathfinder	$264.5	$264.5
Earth Science Multi-Mission Operations (Earth Science Data Systems in FY 2020)	$196.5	$196.5
Earth Science Technology	$60.4	$60.4
Applied Sciences	$47.9	$47.9
Planetary Science	**$1,929.5**	**$1,929.5**
Planetary Science Research	$291.5	$279.5
Planetary Science Research and Analysis	*$197.9*	*$197.9*
Near Earth Object Observations	*$50.0*	
Other Missions and Data Analysis	*$43.6*	*$43.6*
Advanced Multi-Mission Operation System		$38.0
Planetary Defense		$50.0
Other Missions and Data Analysis		*$50.0*
Near Earth Object Observations		$50.0
Lunar Discovery and Exploration		$20.0
Other Missions and Data Analysis		*$20.0*
Lunar Reconnaissance Orbiter (LRO)		$20.0
Discovery	$306.1	$286.1
Psyche	*$25.0*	*$25.0*
Lucy	*$101.4*	*$101.4*
InSight	*$109.4*	
Other Missions and Data Analysis	*$70.3*	*$50.3*
Lunar Reconnaissance Orbiter (LRO)	$20.0	
InSight		$109.4
New Frontiers	$82.1	$82.1
Mars Exploration	$584.7	$584.7
Outer Planets and Ocean Worlds	$457.9	$457.9
Technology (Radioisotope Power in FY 2020)	$207.2	$169.2
Technology	*$207.2*	*$169.2*
Advanced Multi-Mission Operation System	$38.0	

COMPARABILITY ADJUSTMENT TABLES

FY 2018 Budget Structure Crosswalk to FY 2020 Budget Structure

Budget Authority ($ millions)

Astrophysics	**$816.7**	**$816.7**
Astrophysics Research	$204.4	$204.4
Cosmic Origins	$191.6	$191.6
Physics of the Cosmos	$99.9	$99.9
Exoplanet Exploration	$176.0	$176.0
Astrophysics Explorer	$144.7	$144.7
Transiting Exoplanet Survey Satellite (TESS)	*$36.9*	
Other Missions and Data Analysis	*$107.8*	*$107.8*
Transiting Exoplanet Survey Satellite		$36.9
James Webb Space Telescope	**$533.7**	**$533.7**
Heliophysics	**$677.8**	**$677.8**
Heliophysics Research	$200.2	$200.2
Living with a Star	$381.0	$381.0
Solar Probe Plus (Parker Solar Probe in FY 2020)	*$265.8*	
Solar Orbiter Collaboration	*$51.4*	*$51.4*
Other Missions and Data Analysis	*$63.8*	*$63.8*
Parker Solar Probe		$265.8
Solar Terrestrial Probes	$37.8	$37.8
Heliophysics Explorer Program	$58.9	$58.9
Aeronautics	**$624.0**	**$624.0**
Space Technology (Exploration Technology in FY 2020)	**$678.6**	**$678.6**
Space Technology (Exploration Technology in FY 2020)	**$678.6**	**$678.6**
Agency Technology and Innovation	$31.9	
SBIR and STTR	$180.0	$180.0
Space Technology Research & Development	$466.7	
Early Stage Innovation and Partnerships		$100.2
Technology Maturation		$148.0
Technology Demonstration		$250.4
Exploration (Deep Space Exploration Systems in FY 2020)	**$3,934.1**	**$3,934.1**
Space Operations (LEO and Spaceflight Operations in FY 2020)	**$4,740.8**	**$4,740.8**
Education	**$37.3**	**$37.3**
Safety, Security, and Mission Services	**$2,830.2**	**$2,830.2**
Center Management and Operations	**$1,992.5**	**$1,992.5**
Agency Management and Operations	**$837.7**	**$837.7**
Agency Management	$361.2	$361.2
Safety and Mission Success	$171.4	$171.4
Agency IT Services (AITS)	$278.1	$278.1
IT Management	*$26.0*	*$26.0*
Applications	*$59.0*	
Infrastructure (Enterprise IT in FY 2020)	*$193.1*	*$252.1*
Strategic Capabilities Asset Program	$27.0	$27.0
Construction & Envrmtl Compl Restoration	**$496.1**	**$496.1**
Inspector General	**$39.3**	**$39.3**
NASA TOTAL	**$19,092.2**	**$19,092.2**

COMPARABILITY ADJUSTMENT TABLES

FY 2019 Budget Structure Crosswalk to FY 2020 Budget Structure

Budget Authority ($ millions)

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	**$889.0**	
Lunar Orbital Platform - Gateway	$504.2	
Adv Cislunar and Surface Capabilities	$116.5	
Exploration Advanced Systems	$268.2	
Exploration Research and Development		**$1,029.0**
Advanced Exploration Systems		$268.2
Gateway		$504.2
Adv Cislunar and Surface Capabilities		$116.5
Human Research Program		$140.0
Exploration Research and Technology (Exploration Technology in FY 2020)	**$1,002.7**	**$862.7**
Exploration Research and Technology (Exploration Technology in FY 2020)	**$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**	**$4,624.6**
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*	*$285.6*
ICESat-2		$23.1
GRACE Follow-On		$11.3
Earth System Science Pathfinder	$235.0	$235.0
Earth Science Multi-Mission Operations (Earth Science Data Systems in FY 2020)	$196.9	$196.9
Earth Science Technology	$59.7	$59.7
Applied Sciences	$53.1	$53.1

COMPARABILITY ADJUSTMENT TABLES

FY 2019 Budget Structure Crosswalk to FY 2020 Budget Structure

Budget Authority ($ millions)

Planetary Science	**$2,234.7**	**$2,234.7**
Planetary Science Research	$258.0	$298.2
Planetary Science Research and Analysis	*$210.3*	*$210.3*
Other Missions and Data Analysis	*$47.7*	*$47.7*
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
InSight	*$22.3*	
Lucy	*$153.3*	*$153.3*
Psyche	*$171.2*	*$171.2*
Other Missions and Data Analysis	*$34.4*	*$34.4*
InSight		$22.3
New Frontiers	$130.2	$130.2
Mars Exploration	$601.5	$601.5
Outer Planets and Ocean Worlds	$285.6	$285.6
Technology (Radioisotope Power in FY 2020)	$210.2	$170.0
Technology	*$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*	
Hubble Space Telescope (HST)	*$78.3*	*$78.3*
Stratospheric Observatory for Infrared Astronomy (SOFIA)	*$74.6*	*$74.6*
Other Missions and Data Analysis	*$33.9*	*$33.9*
Physics of the Cosmos	$136.8	$136.8
Exoplanet Exploration	$52.4	$52.4
Astrophysics Explorer	$245.6	$245.6
Transiting Exoplanet Survey Satellite (TESS)	*$27.5*	
Other Missions and Data Analysis	*$218.1*	*$218.1*
Transiting Exoplanet Survey Satellite		$27.5
James Webb Space Telescope		**$304.6**
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*	*$78.2*
Parker Solar Probe		$107.2
Solar Terrestrial Probes	$91.0	$91.0
Heliophysics Explorer Program	$109.2	$109.2
Aeronautics	**$633.9**	**$633.9**
Education (STEM Engagement in FY 2020)	**$0.0**	**$0.0**
Safety, Security, and Mission Services	**$2,749.7**	**$2,749.7**
Construction & Envrmtl Compl Restoration	**$388.2**	**$388.2**
Inspector General	**$39.3**	**$39.3**
NASA TOTAL	**$19,892.2**	**$19,892.2**

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	BTC	Total
Original Life Cycle Cost	2009	4,448	92	93	94	94	76	66	4,964
Rebaselined Life Cycle Cost	2019	5,990	620	569	534	305	423	1,221	9,663
Actual	n/a	5,991	620	569	534				

ICSSat-2	Date	Prior	FY16	FY17	FY18	FY19	FY20	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	50				

28 August 2018

TO: Jeff DeWit, Chief Financial Officer FROM:

J.D. Polk, Chief Health and Medical Officer

SUBJECT: Congressional Required Annual Report on TREAT Astronauts Implementation

The National Aeronautics and Space Administration Transition Authorization Act of 2017 (Public Law 115-10) authorized the "To Research, Evaluate, Assess, and Treat Astronauts Act," or the TREAT Astronauts Act. Section 443(c) of the 2017 Act requires an annual report on the program to be submitted not later than the date of submission of the President's annual budget request for that fiscal year. As written, the legislation authorizing the TREAT Astronauts Act has been implemented by the National Aeronautics and Space Administration (NASA) according to the stipulations required.

Currently, NASA works closely with the Department of Labor (DOL) and utilizes their process for astronaut claims under the Federal Employees Compensation Act, as well as the Veterans Affairs (VA) process for those astronauts who were active duty military at the time of their NASA service.

For those claims that occur post-employment or in which the causality or occupational association from spaceflight is unclear, NASA has established an Occupational Health Working Group composed of physicians and experts that can assess the feasibility of an association of the illness or injury to human spaceflight and make a recommendation to the Chief Health and Medical Officer as to whether the agency should cover the claim. The agency Chief Health and Medical Officer will make a decision at the behest of the NASA Administrator, and inform both the Administrator and the Chief Financial Officer of the claim, so that NASA can assure that funds are allocated for the coverage of the claim. NASA has also begun the process of developing the internal NASA policies and charters to govern the process and crafting implementing regulations for publication in the Federal Register.

In an effort to expedite astronaut claims as well as centralize expertise, the Office of Workers' Compensation Programs in the DOL has created a new drop down menu category on the electronic claim form for "astronaut" and is working to have their Cleveland Office (which handles specialized cases) begin handling astronaut claims. This will allow NASA to educate one office on spaceflight physiology, pathology, and nuances of space medicine as opposed to attempting to educate every claims office in the DOL. This also allows for better aggregation of data on astronaut claims.

In addition, due to the findings from the Potomac Institute Report on the TREAT Astronauts Act, NASA has begun meeting with and engaging with TRICARE and the VA in order to better understand what is required to cover our active duty astronauts, what would be required for implementation, in addition to the pros and cons (including what legislative authorities are permissible or would be needed) if NASA were to extend the TRICARE coverage beyond active duty members to all astronauts, as was recommended in the report. Recent changes to TRICARE as a program, as well as legislation for the Defense Health Agency, necessitates that NASA engage with those entities to understand how they will implement their programs. NASA is working with those entities to identify limitations, costs, and medical diagnostic capabilities associated with a TRICARE insurance to understand if this option would be suitable for the total astronaut population diagnosis and treatment, and if leverage of large databases, such as that used by the VA, could be beneficial for comparison studies for research on astronaut health.

For example, the recent discovery of optic nerve and mild brain edema necessitates that the Magnetic Resonance Imaging (MRI) performed on astronauts be of a particular magnet strength, particular slice, and particular coils in order to have a direct comparison to the MRI pre and post spaceflight. We are engaging to find out how ubiquitous this specialized piece of equipment is in the VA system, military system, and communities.

The goal is to find treatment locations that are convenient for the retired astronaut in order to encourage participation and data gathering, prevent undue hardship to the individual, and assure follow up for medical diagnoses. Ideally, this will be a system that will allow both a high level of care and high level of return on data back to NASA in order to inform future spaceflight missions, and the commercial spaceflight sector of the physiologic risks.

Currently, the programs as outlined, are running within budgetary guidelines. Starting in FY19, implementation of the expanded health monitoring for former astronauts and TREAT Astronauts Act administration at the Johnson Space Center will increase local procurements by approximately $400,000 annually. There are currently three active astronaut DOL cases going through the DOL process but no former astronaut (TREAT Astronauts Act cases) pending. Coverage, treatment, and costs have yet to be determined in these cases. Therefore, figures for the cost of treatment not covered by DOL and in which NASA would in turn be the secondary payer, are not yet available. As annual cost data becomes available, and trends are established, they will be updated into this report.

J.D. Polk, DO, MS, MMM, CPE, FACOEP, FAsMA
Chief Health and Medical Officer, NASA Headquarters

Cost and Schedule Performance Summary

2019 Major Program Annual Report Summary

The 2019 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 2019 MPAR consists of this summary and FY 2020 Congressional Justification pages designated as "Projects in Development," for the projects outlined below. 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 2019 NASA Budget Estimates

There are three new projects with estimated lifecycle costs greater than $250 million that received authority to proceed into the development phase since NASA submitted its 2018 MPAR in the FY 2019 NASA Congressional Justification.

- The Double Asteroid Redirection Test (DART) project with a baseline development cost of $258.3 million;
- The Low Boom Flight Demonstrator (LBFD) project with a baseline development cost of $467.7 million; and
- The Lucy project with a baseline development cost of $622.2 million.

All three projects have a joint confidence level of 70 percent.

There are four projects that successfully launched since NASA submitted its 2018 MPAR in the FY 2019 NASA Congressional Justification.

1. TESS successfully launched on April 18, 2018;
2. InSight successfully launched on May 9, 2018;
3. GRACE-FO successfully launched on May 22, 2018; and
4. ICESat-2 successfully launched on September 15, 2018.

Changes in Development Cost and Schedule Estimates from the 2018 MPAR

Based on the Consolidated Appropriations Act, 2019 the Webb project is rebaselined with a development cost of $7,002.6 million and a LRD of March 2021.

Three projects (LCRD, Sentinel-6, and SWOT) had no changes in their development cost or schedule estimates over the last year. Another three projects had development cost decreases ICESat-2 (down -4%), Landsat 9 (down -1%) and PSP (down -7%) with no schedule changes. Additionally, another two projects (GRACE-FO and SOC) had no changes to their development cost with the following schedule changes. The GRACE-FO project saw a 1 month schedule increase. While SOC was TBD when NASA submitted its 2018 MPAR in the FY 2019 NASA Congressional Justification the schedule for SOC has increased by 16 months.

The EGS and SLS projects both experienced development cost increases (up 4% and up 14% respectively). Both projects had a schedule delay of an additional 6 months. These increases are based on a launch readiness for Exploration Mission (EM)-1 of June 2020. NASA held an Agency Program Management Council (APMC) meeting approving a replan of the EGS and SLS projects in December 2017. The appropriate Congressional notifications were provided on April 10, 2018.

Cost and Schedule Performance Summary

The Orion program's estimated development cost for its Exploration Mission (EM)-2 launch readiness has increased by 9% with a schedule change reduction of -10 months against its Agency Baseline Commitment (ABC). While Orion's schedule ABC is April 2023, Orion is still consistently targeting an earlier launch readiness date. Orion has not had to replan its program costs because its life cycle cost definition is different from SLS and EGS, which are tied to the EM-1, while Orion's life cycle only becomes complete with crewed flight on EM-2.

Additionally, two projects are reporting increases in their development cost, ICON (up 1%) and Mars 2020 (up 2%). While there was no schedule change to the Mars 2020 project the ICON project, whose schedule was TBD in the last year's budget, remains TBD. The NISAR project is reporting a development cost decrease (down -2%) with no schedule change.

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 EM-1 or EM-2

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:

- 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.

Cost and Schedule Performance Summary

- The Space Launch System (SLS) and Exploration Ground Systems (EGS): The EM-1 and EM-2 launch dates are under review pending completion of independent assessments of core stage production and the integrated EM-1 mission schedule. The core stage production assessment includes representatives with experience in aerospace manufacturing and covers production schedule risks, risk mitigation approaches in work, and recommendations for additional schedule risk mitigations and corrective actions. In addition, an independent schedule review lead by the NASA Office of the Chief Financial Officer will be assessing the integrated schedule and associated risk factors ahead of EM-1, taking into account technical complexity and delays caused by the government furlough. NASA leadership will review the results of these assessments in spring 2019 before considering potential updates to the EM-1 and EM-2 launch planning dates.
- LCRD: The project is intended to 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 and has completed payload integration and testing. The U.S. Air Force managed spacecraft bus provider (Northrop Grumman) is experiencing cost growth and schedule delays. The project is currently going through the replan as a result of the spacecraft bus technical and schedule issues, as such cost and schedule are under review. NASA expects the replan to be completed in March-April timeframe, at which point NASA will have and can provide refined schedule and cost baselines.

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 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 2019			Baseline	FY 2019	
DART	2019	70	258.3	258.3	0%	LRD	Feb 2022	Feb 2022	0
EGS*	2015	80	1,843.5	2,245.0	22%	LR for EM-1	Nov 2018	Jun 2020	19
ICON	2015	70	196.0	198.2	1%	LRD	Oct 2017	TBD	N/A
Landsat-9	2018	70	634.2	628.2	-1%	LRD	Nov 2021	Nov 2021	0
LBFD	2019	70	467.7	467.7	0%	First Flight	Jan 2022	Jan 2022	0
LCRD**	2017	70	91.8	91.8	0%	LRD	Nov 2019	Nov 2019	0
Lucy	2019	70	622.2	619.2	0%	LRD	Nov 2021	Nov 2021	0
Mars 2020	2017	70	1,676.9	1,725.4	3%	LRD	Jul 2020	Jul 2020	0
NISAR	2017	70	661.0	667.4	1%	LRD	Sep 2022	Sep 2022	0
Orion***	2016	70	6,768.4	7,147.2	6%	LR for EM-2	Apr 2023	Jun 2022	-10
PSP	2015	70	1,055.7	974.3	-8%	LRD	Aug 2018	Aug 2018	0
Sentinel-6	2017	70	465.0	465.9	0%	LRD	Nov 2021	Nov 2021	0
SLS	2015	70	7,021.4	8,050.0	15%	LR for EM-1	Nov 2018	Jun 2020	19
SOC	2014	N/A	376.9	310.0	-18%	LRD	Oct 2018	Feb 2020	16
SWOT	2017	80	571.5	571.5	0%	LRD	Apr 2022	Apr 2022	0
Webb****	2012	66	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.*

*** LCC and LRD reflect KDP-C baseline. The LCRD project is currently undergoing a replanning process due to USAF NGIS spacecraft bus technical and schedule issues. NASA will provide an updated cost and schedule once the replanning has been completed and approved.*

**** 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 Appropriations 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.*

Launch Readiness (LR) *Launch Readiness Date (LRD)* *Exploration Mission (EM)*

FY 2020 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, $5,021,700,000, to remain available until September 30, 2021.

Note.—A full-year 2019 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2019 (Division C of P.L. 115–245, as amended). The amounts included for 2019 reflect the annualized level provided by the continuing resolution.

EXPLORATION TECHNOLOGY

For necessary expenses, not otherwise provided for, in the conduct and support of exploration technology 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, $1,014,300,000, to remain available until September 30, 2021.

Note.—A full-year 2019 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2019 (Division C of P.L. 115–245, as amended). The amounts included for 2019 reflect the annualized level provided by the continuing resolution.

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, $4,285,700,000, to remain available until September 30, 2021.

Note.—A full-year 2019 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2019 (Division C of P.L. 115–245, as amended). The amounts included for 2019 reflect the annualized level provided by the continuing resolution.

FY 2020 PROPOSED APPROPRIATIONS LANGUAGE

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, $6,303,700,000, to remain available until September 30, 2021.

Note.—A full-year 2019 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2019 (Division C of P.L. 115–245, as amended). The amounts included for 2019 reflect the annualized level provided by the continuing resolution.

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, $666,900,000, to remain available until September 30, 2021.

Note.—A full-year 2019 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2019 (Division C of P.L. 115–245, as amended). The amounts included for 2019 reflect the annualized level provided by the continuing resolution.

SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS ENGAGEMENT

Unobligated balances previously appropriated under this heading or the heading "Education" 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.

Note.—A full-year 2019 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2019 (Division C of P.L. 115–245, as amended). The amounts included for 2019 reflect the annualized level provided by the continuing resolution.

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, $3,084,600,000, to remain available until September 30, 2021.

FY 2020 Proposed Appropriations Language

Note.—A full-year 2019 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2019 (Division C of P.L. 115–245, as amended). The amounts included for 2019 reflect the annualized level provided by the continuing resolution.

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, $600,400,000, to remain available until September 30, 2025: 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 2020 in an amount not to exceed $14,900,000: 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.

Note.—A full-year 2019 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2019 (Division C of P.L. 115–245, as amended). The amounts included for 2019 reflect the annualized level provided by the continuing resolution.

Inspector General

For necessary expenses of the Office of Inspector General in carrying out the Inspector General Act of 1978, $41,700,000, to remain available until September 30, 2021.

Note.—A full-year 2019 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2019 (Division C of P.L. 115–245, as amended).

Administrative Provisions

Funds for any announced prize otherwise authorized shall remain available, without fiscal year limitation, until the prize is claimed or the offer is withdrawn.

Not to exceed 10 percent of any appropriation made available for the current fiscal year for the National Aeronautics and Space Administration in this Act, or provided for the National Aeronautics and Space Administration under previous appropriations Acts that remain available for obligation or expenditure in fiscal year 2020, 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 such 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 504 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 504 of this Act, shall be treated as a reprogramming under section 504 of this Act and shall not be available for obligation or expenditure except in compliance with the procedures set forth in that section.

ACRONYMS AND ABBREVIATIONS

$K	Dollars in thousands
$M	Dollars in millions
21CSLC	21st Century Space Launch Complex
3U	3-unit
45SW	U.S. Air Force 45th Space Wing
AA	Ascent Abort
AAM	Advanced Air Mobility
AANAPISI	Asian American and Native American Pacific Islander-Serving Institutions
AAV	Advanced Air Vehicles
ABC	Agency Baseline Commitment
ABoVE	Arctic Boreal and Vulnerability Experiment
AC	Advanced Composites
ACC	Advanced Composites Consortium
ACCESS	Advancing Collaborative Connections for Earth System Science
ACCESS-II	Alternative Fuel Effects on Contrails and Cruise Emissions II
ACE	Advanced Composition Explorer (Heliophysics)
ACE	Aerosol, Cloud, and Ecosystems (Earth Science)
ACME	Advanced Combustion via Microgravity Experiments
ACT	Advancd Component Technologies
ACTE	adaptive compliant trailing-edge technology
ACSC	Advanced Cislunar and Surface Capabilities
ADAP	Astrophysics Data Analysis Program
ADCAR	Astrophysics Data Curation and Archival Research
ADS-B	Automatic Dependent Surveillance-Broadcast
AEDL	Advanced Entry Descent and Landing
AEPS	Advanced Electric Propulsion Systems
AES	Advanced Exploration Systems
AETC	Aerosciences Evaluation and Test Capability
AFO	Altimetry Follow-On
AFRC	Armstrong Flight Research Center
AFRL	Air Force Research Laboratory
AFTA	Astrophysics Focused Telescope Assets
AIM	Aeronomy of Ice in the Mesosphere
AirMOSS	Airborne Microwave Observatory of Subcanopy and Subsurface
AIRS	Atmospheric Infrared Sounder
AIST	Advanced Information Systems Technology
AITS	Agency Information Technology Services
AMMOS	Advanced Multi-Mission Operations System
AMO	Agency Management and Operations
AMR	Advanced Microwave Radiometer
AO	Announcements of Opportunity

ACRONYMS AND ABBREVIATIONS

AOSP	Airspace Operations and Safety Program
APL	Applied Physics Laboratory
APMC	Agency Project Management Council
AR	Advanced Radiometer
ARC	Ames Research Center
ARCD	Aerospace Research and Career Development
ARM	Asteroid Redirect Mission
ARMD	Aeronautics Research Mission Directorate
ARRA	American Recovery and Reinvestment Act
ARSET	Applied Remote SEnsing Training
ARTCC	Atlanta Air Route Traffic Control Center
ARTEMIS	Acceleration, Reconnection, Turbulence and Electrodynamics of the Moon's Interaction with the Sun
ASCAN	Astronaut Candidate
ASCENDS	Active Sensing of CO2 Emissions over Nights, Days, and Seasons
ASDM	Astrophysics Decadal Strategic Mission
ASM	Aquistion Strategy Meeting
ASI	Agenzia Spaziale Italiana
ASIAS	Aviation Safety Information Analysis and Sharing
ASPERA	Analyzer of Space Plasmas and Energetic Atoms
ATCC	A-Complex Test Control Center
ATCT	Charlotte Air Traffic Control Tower
ATD	Air Traffic Management Technology Demonstration-1
ATI	Advanced Technology Initiatives
ATLAS	Advanced Topographic Laser Altimeter System
ATM	Air Traffic Management
ATTREX	Airborne Tropical TRopopause EXperiment
AU	Astronomical Units
AURA	Association of Universities for Research in Astronomy
BAA	Broad Agency Announcement
BARREL	Balloon Array for Radiation-belt Relativistic Electron Losses
BEAM	Bigelow Expandable Activity Module
BEDI	Big Earth Data Initiative
BFELoB	Budget Formulation & Execution Lines of Business
BPR	Baseline Performance Review
BPS	Brine Processor Assembly (ISS O&M)
BPS	Biological and Physical Sciences (ISS Research)
BTC	budget to complete
BWG	Beam Wave Guide
CAL	Cold Atom Laboratory
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation

ACRONYMS AND ABBREVIATIONS

CAMMEE	Committee on Aerospace Medicine and the Medicine of Extreme Environments
CAP	Cross-Agency Priority
CARVE	Carbon in Arctic Reservoirs Vulnerability Experiment
CAS	Convergent Aeronautics Solutions
CASIS	Center for the Advancement of Science in Space
CAST	Commercial Aviation Safety Team
CATALYST	Cargo Transportation and Landing by Soft Touchdown
CATS	Cloud Aerosol Transport System
CATSAT	Cognitive Application Technology Satellite
CBM	Conditioned Based Maintenance
CBT	Computer-Based Training
CCAFS	Cape Canaveral Air Force Station
CCD	charge-coupled device
CCDev2	Commercial Crew Development Round 2
CCiCap	Commercial Crew integrated Capability
CCM	Camera Control Module
CCMC	Community Coordinated Modeling Center
CCP	Commercial Crew Program
CCtCap	Commercial Crew transportation Capabilities
CDC	Centers for Disease Control
CDI	Climate Data Initiative
CDM	Continuous Diagnostic Mitigation
CDR	Critical Design Reviews
CDSCC	Canberra Deep Space Communication Complex
CDTI	Center for the Development of Industrial Technology
CECR	Construction and Environmental Compliance and Restoration
CeREs	Compact Radiation Belt Explorer
CERES	Clouds and the Earth’s Radiant Energy
CFD	Computational Fluid Dynamics
CFOC	Chief Financial Officer’s Council
CGE	Concur Government Edition
CHAMPS™	CubeSat High-Impulse Adaptable Modular Propulsion System™
CHESS-4	Colorado High-resolution Echelle Stellar Spectrograph
CHS	Crew Health and Safety
CIBER	Cosmic Infrared Background Experiment Rocket
CINDI	Coupled Ion Neutral Dynamic Investigation
CIPS	Cloud Imaging and Particle Size
CIRs	Co-rotating interaction regions
CL	Confidence level
CLARREO	Climate Absolute Radiance and Refractivity Observatory
CM	Crew Module
CMA	Crew Moldule Adapter

ACRONYMS AND ABBREVIATIONS

CMEs	Coronal Mass Ejections
CMO	Center Management and Operations
CMS	Carbon Monitoring System
CNES	Centre National d'Etudes' Spatiales
CoF	Construction of Facilities
COFAR	Council on Financial Assistance Reform
Comet C-S	Comet Churyumov-Gerasimenko
COOP	Continuity of Operations
COR	Cosmic Origins
CORAL	Coral Reef Airborne Laboratory
CoSTEM	Committee on science, technology, engineering, and mathematics
COTS	Commercial off-the-shelf
CPC	Certification Products Contracts
CPOD	CubeSat Proximity Operations Demonstration
CREAM	Cosmic Ray Energetics and Mass
CRP	Commercialization Readiness Program
CRS	Commercial Resupply Services
CRT	Climate Resilience Toolkit
CRV	Current replacement value
CSA	Canadian Space Agency
CSC	Computer Sciences Corporation
CSM	Crew and Service Module
CSL	Belgian Centre Spatial de Liège
CSLI	CubeSat Launch Initiative
CSO	Communications Services Office
CSP	Communications Services Program
CST	Commerical Supersonic Transport
CSTD	Crosscutting Space Technology Development
CT	Computerized Tomography
CUSP	CubeSat Mission to Understand Solar Particles
CYGNSS	Cyclone Global Navigation Satellite System
D&B	Dun and Bradstreet
DAA	Detect and Avoid
DAAC	Distributed Active Archive Center
DAEP	The DSN Aperature Enhancement Project
DART	Double Asteroid Redirection Test
DATA	Digital Accountability and Transparency Act
DCT	Development to Certification Timeline
DESDynI	Deformation, Ecosystem Structure and Dynamics of Ice
DISCOVER-AQ	Deriving Information on Surface Conditions from COlumn and VERtically Resolved Observations Relevant to Air Quality
DLP	Data Loss Prevention

ACRONYMS AND ABBREVIATIONS

DLR	German Aerospace Center
DLS	Deployable launch system
DNA	Deoxyribonucleic acid
DoD	Department of Defense
DOE	Department of Energy
DOF	Degree-of-Freedom
DOI	Department of Interior
DOJ	Department of Justice
DOL	Department of Labor
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
DPMC	Directorate Program Management Council
DPR	Dual-frequency Precipitation Radar
DRE	discrete roughness elements
DRT	Dynamic Rollout Test
DRIVE	Diversify, Realize, Integrate, Venture, Educate
DSAC	Deep Space Atomic Clock
DSCC	Deep Space Communications Complex
DSCOVR	Deep Space Observatory
DSI	Deutsches SOFIA Institut
DSN	Deep Space Network
DSAC	Deep Space Atomic Clock
DSOC	Deep Space Optical Communication
DSS	Deep Space Station
DTN	Disruption Tolerant Network
DUNS	Data Universal Numbering System
EAP	Electric Aircraft Propulsion
ECAST	Expert and Citizen Assessment of Science and Technology
ECCPP	The East Coast Commercial Payload Processing Contract
ECOSTRESS	ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station
ECLSS	Environmental Control and Life Support Systems
ECR	Environmental Compliance and Restoration
ECU	Engine Controller Units
EGS	Exploration Ground Systems
ERD	Exploration Research and Development
ESD	Exploration Systems Development
ESM	The European Service Module
eCryo	Evolvable Cryogenics
EFT	Exploration Flight Test
EGS	Exploration Ground Systems
EHRI	Enterprise HR Integration
EHRS	Electronic Health Records System
EICC	EPSCoR Interagency Coordinating Committee
ELFIN	Electroon Losses and Fields Investigation

ACRONYMS AND ABBREVIATIONS

ELV	Expendable Launch Vehicle
EM	Exploration Mission
EO-1	Earth Observing-1
EONS	Education Opportunities in NASA STEM
eOPF	electronic Official Personnel Folder
EOS	Earth Observation Systems
EPA	Environmental Protection Agency
EPIC	Earth Poly-Chromatic Imaging Camera
EPSCoR	Established Program to Stimulate Competitive Research
EQM	Engineering Qualification Model
ERA	Environmentally Responsible Aviation
ERBS	Earth Radiation Budget Science
ESA	European Space Agency
ESAero	Empirical Systems Aerospace
ESDN	Edison Demonstration of Smallsat Networks
ESDS	Earth Science Data Systems
ESM	Earth Systematic Missions
ESPRIT	European System Providing Refueling, Infrastructure, and Telecommunications
ESSP	Earth System Science Pathfinder
ESTEEM	Earth Systems, Technology and Energy Education for MUREP
ESTO	Earth Science Technology Office
ESTP	Earth Science Technology Program
ETD	Exploration Technology Development
ETS2	E-Gov Travel Service 2
EUL	Enhanced Use Leasing
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EUS	Exploration Upper Stage
EVI	Earth Venture Instruments
EVA	Extravehicular Activity
EVM	Earth Venture small Missions
EX	Explorers
FAA	Federal Aviation Administration
FDC	Flight Demonstrations and Capabilities
FDMS	Federal Docket Management System
FEVS	Federal Employee Viewpoint Survey
FFATA	Federal Funding Accountability and Transparency Act
FFI	Forsvarets Forskning Institute
FGS	Fine Guidance Sensor
FIRST	For Inspiration and Recognition of Science and Technology
FIT	Financial Innovation and Transformation
FMLoB	Financial Management Lines of Business

ACRONYMS AND ABBREVIATIONS

FO	Follow-On
FOC	Full operational capability
FPB	Flight Planning Board
FPI	Fast Plasma Investigation
FPPS	Federal Personnel and Payroll System
FRR	Flight Readiness Review
FSR	Formulation Syncronization Review
FY	Fiscal Year
G-3	Gulfstream 3
GALEX	Galaxy Evolution Explorer
GCIS	Global Change Information System
GCR	Grand Challenge Research
GDC	Geospace Dynamics Constellation
GEDI	Global Ecosystem Dynamics Investigation Lidar
GEMS	Gravity and Extreme Magnetism
GEO-CAPE	GEOstationary Coastal and Air Pollution Events
GFAST	The Ground Flight Application Software Team
GFZ	German Research Centre for Geosciences
GIBS	Global Imagery Browse Services
GIS	Geographic Information System
GLOBE	Global Learning and Observations to Benefit the Environment
GMAO	Global Modeling and Assimilation Office
GNC	Guidance, Navigation, and Control
GNSS	Global Navigation Satellite System
GOES	Geostationary Operational Environmental Satellite
GOLD	Global-scale Observations of the Limb and Disk
GPM	Global Precipitation Measurement
GPS	Global Positioning System
GPSP	Global Positioning System-Payload
GRACE	Gravity Recovery and Climate Experiment
GRAIL	Gravity Recovery and Interior Laboratory
GRC	Glenn Research Center
GRC-PBS	Glenn Research Center Plum Brook Station
GRIFEX	GEO-CAPE Readout Integrated Circuit Experiment
GSA	General Services Administration
GSE	Ground Support Equipment
GSI	Ground Systems Implementation
GSDO	Ground Systems Development and Operations Program Office
GSFC	Goddard Space Flight Center
GSLV	Geosynchronous Satellite Launch Vehicle
GSRT	GSFC System Review Team
GW	Gravity Waves

ACRONYMS AND ABBREVIATIONS

HAWC+	High-resolution Airborne Wideband Camera
HB	High Bay
HBCU	Historically Black Colleges and Universities
HECC	High End Computing Capability
HEEET	Heat shield for Extreme Entry Environment Technology
HEO	Human Exploration and Operations
HEOMD	Human Exploration and Operations Mission Directorate
HERA	Human Exploration Research Analog
HERO	Human Exploration Research Opportunity
HF	High Frequency
HGEP	Hybrid Gas-Electric Propulsion
HHS	Department of Health and Human Services
HIAD	Hypersonic Inflatable Aeroshell Decelerator
HICO	Hyperspectral Imager for the Coastal Ocean
HIS	Heavy Ion Sensor
HITL	human-in-the-loop
HITT	High Intensity Interval Training
HLS	Harmonized Landsat/Sentinel
HMI	Helioseismic and Magnetic Imager
HMTA	Health and Medical Technical Authority
HMV	Heavy Maintenance Visit
HP3	Heat Flow and Physical Properties Package
HQ	Headquarters
HR	Human resources
HRP	Human Research Program
HS-3	Hurricane and Severe Storm Sentinel
HSFO	Human Space Flight Operations
HSI	Hispanic-Serving Institutions
HVAC	Heating, Ventilating, and Air Conditioning
HyspIRI	Hyperspectral and Infrared Imager
HT	Hypersonic Technology
I&T	Integration & Test
I3P	Infrastructure Integration Program
IAA	Interagency Agreement
IADS	Integrated Arrival/Departure/Surface
IAE	Integrated Acquisition Environment
IASP	Integrated Aviation Systems Program
IBEX	Interstellar Boundary Explorer
ICESat-2	Ice, Cloud, and land Elevation Satellite-2
ICON	Ionospheric Connection Explorer
ICPS	Interim Cryogenic Propulsion Stage

ACRONYMS AND ABBREVIATIONS

IDIQ	indefinite-delivery-indefinite-quantity
IDS	Intrusion Detection Systems
ILLUMA-T	The Integrated LCRD LEO User Modem and Amplifier Terminal
ILT	Instructor-Led Training
IMAP	Interstellar Mapping and Accleration Probe
IMC	International Mission Contributions
IMPACT	Interagency Implementation and Advance Concepts Team
IMPACTS	Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Storms
IMT	Integreated Modal Test
InSight	Interior Exploration using Seismic Investiations, Godesy and Heat Transport
INTA	National Institute of Aerospace Technology
InVEST	In-space Validation of Earth Science Technology
IOC	Initial operating capability
IOP/SS	Ignition Overpressure Protection and Sound Suppression
IPAO	Independent Program Assessment Office
IPCC	Intergovernmental Panel on Climate Change
IR	Infrared
IRIS	Interface Region Imaging Spectrograph
IRS	Internal Revenue Service
ISARA	Integrated Solar Array and Reflectarray Antenna
ISCM	Information Security Continuous Monitoring
ISERV	ISS SERVIR Environmental Research and Visualization System
ISIM	Integrated Science Instrument Module
ISRO	Indian Space Research Organisation
ISRS	In-Space Robotic Servicing
ISRU	in-situ resource utilization
ISS	International Space Station
IRT	Independent Review Team
IT	Information technology
I-trek	I turn research into empowerment and knowledge
ITSEC-EDW	IT Security Enterprise Data Warehouse
ISPF	In Space Propulsion Facility
IV&V	Independent Verification and Validation
IXPE	Imaging X-Ray Polarimetry Explore
JAXA	Japanese Aerospace Exploration Agency
JCL	Joint Confidence Level
JEL	jacking, equalizing, and leveling
JEM-EF	Japanese Experiment Module – Exposed Facility
JHU	Johns Hopkins University
JPL	Jet Propulsion Laboratory
JPSS	Joint Polar Satellite System

ACRONYMS AND ABBREVIATIONS

JSC	Johnson Space Center
JUICE	Jupiter Icy Moons Explorer
KaBOOM	Ka-Band Objects Observation and Monitoring
KARI	Korea Aerospace Research Institute
KaRIn	Ka-band Radar Interferometer
KBOs	Kuiper Belt objects
KDP	Key Decision Point
KOA	Keck Observatory Archive
KSC	Kennedy Space Center
KUS	Kenney Uplink Station
LADEE	Lunar Atmosphere and Dust Environment Explorer
LaRC	Langley Research Center
LAS	Launch Abort System
LBTI	Large Binocular Telescope Interferometer
LC	Launch Complex
LCC	Life Cycle Cost
LCPSO	Land Cover Project Science Office
LCRD	Laser Communications Relay Demonstration
LCAS	Low-Cost Access to Space
LCS	Launch Communications Segment
LDCM	Landsat Data Continuity Mission
LDEP	Lunar Discovery and Exploration Program
LDSD	Low Density Supersonic Decelerator
LEARN	Leading Edge Aeronautics Research for NASA
LED	Light-Emitting Diode
LEE	Latching End Effectors
LEED	Leadership in Energy and Environmental Design
LETF	Launch Equipment Test Facility
LH2	Liquid Hydrogen
LHASA	Landslide Hazard Assessment for Situational Awareness
LIDAR	Light Detection and Ranging
LIS	Lightning Imaging Sensor
LISA	Laser Interferometer Space Antenna
LLCD	Lunar Laser Communication Demonstration
LLO	Low Lunar Orbit
LM	Lockheed Martin
LMSSC	Lockheed Martin Space Systems Company
LoB	Lines of Business
LOX	liquid oxygen
LPGF	The Low Profile Grapple Fixture
LRA	Laser Retro-reflector Assembly
LRD	Launch Readiness Date
LRO	Lunar Reconnaissance Orbiter

ACRONYMS AND ABBREVIATIONS

LRR	Launch Readiness Review
LSAH	Lifetime Surveillance of Astronaut Health
LunIR	Lunar InfraRed imaging
LSP	Launch Services Program
LVC-DE	Live Virtual Constructive-Distributed Environment
LVSA	Launch Vehicle Stage Adapter
LWS	Living With a Star
MAA	MUREP Aerospace Academy
MAF	Michoud Assembly Facility
MAIA	Multi-Angle Imager for Aerosols
MAIANSE	MUREP for American Indian and Alaskan Native STEM Engagement
MARSIS	Mars Advanced Radar for Subsurface and Ionospheric Sounding
MAVEN	Mars Atmosphere and Volatile EvolutioN
MCC	Mission Control Center
MCF	Modular Computing Facility
MCI	Minority University Research and Education Program Community College Curriculum Improvement
MCR	Mission Concept Review
MDR	Mission Design Review
MEaSUREs	Making Earth System data records for Use in Research Environments
MEDLI	Mars Entry, Descent, and Landing Instrumentation
MEI	Minority University Research and Education Program Educator Institute
MER	Mars Exploration Rover
MERLIN	Mesoscale Eastern Range Lightning Information Network
MERRA	Modern Era Retrospective-analysis for Research and Applications
MESSENGER	MErcury Surface, Space ENvironment, GEochemistry, and Ranging
MIDEX	Medium-Class Explorers
MIRI	Mid Infrared Instrument
MIRO	MUREP Institutional Research Opportunity
MIs	minority institutions
MIT	Massachusetts Institute of Technology
M-I-T	Magnetosphere-Ionosphere-Thermosphere
MLCC	multi-layer ceramic capacitor
MLTI	Mesosphere-lLwer Thermosphere-Ionosphere
MMOD	MicroMeteoroid and Orbital Debris
MMS	Magnetospheric Multiscale
MO	Missions of Opportunity
MO&I	Mission Operations and Integration
MODIS	Moderate Resolution Imaging Spectroradiometer
MOM	Mars Orbiter Mission
MOMA-MS	Mars Organic Molecule Analyzer Mass Spectrometer
MOO	Multi-Mission Operations

ACRONYMS AND ABBREVIATIONS

MOXIE	Mars Oxygen ISRU Experiment
MPAR	Major Program Annual Report
MPCP	Multi-purpose Crew Vehicle Control Board
MPCV	Multi-Purpose Crew Vehicle
MPRAT	Mission Profile Risk Assessment Test
MRI	Magnetic Resonance Imaging
MRO	Mars Reconnaissance Orbiter
MSE	MUREP STEM Engagement
MSFC	Marshall Space Flight Center
MSI	Minority-Serving Institutions
MSL	Measurement Systems Laboratory
MSL	Photonics Mobile Lab (ISS Research)
Mths	Months
MTRS	McMurdo TDRSS Relay System
MUREP	Minority University Research and Education Program
MUSES	Multi-User System for Earth Sensing
MUSS	Multi User Systems and Support
N/A	Not applicable
NAAMES	North Atlantic Aerosols and Marine Ecosystems Study
NAC	National Agency Check
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NCCS	NASA Center for Climate Simulations
NCRP	National Council on Radiation Protection
NDS	NASA Docking System
NEACC	NASA Enterprise Applications Competency Center
NEA Scout	Near-Earth Asteroid Scout
NEN	Near Earth Network
NEO	near-Earth objects
NEOO	Near-Earth Object Observations
NESC	NASA Engineering and Safety Center
NET	No Earlier Than
NextGen	Next Generation Air Transportation System
NextSTEP	Next Space Technologies for Exploration
NCRP	NASA Space Radiation Program Element
NG	Northrop Grumman
NGIS	Northrop Grumman Innovation Systems
NHPA	National Historic Preservation Act
NIAC	NASA Innovative Advanced Concepts
NICER	Neutron star Interior Composition ExploreR
NISAR	NASA-Indian Space Research Organization Synthetic Aperture Radar
NIFS	NASA Internship, Fellowship, and Scholarship
NIH	National Institutes of Health
NIRCam	Near Infrared Camera

ACRONYMS AND ABBREVIATIONS

NIRISS	Near Infrared Imager and Slitless Spectrograph
NISAR	NASA-ISRO Synthetic Aperture Radar
NISTAR	National Institute of Standards and Technology Advances Radiometer
NISN	NASA Integrated Services Network
NIST	National Institute of Standards and Technology
NLCs	noctilucent clouds
NLS	NASA Launch Services
NMO	NASA Management Office
NOAA	National Oceanographic and Atmospheric Administration
NOx	mono nitrogen oxide
NPP	National Polar-orbiting Partnership
NRA	NASA Research Announcement
NRC	National Research Council
NREP	NanoRacks Exposure Platform
NRPTA	National Rocket Propulsion Test Alliance
NSBRI	National Space Biomedical Research Institute
NSF	National Science Foundation
NSRL	NASA Space Radiation Laboratory
NSSC	NASA Shared Services Center
NSSDC	National Space Science Data Center
NSTP PPD	National Space Policy Launch Infrastructure and Modernization Plan
NTIA	National Telecommunication and Information Administration
NuSTAR	Nuclear Spectroscopic Telescope Array
O2O	Optical to Orion
O&M	Operations and maintenance
O&TM	Operations and Test Management
OA	Office of Audits
OCAMS	OSIRIS-REx Camera Suite
OCFO	Office of the Chief Financial Officer
OCHMO	Office of Chief Health Medical Officer
OCO	Orbiting Carbon Observatory
OCSD	Optical Communications and Sensor Demonstration
OCT	Office of the Chief Technologist
OCTL	Optical Communication Telescope Laboratory
OE	Office of Education
OFT	Orbital Flight Test
OGS	Optical Ground Station
OI	Office of Investigations
OIG	Office of Inspector General
OLA	OSIRIS-REx Laser Altimeter
OLI	Operational Land Imager
OMB	Office of Management and Budget

ACRONYMS AND ABBREVIATIONS

OMDA	Other Missions and Data Analysis
OMG	Oceans Melting Greenland
OMI	Ozone Monitoring Instrument
OMPS	Ozone Mapping and Profiler Suite
ONERA	French Office National d’Etudes et Recherches Aérospatiales
OPM	Office of Personnel Management
ORACLES	Observations of Aerosols above Clouds and their Interactions
Orb-#	Orbital Sciences Commercial Resupply Services #
ORR	Operational Readiness Review
ORU	Orbital Replacement Spares
OSC	Orbital Sciences Corporation
OSHA	Occupational Safety and Health Administration
OSIRIS-REx	Origins Spectral Interpretation Resource Identification and Security-Regolith Explorer
OSMA	Office of Safety and Mission Assurance
OSMU	Orion Service Module Umbilical
OSTM	Ocean Surface Topography Mission
OSTST	Ocean Surface Topography Science Team
OTE	Optical Telescope Element
OTES	OSIRIS-REx Thermal Emission Spectrometer
OVIRS	OSIRIS-REx Visible and Infrared Spectrometer
OVWST	Ocean Vector Winds Science Team
P&O	Production and Operations
PACE	Pre-Aerosol, Clouds, and ocean Ecosystem
PAMSS	Planetary Atmosphere Minor Species Sensor
Pan-STARRS	Panoramic Survey Telescope and Rapid Reporting System
PB	President’s Budget
PBL	Planetrary Boundary Layer
PCA	Physicians’ comparability allowance
PCM	Post Certification Mission
PCOS	Physics of the Cosmos
PDA	progressive damage analysis
PDL	Ponce De Leon
PDR	preliminary design review
PDS	Planetary Data System
PEP	Particle Environment Package
PI	Principal Investigator
PIR	Program Implementation Review
PIV	Personal Identity Verification

ACRONYMS AND ABBREVIATIONS

P.L.	Public Law
PLI	Propellant, Liner, and Insulation
PMM	Precipitation Measurment Missions
PMT	Program Management Team
POA	Payload ORU Accomodations
POWER	Protecting Our Workers and Ensuring Reemployment
PPA	Plasma Pyrolysis Assembly
PPE	Power and Propulsion Element
PP&C	Programmatic, Planning and Control
PQM	Propulsion Qualification Module
PREFIRE	Polar Radiant Energy In The Far Infrared Experiment
PSI	Physical Science Informatics
PSL	Propulsion Systems Laboratory
PSP	Parker Solar Probe
PSMT	Partial Stack Modal Test
Pu	Plutonium
PV	Planetary Ventures, LLC
QM-1	qualification motor 1
QueSST	Quiet Supersonic Technology
QuikSCAT	Quick Scatterometer
RAA	Rayleigh Albedo Anomaly
R&D	Research and Development
R&T	Research and Technology
RAD	Radiation Assessment Detector
RAIF	Research Aircraft Integration Facility
RAO	Right Anterior Oblique
RAP	Robotics Alliance Project
RapidScat	Rapid Scatterometer
RBA	Reflector Boom Assembly
RBI	Radiation Budget Instrument
REALM	RFID Enabled Autonomous Logistics Management
REDD	Reducing Emissions from Deforestation and forest Degradation
RESOLVE	Regolith and Environment Science and Oxygen and Lunar Volatiles Extraction
REXIS	Regolith X-ray Imaging Spectrometer
RF	Radio frequency
RFP	Request for Proposal
RFID	Radio Frequency Identification
RFU	Radio Frequency Unit
RHESSI	Ramaty High Energy Solar Spectroscopic Imager
RID	Research Infrastructure Development
RIME	Radar for Icy Moons Exploration
RISE	Rotation and Interior Structure Experiment
ROD	Record of Decision

ACRONYMS AND ABBREVIATIONS

ROSES	Research Opportunities in Space and Earth Sciences
RPO	Rendezvous and proximity operations
RPODU	Rendezvous, proximity operations, docking and undocking
RPS	Radioisotope Power Systems
RPT	Rocket Propulsion Testing
RRM	Robotic Refueling Mission
RRS	Research Range Services
RS	Reflected Solar
RTCA	Radio Technical Commission for Aeronautics
RTG	Radioisotope Thermoelectric Generator
RVLT	Revolutionary Vertical Lift Technology
S-MODE	SubMesoscale Ocean Dynamics and vErtical Transport
SAA	Space Act Agreement
SAC-D	Satellite for Scientific Applications-D
SAFFIRE	Spacecraft Fire Experiment
SAGE	Stratospheric Aerosol and Gas Experiment
SAM	Spacecraft Atmospheric Monitor (Advanced Exploration Systems)
SAM	Sample Analysis at Mars (Planetary Science)
SAM I	Stratospheric Aerosol Measurement (Earth Science)
SANS	Spaceflight Associated Neuro-ocular Syndrome
SAO	Smithsonian Astrophysical Observatory
SAR	Synthetic Aperture Radar
SAR	System Acceptance Review (Venture Class Missions)
SARDA	Spot and Runway Departure Advisor
SASO	Safe Autonomous Systems Operations
SBA	Small Business Administration
SBIR	Small Business Innovation Research
SCaN	Space Communications and Navigation
SCAP	Strategic Capabilities Asset Program
SDO	Solar Dynamics Observatory
SDR	System Design Review
SEA	STEM Education and Accountability
SEAP	STEM Education and Accountability Projects
SE&I	Systems Engineering and Integration
SEIS	Seismic Experiment for Interior Structure
SEP	solar electric propulsion
SERENA	Search for Exospheric Refilling and Emitted Natural Abundances
SET	Space Environment Testbeds
SETAG	Space Environmental Testing Assets Group
SEWP	Solutions for Enterprise-Wide Procurement
SEXTANT	Station Explorer X-ray Timing and Navigation Technology
SFCO	Space Flight Crew Operations

ACRONYMS AND ABBREVIATIONS

SFS	Space and Flight Support
SGP	Space Geodesy project
SGSS	Space Network Ground Segment Sustainment
SIM	Spectral Irradiance Monitor
SIPS	Science Investigator-led Processing Systems
SIR	System Integration Review
SL-8	SpaceLoft-8
SLI	Sustainable Land Imaging
SLPSRA	Space Life and Physical Sciences Research and Applications
SLPSRAD	Space Life and Physical Sciences Research and Applications Division
SLS	Space Launch System
SMA	Safety and Mission Assurance
SMAP	Soil Moisture Active/Passive
SMART NAS	Shadow Mode Assessments Using Realistic Technologies for the National Airspace System
SMD	Science Mission Directorate
SMEX	Small Explorers
SMS	Safety and Mission Success
SMOS	Soil Moisture and Ocean Salinity
SMS	Safety and Mission Success
SNC	Sierra Nevada Corporation
SOC	Solar Orbiter Collaboration
SOC	Security Operations Center (SSMS)
SOFIA	Stratospheric Observatory for Infrared Astronomy
SOHO	Solar and Heliospheric Observatory
SoloHI	Solar Orbiter Heliospheric Imager
SORCE	Solar Radiation and Climate Experiment
SORTIE	Scintillation Observations and Response of The Ionosphere to Electrodynamics
SOST	Subcommittee on Ocean Science and Technology
SOT	Solar Optical Telescope
SOT-SP	Solar Optical Telescope Spectro-Polarimeter
Space Grant	National Space Grant College and Fellowship Program
SpaceX	Space Exploration Technologies Company
SPB	Solar Pressure Balloon
SPDF	Space Physics Data Facility
SPDM	Special Purpose Dexterous Manipulator
SPHERES	Synchronized Position Hold, Engage, Reorient, and Experimental Satellites
SNC	Sierra Nevada Corporation
SPOC	Science Processing and Operations Center
SPP	Solar Probe Plus
SpX-#	Space Exploration Technologies Company Commercial Resupply Services #

ACRONYMS AND ABBREVIATIONS

SR&T	Strategic Research and Technology
SRB	Strategic Review Board
SRB	Standing Review Board (Commercial Crew Program)
SRC	Sample Return Capsule
SRP	supersonic retrorocket propulsion
SRR	Systems Requirement Review
SSC	Stennis Space Center
SSERVI	Solar System Exploration Research Virtual Institute
SSFL	Santa Susana Field Laboratory
SSL	Space Systems Loral
SSMS	Safety, Security, and Mission Services
ST	Space Technology
STA	Structural Test Article
STDT	Science and Technology Definition Team
STEM	Science, Technology, Education, and Mathematics
STEREO	Solar TErrestrial RElations Observatory
STIP	Strategic Technology Investment Plan
STMD	Space Technology Mission Directorate
STP	Solar Terrestrial Probes
STPH-5 LIS	Space Test Program Houston-5 Lightning Imaging System
STScI	Space Telescope Science Institute
STTR	Small Business Technology Transfer
Suomi NPP	Suomi National Polar-orbiting Partnership
SWxSA	Space Weather Science and Applications
SWEAP	Solar Wind Electrons Alphas and Protons
SWOT	Surface Water Ocean Topography
SwRI	Southwest Research Institute
SXS	Soft X-Ray Spectrometer
TACP	Transformative Aeronautics Concepts Program
TAGSAM	Touch and Go Sample Acquisition Mechanism
TASEAS	Technologies for Assuring Safe Energy and Attitude State
TBD	To Be Determined
TBIRD	TeraByte Infrared Delivery
TBEx	Tandem Beacon-Explorer
TBW	truss-braced wing
TCTE	Total Solar Irradiance Calibration Transfer Experiment
TCU	Tribal Colleges and Universities
TDM	Technology Demonstration Missions
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite Sytem
TDT	Transonic Dynamics Tunnel

ACRONYMS AND ABBREVIATIONS

TEMPO	Tropospheric Emissions: Monitoring of Pollution
TESS	Transiting Exoplanet Survey Satellite
TFM	Traffic Flow Management
TGO	Trace Gas Orbiter
THEMIS	Time History of Events and Macroscale Interactions during Substorms
THOR	Terrestrial HIAD Orbital Reentry
TIM	Total Irradiance Monitor
TIMED	Thermosphere Ionosphere Mesosphere Energetics and Dynamics
TIR-FFD	Thermal-Infrared Free-Flyer
TIRS	Thermal Infrared Sensor
TLI	Trans-Lunar Injection
TMC	Technical and Management and Cost
TOPEX	Topography Experiment
TPS	Thermal Protection System
TRACON	Charlotte Terminal Radar Approach Control
TR&T	Targeted Research & Testing
TRACT	Transport Rotorcraft Airframe Crash Testbed
TRL	Technology Readiness Level
TRISH	Translational Research Institute for Space Health
TROPICS	Time-Resolved Observations of Precipitation Structure and Storm Intensity with a Constellation of Smallsats
TRMM	Tropical Rainfall Measurement Mission
TSI	total solar irradiance
TSIS	Total and Spectral Solar Irradiance Sensor
TSS	Terminal Sequencing and Spacing
TTT	Transformational Tools and Technologies
TWINS	Two Wide-angle Imaging Neutral-atom Spectrometers
UAM	Urban Air Mobility
UAS	Unmanned Aircraft Systems
UAV	unmanned aerial vehicle
UAVSAR	Uninhabited Aerial Vehicle Synthetic Aperture Radar
UHB	ultra-high bypass
UEST	Ultra-Efficient Subsonic Transport
UHF	ultra high frequency
UI	University Innovation
UKSA	United Kingdom Space Agency
ULA	United Launch Alliance
ULS	United Launch Services
UNEX	University-Class Explorers
UPSS	universal propellant servicing system
UPTWT	Unitary Plan Wind Tunnel

ACRONYMS AND ABBREVIATIONS

USAF	United States Air Force
USAID	U.S. Agency for International Development
U.S.C.	United States Code
USDM	U.S. Drought Monitor
USGCRP	U.S. Global Change Research Program
USGS	U.S. Geological Survey
USOS	U.S. Operating Segment of ISS
USRA	Universities Space Research Association
URT	Underway Recovery Test
UTM	UAS Traffic Management
UV	Ultraviolet
UVS	Ultraviolet Spectrograph
UWSMS	Universal Waste Management System
VAB	Vehicle Assembly Building
VAC	Vertical Assembly Center
VAFB	Vandenberg Air Force Base
VCLS	Venture Class Launch Services
VIIP	visual impairment/intra-cranial pressure
VIIRS	Visible Infrared Imaging Radiometer
VIL	Vehicle Integration and Launch
VSPT	Variable-Speed Power Turbine
VTOL	Vertical Take Off and Landing
V&V	Verification and Validation
WANs	Wide Area Networks
WASP	Web Application Security Program
WBS	work breakdown structure
WCCPP	The West Coast Commercial Payload Processing Contract
WCF	Working Capital Fund
Webb	James Webb Space Telescope
WFA	Work from Anywhere
WFF	Wallops Flight Facility
WFIRST	Wide-Field Infrared Survey Telescope
WIF	Worksite Interface
WISE	Wide-field Infrared Survey Explorer
WISPR	Wide-field Imager for Solar PRobe
WSTF	White Sands Test Facility
WWAO	Western Water Applications Office
XMM-Newton	X-ray Multi-Mirror Mission
ZBOT	Zero Boil-Off Tank