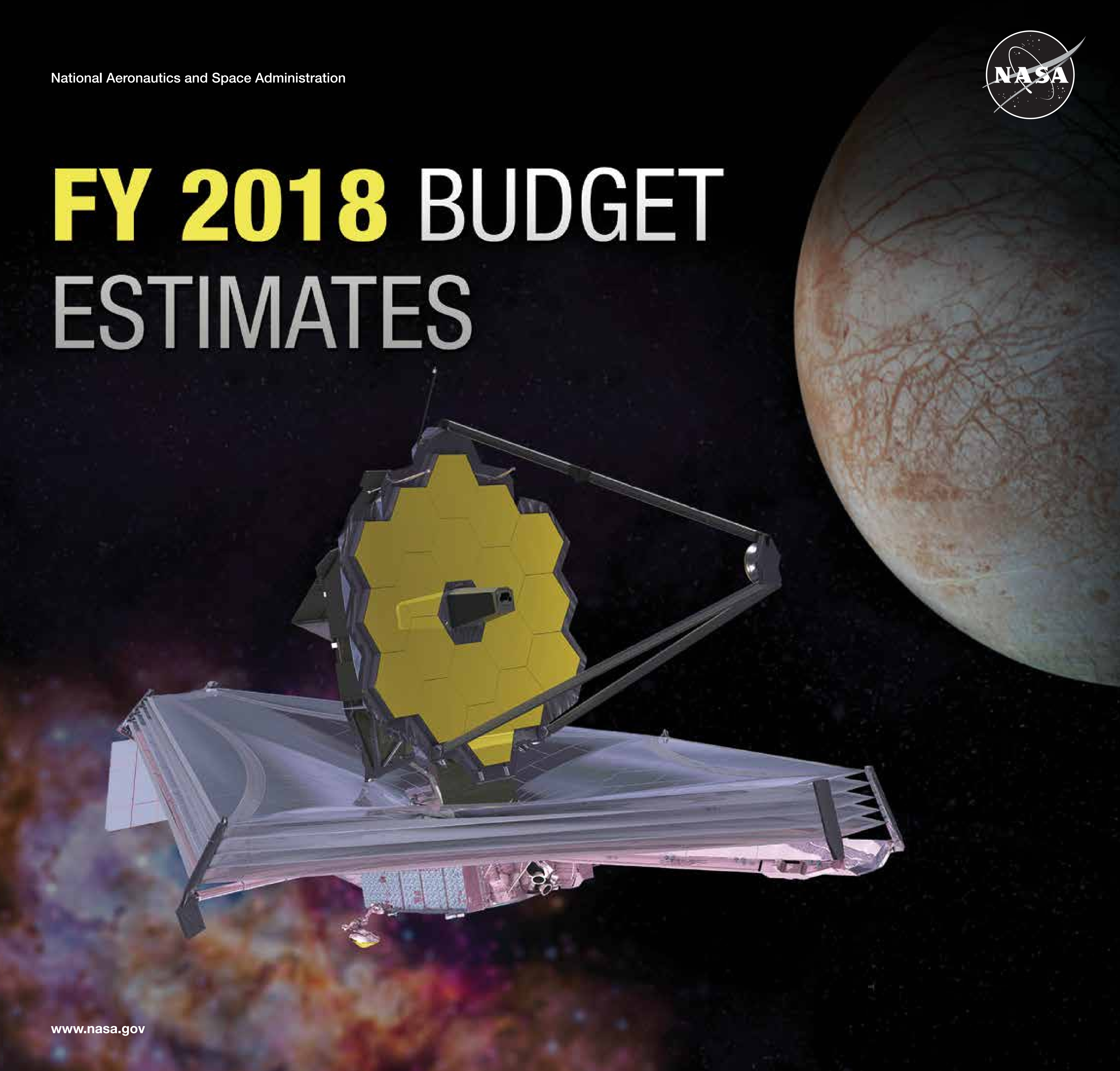
National Aeronautics and Space Administration

FY 2018 BUDGET ESTIMATES



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FY 2018 PRESIDENT'S BUDGET REQUEST SUMMARY

Budget Authority ($ in millions)	Operating Plan 2016	Enacted 2017	PBR 2018	Notional 2019	Notional 2020	Notional 2021	Notional 2022
NASA Total	19,285.0	19,653.3	19,092.2	19,092.2	19,092.2	19,092.2	19,092.2
Science	5,584.1	5,764.9	5,711.8	5,728.7	5,728.7	5,728.7	5,728.7
Earth Science	1,926.6	--	1,754.1	1,769.1	1,769.1	1,769.1	1,769.1
Earth Science Research	477.7	--	406.7	435.1	441.1	459.7	477.8
Earth Science Research and Analysis	347.2	--	287.8	296.5	299.6	313.7	309.1
Computing and Management	130.5	--	118.9	138.6	141.4	146.0	168.7
Earth Systematic Missions	914.6	--	778.0	787.1	755.0	708.7	680.4
Ice, Cloud, and land Elevation Satellite (ICESat-2)	117.4	86.5	92.3	14.2	14.2	14.4	14.7
GRACE FO	59.9	33.7	20.5	11.3	12.3	12.2	14.4
Surface Water and Ocean Topography Mission (SWOT)	114.1	61.7	90.9	121.3	85.0	63.9	32.8
NASA-ISRO Synthetic Aperature Radar (NISAR)	72.4	101.4	55.4	128.1	125.4	101.2	83.9
Sentinel-6	38.2	42.5	53.4	67.5	64.5	40.4	14.9
Landsat 9	56.0	--	175.8	167.4	127.9	121.2	8.8
Other Missions and Data Analysis	456.7	--	289.7	277.4	325.8	355.5	510.9
Earth System Science Pathfinder	233.6	--	264.5	243.8	256.0	271.5	268.3
Venture Class Missions	151.1	--	199.1	174.0	184.0	199.7	202.5
Other Missions and Data Analysis	82.5	--	65.4	69.7	72.0	71.9	65.7
Earth Science Multi-Mission Operations	192.4	--	196.5	194.1	200.7	208.6	218.6
Earth Science Technology	60.7	--	60.4	59.7	63.6	65.9	67.8
Applied Sciences	47.6	--	47.9	49.3	52.8	54.7	56.3
Planetary Science	1,628.0	--	1,929.5	1,921.4	1,916.4	1,911.4	1,911.4
Planetary Science Research	274.0	--	291.5	295.1	298.4	298.9	304.7
Planetary Science Research and Analysis	163.2	--	197.9	201.2	201.2	201.2	201.2
Directorate Management	3.3	--	0.0	0.0	0.0	0.0	0.0
Near Earth Object Observations	50.0	--	50.0	50.0	50.0	50.0	50.0
Other Missions and Data Analysis	57.5	--	43.6	43.9	47.2	47.7	53.5
Discovery	189.0	--	306.1	425.4	488.3	376.8	375.2
InSight	92.1	32.3	109.4	22.3	11.8	9.0	9.0
Lucy	0.0	--	101.4	170.9	205.1	141.1	36.2

FY 2018 PRESIDENT'S BUDGET REQUEST SUMMARY

Budget Authority ($ in millions)	Operating Plan 2016	Enacted 2017	PBR 2018	Notional 2019	2020	2021	2022
Psyche	0.0	--	25.0	160.4	210.0	169.2	181.0
Other Missions and Data Analysis	96.9	--	70.3	71.8	61.4	57.5	149.0
New Frontiers	194.0	--	82.1	121.7	169.4	227.8	307.0
Mars Exploration	513.0	--	584.7	562.5	530.4	356.9	450.7
Mars Rover 2020	321.8	377.5	374.3	363.8	322.8	150.0	120.0
Other Missions and Data Analysis	191.2	--	210.4	198.7	207.6	206.9	330.7
Outer Planets and Ocean Worlds	261.0	--	457.9	318.1	229.3	446.2	267.2
Jupiter Europa	175.0	275.0	425.0	303.0	215.7	432.4	253.6
Other Missions and Data Analysis	86.0	--	32.9	15.1	13.6	13.8	13.6
Technology	197.0	--	207.2	198.6	200.6	204.8	206.6
Astrophysics	762.4	--	816.7	1,045.8	1,153.2	1,200.6	1,200.4
Astrophysics Research	192.8	--	204.4	220.5	225.4	261.9	288.1
Astrophysics Research and Analysis	69.7	--	74.1	81.4	82.6	84.2	84.2
Balloon Project	36.2	--	37.3	40.4	39.9	40.4	37.4
STEM Science Activation	37.0	--	44.0	44.6	45.9	47.0	48.7
Other Missions and Data Analysis	49.9	--	49.1	54.1	57.1	90.3	117.8
Cosmic Origins	195.6	--	191.6	190.0	142.0	157.8	156.4
Hubble Space Telescope (HST)	98.3	--	83.3	83.3	83.3	98.3	98.3
Stratospheric Observatory for Infrared Astronomy (SOFIA)	83.6	--	79.9	79.8	39.8	16.6	0.0
Other Missions and Data Analysis	13.7	--	28.4	26.9	18.9	42.9	58.1
Physics of the Cosmos	125.3	--	99.9	109.4	111.1	93.6	93.7
Exoplanet Exploration	141.2	--	176.0	350.8	473.3	475.8	440.2
Astrophysics Explorer	107.6	--	144.7	175.1	201.3	211.5	222.1
Transiting Exoplanet Survey Satellite (TESS)	62.5	89.0	36.9	9.1	2.5	0.0	0.0
Other Missions and Data Analysis	45.1	--	107.8	166.0	198.8	211.5	222.1
James Webb Space Telescope	620.0	569.4	533.7	304.6	197.2	149.8	150.0
Heliophysics	647.2	--	677.8	687.8	692.8	697.8	697.8
Heliophysics Research	160.0	--	200.2	217.2	214.8	219.0	219.5
Heliophysics Research and Analysis	36.3	--	49.9	58.2	58.6	58.6	58.6
Sounding Rockets	49.8	--	59.0	61.1	63.1	63.1	63.1
Research Range	21.6	--	24.1	25.5	25.5	25.6	25.6
Other Missions and Data Analysis	52.2	--	67.1	72.4	67.6	71.7	72.2
Living with a Star	337.1	--	381.0	255.9	123.3	118.9	122.1
Solar Probe Plus	255.6	210.3	265.8	107.2	30.6	22.1	22.2

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Budget Authority ($ in millions)	Operating Plan 2016	Enacted 2017	PBR 2018	Notional 2019	2020	2021	2022
Solar Orbiter Collaboration	32.8	97.7	51.4	66.3	2.3	2.4	2.3
Other Missions and Data Analysis	48.7	--	63.8	82.4	90.5	94.4	97.6
Solar Terrestrial Probes	49.5	--	37.8	97.9	171.5	185.1	191.1
Heliophysics Explorer Program	100.6	--	58.9	116.8	183.1	174.9	165.1
Ionospheric Connection Explorer (ICON)	48.4	49.4	9.0	4.5	1.3	0.0	0.0
Other Missions and Data Analysis	52.3	--	50.0	112.2	181.8	174.9	165.1
Aeronautics	633.8	660.0	624.0	624.4	624.4	624.4	624.4
Aeronautics	633.8	--	624.0	624.4	624.4	624.4	624.4
Airspace Operations and Safety Program	147.1	--	108.7	107.7	107.1	107.8	109.7
Advanced Air Vehicles Program	254.9	--	232.7	223.8	233.2	236.7	241.8
Integrated Aviation Systems Program	128.3	--	173.5	178.5	167.8	139.2	132.9
Low Boom Flight Demonstrator	0.0	--	79.2	88.3	80.0	45.8	30.0
Transformative Aero Concepts Program	103.5	--	109.2	114.5	116.3	140.7	139.9
Space Technology	686.4	686.5	678.6	679.3	679.3	679.3	679.3
Space Technology	686.4	--	678.6	679.3	679.3	679.3	679.3
Agency Technology and Innovation	31.5	--	31.9	31.9	31.9	31.9	31.9
SBIR and STTR	200.9	--	180.0	180.0	180.0	180.0	180.0
Space Technology Research and Development	454.0	--	466.7	467.4	467.4	467.4	467.4
RESTORE-L	133.0	130.0	0.0	0.0	0.0	0.0	0.0
Laser Communications Relay Demonstration	30.5	25.7	21.5	17.2	0.0	0.0	0.0
Exploration	3,996.2	4,324.0	3,934.1	4,259.7	4,513.3	4,437.9	4,449.9
Exploration Systems Development	3,640.8	3,929.0	3,584.1	3,739.7	3,898.2	3,771.5	3,762.3
Orion Program	1,270.0	1,350.0	1,186.0	1,170.2	1,123.4	1,124.5	1,124.5
Crew Vehicle Development	1,251.5	--	1,175.5	1,159.7	1,112.9	1,114.0	1,114.0
Orion Program Integration and Support	18.5	--	10.5	10.5	10.5	10.5	10.5
Space Launch System	1,971.9	2,150.0	1,937.8	2,083.6	2,265.6	2,177.6	2,177.4
Launch Vehicle Development	1,921.9	--	1,881.7	2,032.7	2,189.9	2,101.1	2,101.1
SLS Program Integration and Support	50.0	--	56.1	50.9	75.6	76.5	76.3

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Budget Authority ($ in millions)	Operating Plan 2016	Enacted 2017	PBR 2018	Notional 2019	2020	2021	2022
Exploration Ground Systems	398.9	429.0	460.4	486.0	509.1	469.5	460.5
Exploration Ground Systems Development	398.9	--	460.4	470.7	493.7	453.8	444.8
EGS Program Integration and Support	0.0	--	0.0	15.3	15.4	15.7	15.7
Exploration Research and Development	355.4	395.0	350.0	520.0	615.1	666.4	687.6
Human Research Program	145.0	--	140.0	140.0	140.0	140.0	140.0
Advanced Exploration Systems	210.4	--	210.0	380.0	475.1	526.4	547.6
Space Operations	5,032.3	4,950.7	4,740.8	4,532.8	4,279.2	4,354.6	4,342.6
Space Shuttle	5.4	--	0.0	0.0	0.0	0.0	0.0
International Space Station	1,436.4	--	1,490.6	1,561.3	1,611.4	1,616.5	1,635.2
International Space Station Program	1,436.4	--	1,490.6	1,561.3	1,611.4	1,616.5	1,635.2
ISS Systems Operations and Maintenance	1,092.5	--	1,173.1	1,219.7	1,214.7	1,213.9	1,232.5
ISS Research	343.9	--	317.5	341.7	396.7	402.6	402.6
Space Transportation	2,667.8	--	2,415.1	2,118.7	1,811.4	1,868.6	1,808.9
Crew and Cargo Program	1,424.0	--	1,683.2	1,945.6	1,775.5	1,832.3	1,772.6
Commercial Crew Program	1,243.8	--	731.9	173.1	35.8	36.3	36.3
Space and Flight Support (SFS)	922.7	--	835.0	852.7	856.4	869.4	898.5
21st Century Space Launch Complex	28.4	--	0.0	0.0	0.0	0.0	0.0
Space Communications and Navigation	669.8	--	576.3	580.4	576.4	585.5	614.6
Space Communications Networks	592.2	--	493.0	489.5	433.5	461.4	464.5
Space Communications Support	77.7	--	83.3	90.9	142.9	124.0	150.1
Human Space Flight Operations	100.6	--	124.4	136.1	143.9	147.8	147.8
Launch Services	81.2	--	86.8	88.6	88.6	88.6	88.6
Rocket Propulsion Test	42.7	--	47.6	47.6	47.6	47.6	47.6
Education	115.0	100.0	37.3	0.0	0.0	0.0	0.0
Safety, Security, and Mission Services	2,772.4	2,768.6	2,830.2	2,859.4	2,859.4	2,859.4	2,859.4
Center Management and Operations	1,987.6	--	1,992.5	2,036.8	2,036.8	2,036.8	2,036.8
Center Institutional Capabilities	1,533.1	--	1,533.3	1,561.5	1,561.5	1,561.5	1,561.5
Center Programmatic Capabilities	454.5	--	459.2	475.3	475.3	475.3	475.3

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Budget Authority ($ in millions)	Operating Plan 2016	Enacted 2017	PBR 2018	Notional 2019	2020	2021	2022
Agency Management and Operations	784.8	--	837.7	822.6	822.6	822.6	822.6
Agency Management	361.9	--	361.2	376.3	376.3	376.3	376.3
Safety and Mission Success	176.2	--	171.4	171.4	171.4	171.4	171.4
Safety and Mission Assurance	49.7	--	49.8	49.8	49.8	49.8	49.8
Chief Engineer	83.4	--	83.7	83.7	83.7	83.7	83.7
Chief Health and Medical Officer	4.0	--	4.4	4.4	4.4	4.4	4.4
Independent Verification and Validation	39.1	--	33.5	33.5	33.5	33.5	33.5
Agency IT Services (AITS)	219.8	--	278.1	247.9	247.9	247.9	247.9
IT Management	15.1	--	26.0	20.7	21.1	20.8	20.9
Applications	55.8	--	59.0	57.2	56.4	56.4	56.4
Infrastructure	148.9	--	193.1	170.0	170.4	170.7	170.6
Strategic Capabilities Asset Program	26.9	--	27.0	27.0	27.0	27.0	27.0
Construction and Environmental Compliance and Restoration	427.4	360.7	496.1	368.6	368.6	368.6	368.6
Construction of Facilities	352.9	--	408.2	280.7	280.7	280.7	280.7
Institutional CoF	278.2	--	280.7	280.7	280.7	280.7	280.7
Exploration CoF	28.3	--	95.9	0.0	0.0	0.0	0.0
Space Operations CoF	36.7	--	16.6	0.0	0.0	0.0	0.0
Science CoF	4.6	--	15.0	0.0	0.0	0.0	0.0
Aeronautics CoF	5.1	--	0.0	0.0	0.0	0.0	0.0
Environmental Compliance and Restoration	74.5	--	87.9	87.9	87.9	87.9	87.9
Inspector General	37.4	37.9	39.3	39.3	39.3	39.3	39.3
NASA Total	19,285.0	19,653.3	19,092.2	19,092.2	19,092.2	19,092.2	19,092.2

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

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FY 2018 BUDGET REQUEST EXECUTIVE SUMMARY

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MESSAGE FROM THE ADMINISTRATOR (ACTING)

I am pleased to present President Trump's FY 2018 $19 billion budget request for NASA.

NASA helps fuel the engine of American innovation by planning to take humans deeper into space, increasing U.S. technological capabilities, making new discoveries about our solar system and the universe, and inspiring the next generation even as it creates good jobs and great economic benefits for our nation.

This budget enables continued American leadership in space. It focuses on NASA's core missions and the cutting edge capabilities we'll need to carry them out. It supports a sustained cadence of science and technology breakthroughs and missions that will take humans back to the vicinity of the moon and beyond.

The budget supports and expands public-private partnerships as the foundation of future U.S. civilian space efforts. Such partnerships have enabled American industry to provide cargo resupply services for the International Space Station and the imminent return of the capability to launch astronauts from American soil. The Budget creates new opportunities for collaboration with industry in space station operations, deep space habitation, Earth observation, and the development of new technologies. In this and many other ways, NASA remains a good investment for the nation. Our missions help develop our evolving industrial base – which strengthens our economic and national security – and give our nation greater capabilities and flexibility to achieve challenging exploration goals.

Building on an incredible history of achievement in science, this request pushes out the frontiers of knowledge by enabling us to bring testing and construction of our next Great Observatory, the James Webb Space Telescope, to its final stages before its 2018 launch. It continues our work to put the InSight lander on Mars and send the Mars 2020 rover to the Red Planet in advance of sending humans there, in addition to a diverse portfolio of missions to explore our solar system and universe. It advances development of our next great outer planets mission – the long awaited visit to Jupiter's moon Europa.

We remain committed to studying our home planet and the universe, but are reshaping our focus within the resources available to us. While some planned missions in Earth science will not go forward, this budget is not far from where we have been in recent years. It enables our wide ranging science work on many fronts, which continues to lead the world in its size, scope, and scientific output.

While we are ending our mission to an asteroid, known as the Asteroid Redirect Mission, many of the central technologies in development for that mission, such as solar electric propulsion, will continue, as they constitute vital capabilities needed for future human deep space missions. Our commitment to breakthroughs on many fronts in space technology remains strong.

NASA remains commited to conducting world-class Aeronautics research and development, and we will continue to develop the next generation technologies to improve air travel and air traffic management, including a focus on making supersonic commercial air travel a reality once again.

While we will no longer operate a formal Office of Education, we will continue to leverage our unique assets to further advance our Nation's education goals. NASA remains committed to engaging the next generation of explorers, indeed learners of all ages, to maintain our competitiveness now and for generations to follow.

In his speech to both houses of Congress, the President said, "American footprints on distant worlds are not too big a dream." NASA is already working toward that goal, and we look forward to the amazing

MESSAGE FROM THE ADMINISTRATOR (ACTING)

milestones this budget will help us reach, and to continuing America's leadership in achieving long-term goals in space.

This budget reflects tough choices within today's constrained fiscal environment, but we are confident and optimistic that as NASA leads the world in space, it also can lead the way in a more effective, modern government. Our nation needs NASA more than ever. The agency's work every single day is vitally important, and we look forward with this budget to delivering continued great value for the taxpayer.

Robert M. Lightfoot, Jr.

Administrator (Acting)

BUDGET HIGHLIGHTS

The President's strong support and vision for NASA are reflected in the FY 2018 President's Budget, which will drive new breakthroughs in science and technology while ensuring that we maintain our continuity of purpose. NASA's historic and enduring purpose is captured in three major strategic thrusts: Discover, Explore, Develop. 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 aeronautics and space systems that allow American industry to increase market share and create new markets, on Earth and increasingly in the near-Earth region of space.

NASA conducts its missions in support of and aligned to 6 major National strategic themes:

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

NASA's discoveries literally 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 and 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 in aeronautics 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 these innovations.

One of NASA's core missions is to expand scientific knowledge. Currently, we do this by tackling some of the world's greatest questions: Are we alone? How does our planet work? 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 because of the visibility and national-level importance space efforts have represented. As a result, the Agency plays 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 aid 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. The ISS took fresh impetus from the addition of Russia to the partnership at the end of the Cold War.

Enhancing National Security and the Industrial Base

NASA was established at the dawn of the Cold War with a very specific strategic and national power projection mission. Today, the security environment has evolved to include more divergent and diffuse threats and actors. With more nations having access to space and space technology come challenges as well as opportunities. New regional alliances and non-state players also challenge traditional U.S. relationships on Earth and in space. Of particular relevance are the assertion of national power in space and the increasing global competition in advanced science and technology. Because of NASA's role in the international community, it can help national security leaders manage global risks.

BUDGET HIGHLIGHTS

NASA also contributes to the Nation's security, driving technology and innovation using the country's vast intellectual, economic, and industrial base to contribute to our unique challenges. NASA also engages new and existing U.S. companies and academia, supporting and growing the national industrial base shared by many other government agencies.

Catalyzing Economic Development and Growth

NASA has always been a driver of national economic development and growth. In fact, our founding charter calls out this important theme and historically, over 80 percent of our funds have been spent outside the Agency.

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 aircraft development represent a rough yardstick and benchmark of national capability across a wide spectrum of activities.

Overall, recognizing the growth of technologies and innovations increasing outside of the Agency, NASA is instituting a robust partnership and acquisition strategy, in part focused on leveraging and collaborating with the private sector and academia to harness their innovations for our missions.

Addressing Societal Challenges

NASA strives to maintain its importance, utility, and relevance to the U.S. public. We do this by tackling significant societal challenges and providing invaluable benefits to citizens. The scope and nature of the challenges that NASA seeks to address have changed over time. Originally tied to supporting national security and improving the quality of life with advances in aeronautics, communications satellites, and Earth remote sensing, our mandate is now much broader. We seek to address challenges associated with: data gathering and research to improve prediction of weather, climate, and natural hazards; advancing the state of technology R&D across a spectrum of fields, including aeronautics; developing launch, space transportation and human spaceflight capabilities; cybersecurity; gathering of data regarding our home planet to improve and protect life; planetary/heliophysics/astrophysics questions; and improving U.S. national innovation capacity. NASA also addresses civilization-level challenges to society research and discoveries that address the very nature of life, its ability to adapt outside our planet, and its origin, possible diversity, and future.

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. 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 in part due to our ability to inspire and create access to challenges that are out of this world. A core component of national power is a nation's technical workforce, responsible for developing many of the innovations that have contributed to U.S. productivity gains over the last century. In February 2017, NASA announced the discovery of the largest batch of Earth-size, habitable-zone planets around a single star. The announcement was downloaded over 4 million times, and NASA fielded over 10,000 questions via social media. With over 10 million views on the mission page, and 42% of all government website traffic going to NASA during the historic flyby. The Agency similarly inspired millions during Scott Kelly's yearlong stay aboard the ISS.

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.

Connecting Strategy and Budget

NASA achieves its strategic goals through its flight missions, research, and enabling capabilities. NASA's management and budget are organized to efficiently carry out the agency's mission.

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

NASA's Science account funds on-going discovery and exploration of our planet, other planets and planetary bodies, our star system in its entirety, and funds observations out into our galaxy and 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. The FY 2018 budget request for Science is $5,711.8 million.

This budget reinvigorates robotic exploration of the solar system, including funding for a Europa Clipper mission to fly repeatedly by Jupiter's icy ocean moon Europa. It provides full funding for launch in 2018 of the InSight mission to study the deep interior of Mars, the Mars 2020 mission, and the recently selected Discovery asteroid missions (Lucy and Psyche).

Webb, a successor to the Hubble telescope, is on schedule for its October 2018 launch. The request also funds formulation of the Wide Field Infrared Survey Telescope (WFIRST) mission, the next major observatory beyond Webb and the highest-priority large mission in the Decadal Survey. Astrophysics Explorer missions in formulation and development include the Transiting Exoplanet Survey Satellite (TESS), and the Imaging X-Ray Polarimetry Explorer (IXPE). NICER, launching to the ISS in 2017 as part of an innovative use of the platform for SMD objectives, will study the extraordinary gravitational, electromagnetic, and nuclear-physics environments of neutron stars. The request also includes funding for the Stratospheric Observatory for Infrared Astronomy (SOFIA), which will be subject to the 2019 Senior Review for Astrophysics.

NASA continues to learn more about Earth. The Sustainable Land Imaging program will provide U.S. users with high-quality, global, land imaging measurements that are compatible with the existing 44-year Landsat record; that will address near- and longer-term issues of continuity risk; and that will evolve flexibly and responsibly through investment in, and introduction of, new sensor and system technologies. This budget supports launch of Landsat 9 as early as FY 2021. The request fully funds Ice, Cloud, and land Elevation Satellite (ICESat-2); Gravity Recovery and Climate Experiment (GRACE-FO); Surface Water and Ocean Topography (SWOT); NASA-ISRO Strategic Aperture Radar (NISAR); and many other future Earth Science missions.

The request fully funds several major missions to advance our understanding of the Sun and its impact on the Earth, including Solar Probe Plus (SPP) and Solar Orbiter Collaboration (SOC). The request also funds the Ionospheric Connection Explorer (ICON) and Global-scale Observations of the Limb and Disk (GOLD) Explorer missions. 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, while GOLD will measure densities and temperatures in Earth's thermosphere and ionosphere. The request includes NASA work in support of interagency space weather efforts outlined in Space Weather Action Plan and Space Weather Strategy.

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 will implement the recommendations from a recent study of the National Academies that concluded that, due to recent technological progress in both private sector and through federal investments, these small satellites are suitable to address specific high-priority science goals. A targeted $70 million per year investment strategy will focus 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. This initiative will also leverage and align with investments by the Space Technology Mission Directorate (STMD).

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.

It 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 while minimizing negative impacts on the environment. The FY 2018 budget request for Aeronautics is $624.0 million.

The FY 2018 budget request for NASA Aeronautics will demonstrate and validate concepts that enable breakthroughs in the speed and efficiency of aircraft through cutting edge research into new aircraft shapes and propulsion systems. The request supports development of a supersonic X-plane, referred to as the Low Boom Flight Demonstrator (LBFD), scheduled for first flight in FY 2021. The LBFD will demonstrate quiet supersonic flight over land, which will ultimately open a new market to U.S. industry. Also, NASA will continue to advance new fuel efficient subsonic aircraft configurations that can reduce fuel consumption by 50 percent while also dramatically reducing noise. NASA will also continue exploring new hybrid and all electric propulsion technologies including a flight demonstration of a general aviation scale all electric X-plane.

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 conduct a series of flight tests that will demonstrate new concepts and technologies that will increase the rate of arrivals and departures. NASA Aeronautics is developing key technologies and standards that will enable safe operations of unmanned aircraft systems (UAS) in the Nation's airspace including low altitude operations of small UAS. The request also supports a healthy hypersonic research effort, coordinated with the Department of Defense (DoD), to leverage flight test data that supports NASA's research while simultaneously reducing risk and enhancing effectiveness of DoD's programs.

BUDGET HIGHLIGHTS

SPACE TECHNOLOGY DRIVES INNOVATION AND EXPLORATION

Space Technology rapidly develops, demonstrates, and infuses revolutionary, high-payoff technologies through transparent, collaborative partnerships, expanding the boundaries of the aerospace enterprise. NASA's space technology feeds missions that strengthen our national security and the industrial base while contributing to economic development and growth. These transformative technologies also enable NASA's missions by reducing cost and complexity while increasing capabilities, and often have broad application within American industry and other government agencies. Technology drives innovation and exploration by expanding utilization of near-Earth space, developing efficient and safe transportation through space; increasing access to planetary surfaces; enabling humans to live and explore beyond low Earth orbit; enabling the next generation of Science missions; and growing the U.S. industrial and academic base to continue the Nation's economic leadership. The FY 2018 budget request for Space Technology is $678.6 million

The FY 2018 budget continues development of high-powered solar electric propulsion technologies that will enable extremely efficient orbit transfer and accommodate increasing power demands for satellites. The Agency plans to incorporate high power solar electric propulsion technology in its human exploration architecture for deep space missions. In addition, over the next year, Space Technology will conduct several in-space demonstrations including a deep space atomic clock for advanced navigation and flight testing of a high performing propellant alternative to highly toxic hydrazine. Space Technology will complete flight hardware development for the Laser Communications Relay Demonstration and four technologies for the Mars 2020 mission. Industry partners will conduct In-Space Robotic Manufacturing & Assembly ground tests to reduce the risk associated with robotic manipulation of structures and remote manufacturing of structural trusses. NASA will also restructure its investment in satellite servicing technology to reduce its cost and better position it to support a nascent commercial satellite servicing industry.

In addition, Space 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. Space Technology will continue to prioritize "tipping point" technologies through public private partnerships and early-stage innovation with over 600 awards to small businesses, private innovators, and academia to spark new ideas for the benefit of U.S. aerospace and high tech industries. As efforts complete, appropriate technologies will be transferred and commercialized to benefit a wide range of users to ensure the nation realizes the full economic value and societal benefit of these innovations.

EXTENDING HUMAN PRESENCE INTO THE SOLAR SYSTEM

One of NASA's key goals is opening the space frontier. With the objective of extending human presence deeper into the solar system through a sustainable human and robotic spaceflight program, the Agency has developed 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.

Exploration programs continue to develop robust capabilities intended to ensure flexibility in destination, affordability, and sustainability in the Nation's human spaceflight program leading initially towards a cislunar presence and missions to Mars and beyond. NASA will evolve these core capabilities through continued technical advancements maintaining our leadership role in human spaceflight. The agency has developed a phased approach for this activity, starting with ISS and progressing to cislunar space and beyond. The Exploration account develops systems and capabilities required for deep-space exploration. The FY 2018 budget request for Exploration is $3,934.1 million. NASA plans to explore approaches for reducing the costs of exploration missions to enable a more expansive exploration program.

The Exploration Systems Development programs are creating the first components of this architecture for human exploration beyond low Earth orbit. Orion, the deep space crew vehicle, will take us to cislunar space atop the Space Launch System (SLS), the deep space rocket supported by Exploration Ground Systems (EGS) for integration and launch. NASA will conduct deep-space missions to test systems and concepts, paving the way for long-duration human space exploration while conducting a variety of science missions. Opening the space frontier requires expansion of technical and scientific knowledge to tackle complex problems and creative new solutions to meet demands never before encountered by humans. NASA must understand and mitigate the effects of long-term human exposure to space and the Human Research Program (HRP) is conducting research on the ISS toward this end. NASA's Advanced Exploration Systems (AES) is also developing technologies and maturing systems required for deep-space missions by identifying and pioneering new solutions to technical and human challenges.

LIVING AND WORKING IN SPACE

The Space Operations Account funds critical NASA capabilities that create pathways for discovery and human exploration of space. NASA is making discoveries, creating economic and commercial markets and applications, while addressing societal challenges.

These capabilities include research on, operation of, and 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. The FY 2018 budget request for Space Operations is $4,740.8 million.

ISS is an unparalled global project that exhibts National leadership and engages the pubic 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 2018, 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's Missions and Discoveries Strengthen the Nation's STEM Education and Future Workforce

NASA's programs continue to share the excitement of the Agency's science and engineering missions with learners, educators, and the public. NASA's discoveries and the many resources available about it online and in numerous public outreach and engagement activities across our missions ensures that students and educators will have access to NASA information and the work of the top scientists and engineers in government.

NASA remains committed to providing internships and fellowships and using its unique capabilities, resources, and expertise to inspire the future STEM workforce. The FY 2018 budget request terminates the Office of Education, given its challenges in implementing a NASA-wide education strategy and current fiscal constraints.

Managing NASA's People and Capabilities to Safely Accomplish our Mission

NASA's mission support directly enables NASA's portfolio of missions in aeronautics and space exploration. 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 2018, NASA will strengthen cybersecurity capabilities, safeguarding critical systems and data. 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 FY 2018 budget request for Safety, Security, and Mission Services is $2,830.2 million.

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 2018, 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. The FY 2018 request for Construction and Environmental Compliance and Restoration is $496.1 million.

NOTES ON THE BUDGET

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 2018 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. 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

NASA presents the FY 2018 budget request in full-cost, where all project costs are allocated to the project, including labor funding for the Agency's civil service workforce. Note that budget figures in tables may not sum because of rounding.

OUTYEAR FUNDING ASSUMPTIONS

At this time, funding lines beyond FY 2018 should be considered notional.

EXPLANATION OF FY 2016 AND FY 2017 BUDGET COLUMNS

FY 2016 Column

The FY 2016 Actual column in budget tables is consistent with the approved Agency spending plan (i.e. operating plan) control figures at the time of the budget release. Budget structure and figures are adjusted for comparability to the FY 2017 request.

All FY 2016 budget figures represent appropriations reflect funding amounts specified in the July 2016 Operating Plan per P.L. 114-113.

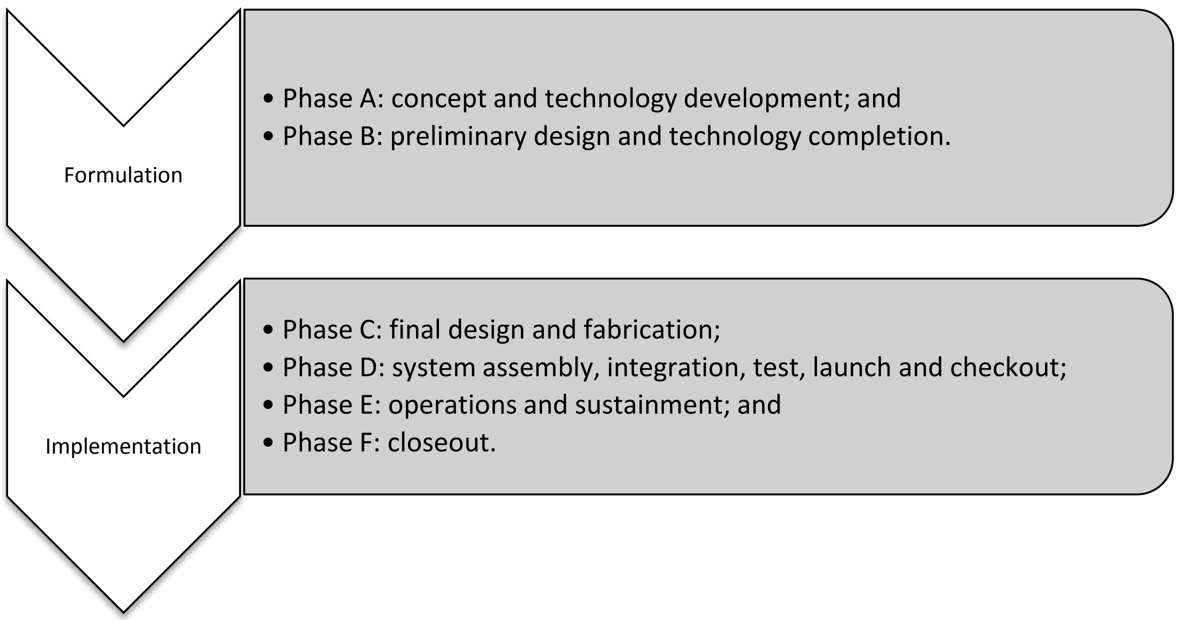
FY 2017 Column

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. The numbers do not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million. As of budget release, an initial FY 2017 operating plan has not been developed and submitted to the Congress. As a result, budget tables show only accounts, themes, or programs where appropriations are called out in P.L. 115-31. Tables also show tentatively planned FY 2017 funding for projects in development (subject to change pending finalization of the FY 2017 initial operating plan).

EXPLANATION OF BUDGET TABLES AND SCHEDULES

EXPLANATION OF PROJECT SCHEDULE COMMITMENTS AND KEY MILESTONES

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



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

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

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

EXPLANATION OF BUDGET TABLES AND SCHEDULES

Formulation

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

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

EXPLANATION OF BUDGET TABLES AND SCHEDULES

Implementation

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

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

EXPLANATION OF BUDGET TABLES AND SCHEDULES

Other Common Terms for Mission Planning

Term	Definition
Decision Authority	The individual authorized by the Agency to make important decisions on programs and projects under their authority.
Formulation Authorization Document	The document that authorizes the formulation of a program whose goals will fulfill part of the Agency's Strategic Plan and Mission Directorate strategies. This document establishes the expectations and constraints for activity in the Formulation phase.
Key Decision Point (KDP)	The lifecycle gate at which the decision authority determines the readiness of a program or project to progress to the next phase of the life cycle. The KDP also establishes the content, cost, and schedule commitments for the ensuing phase(s).
Launch Manifest	This 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 7120.5E NASA Space Flight Program and Project Management Requirements: https://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.

SCIENCE

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Earth Science	1926.6	--	**1754.1**	1769.1	1769.1	1769.1	1769.1
Planetary Science	1628.0	--	**1929.5**	1921.4	1916.4	1911.4	1911.4
Astrophysics	762.4	--	**816.7**	1045.8	1153.2	1200.6	1200.4
James Webb Space Telescope	620.0	569.4	**533.7**	304.6	197.2	149.8	150.0
Heliophysics	647.2	--	**677.8**	687.8	692.8	697.8	697.8
Total Budget	**5584.1**	**5764.9**	**5711.8**	**5728.7**	**5728.7**	**5728.7**	**5728.7**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

SCIENCE

Planetary Science

Astrophysics

James Webb Space Telescope

SCIENCE

Heliophysics

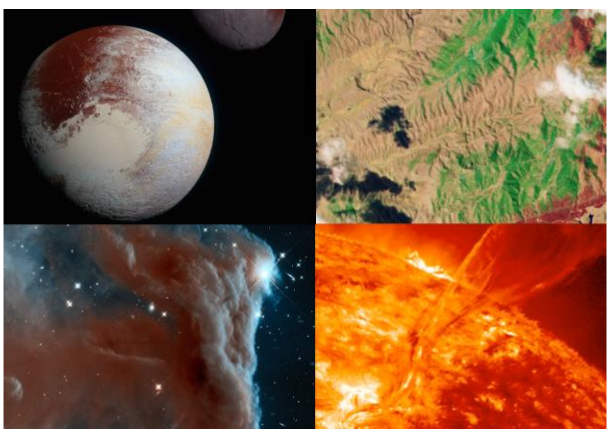
SCIENCE

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Earth Science	1926.6	--	**1754.1**	1769.1	1769.1	1769.1	1769.1
Planetary Science	1628.0	--	**1929.5**	1921.4	1916.4	1911.4	1911.4
Astrophysics	762.4	--	**816.7**	1045.8	1153.2	1200.6	1200.4
James Webb Space Telescope	620.0	569.4	**533.7**	304.6	197.2	149.8	150.0
Heliophysics	647.2	--	**677.8**	687.8	692.8	697.8	697.8
Total Budget	**5584.1**	**5764.9**	**5711.8**	**5728.7**	**5728.7**	**5728.7**	**5728.7**
Change from FY 2017			**-53.1**				
Percentage change from FY 2017			**-0.9%**				

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



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 inform policy, 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 deliver answers to profound questions, such as:

- How did our solar system originate and change over time?
- How did life originate, and are we alone?
- How and why are Earth's climate and the environment changing?
- How did the universe begin and evolve, and what will be its destiny?
- What drives variations in the Sun, and how do these changes affect the solar system and drive space weather?

NASA science programs address fundamental research about the universe and our place in it. Fundamental research covers all areas of science and the intersections thereof when addressing questions such as "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 and natural resource managers. NASA is also working to improve its operations and is increasingly launching its science missions on schedule and on budget. Our discoveries continue to rewrite textbooks; inspire children to pursue careers in science, technology, engineering, and mathematics (STEM); and demonstrate U.S. leadership worldwide.

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 over 30 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 that process, NASA must also adapt the science-based decadal survey recommendations to actual budgets, existing technological capabilities, national policy, partnership opportunities, and other programmatic factors. Assessments of how this budget request supports the recommendations of the most recent decadal surveys are included below.

EXPLANATION OF MAJOR CHANGES IN FY 2018

This budget reinvigorates robotic exploration of the solar system by providing $1.9 billion for Planetary Science, including funding for a Europa Clipper mission to fly repeatedly by Jupiter's icy ocean moon Europa. It also provides full funding for the Mars 2020 mission.

The budget also supports initiatives that use smaller, less expensive satellites and/or public-private partnerships to advance science in a cost-effective manner. An SMD-wide CubeSat/SmallSat initiative will implement the recommendations from a recent study of the National Academies that concluded that, due to recent technological progress in both private sector and through federal investments, these small satellites are suitable to address specific high-priority science goals. A targeted $70 million per year investment strategy will focus 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. This initiative will also leverage and align with investments by the Space Technology Mission Directorate (STMD).

The budget provides $1.8 billion for a focused, balanced Earth science portfolio that supports the priorities of the science and applications communities. Given budget constraints and higher priorities within Science, the request terminates five Earth Science missions —Pre-Aerosol, Clouds, and ocean Ecosystem (PACE), Orbiting Carbon Observatory (OCO)-3, Radiation Budget Instrument (RBI), Deep Space Climate Observatory (DSCOVR) Earth-viewing instruments, and Climate Absolute Radiance and Refractivity Observatory (CLARREO) Pathfinder—and reduces funding for Earth science research grants. Except for the CLARREO Pathfinder (a technology demonstration for the CLARREO mission), the terminated missions were not identified as high priority (Tier 1) in the 2007 Earth Science Decadal Survey. The budget also terminates the Carbon Monitoring System, a project that NASA developed in 2010 in response to congressional direction.

The budget supports all planned activities within the Science Mission Directorate's STEM Science Activation project, unchanged by the proposed termination of the NASA Office of Education (OE). The budget for Science does not support OE programs.

SCIENCE

ACHIEVEMENTS IN FY 2016

SCIENCE RESULTS

In Planetary Science, the Cassini mission had numerous exceptional accomplishments. In a January ring-grazing orbit, Cassini obtained the closest-ever view of Saturn's moon Daphnis. Gravity from this little moon raises waves in the nearby rings in both directions (showing even little bodies can have a big impact on ring structure). Cassini also made observations of the moon Pan at eight times the resolution ever seen before. The odd-looking satellite has captivated the public, who described it as adorable, doughy, and delicious because of its ravioli-like shape. Like a snowball rolling along and picking up more snow, Pan is accreting material around its bulging mid-section. Scientists reported that the south polar region of the moon Enceladus is warmer than expected just a few feet below the icy surface. This suggests the ocean of liquid water may be only a couple miles beneath this region.

In Astrophysics, scientists using NASA's Spitzer Space Telescope, along with observations from ground-based telescopes, discovered a system of seven Earth-sized planets around the nearby ultra-cool dwarf star Transiting Planets and Planetesimals Small Telescope (TRAPPIST)-1. A team of scientists measured 34 separate eclipses from the seven planets over a period of 20 days. The Spitzer observations preceded 75 days of near-continuous observations by the Kepler Space Telescope. Measurements of the mass and size of these planets indicate that at least six and perhaps all seven planets are likely to be rocky in composition. Three of these planets are located in the habitable zone, the area around the parent star where a rocky planet is most likely to have liquid water on its surface. The discovery sets a new record for greatest number of habitable-zone planets found around a single star outside our solar system. All of these seven planets could have liquid water—key to life as we know it—under the right atmospheric conditions, but the chances are highest with the three in the habitable zone.

A steady pace of important science results continued in the past year. In Earth Science, a new study of the first year of observational data from NASA's Soil Moisture Active Passive (SMAP) mission provided significant surprises that will help in modeling Earth's climate, forecasting our weather and monitoring agricultural crop growth. Scientists used SMAP measurements to estimate how long it takes for soil moisture from rainfall to dissipate in the top two inches of Earth's topsoil. The team found that, on average, about one-seventh of the amount of rain that falls is still present in the topmost layer of soils three days later. This persistence is greatest in Earth's driest regions. Although the top two inches of topsoil contains an infinitesimal fraction of our planet's water, that tiny amount plays a disproportionately critical role in the cycling of water, which has major impacts in everything from agriculture, weather, climate and even the spread of disease. Among the study's other findings, the team found that SMAP data identify regions where the rate at which soils dry may influence weather and affect and amplify droughts and floods. When moisture evaporates from wet soil, it cools the soil, but when the soil gets too dry, that cooling diminishes. This, in turn, can lead to hotter weather and heat waves that extend and deepen drought conditions. Scientists had not directly studied such effects previously.

In Heliophysics, scientists directly observed magnetic reconnection for the first time in situ on October 16, 2015 when the four-spacecraft NASA Magnetospheric Multiscale (MMS) mission flew through an invisible maelstrom in space. Magnetic reconnection occurs when magnetic fields collide and re-align explosively into new positions, and it is one of the prime drivers of a host of explosive processes around the universe—from giant eruptions on the sun to events near black holes to how interstellar matter insinuates itself across the magnetic boundaries of our solar system. Magnetic reconnection also drives space weather much closer to home; we must protect robotic missions and astronauts by understanding our space environment and the constant dance of radiation and energy coursing through it. Thanks to its break-through technological advancements and complex orbits, MMS is the only mission capable of observing particle interaction at the temporal and spatial resolutions needed to see the fast and highly localized processes involved in magnetic reconnection. Since MMS began its prime mission phase in September 2015, the spacecraft have observed at least nine reconnection events in Earth's magnetosphere.

NASA highlights these and many other scientific results in the pages that follow.

COST AND SCHEDULE PERFORMANCE

The majority of Science missions continue to demonstrate good cost and schedule performance. NASA launched four Science missions since the release of the FY 2017 Budget Request. The U.S. contribution to Japan's ASTRO-H mission, launched in February 2016, was 59 percent over its original 2010 budget. NASA launched the Origins, Spectral Interpretation, Resource Identification, Security - Regolith Explorer (OSIRIS-REx) in September 2016; it was 20 percent under budget. NASA launched the Cyclone Global Navigation Satellite System (CYGNSS) five months early in December 2016; it was 15 percent under budget. Finally, NASA launched the Stratospheric Aerosols and Gas Experiment (SAGE-III) to the International Space Station (ISS) in February 2017, about 2.5 years late and 42 percent over its original 2012 budget. The net underrun for development of these four projects, compared to their original commitments, was 12 percent.

Five Science missions under development for more than one year remain within their original cost and schedule estimates: Ionospheric Connection Explorer (ICON), Gravity Recovery and Climate Experiment Follow-On (GRACE-FO), Transiting Exoplanet Survey Satellite (TESS), Solar Probe Plus (SPP), and Solar Orbiter Collaboration (SOC).

NASA confirmed five new Science missions to enter development during the past year: Global Ecosystem Dynamics Investigation (GEDI), Mars 2020 rover, Tropospheric Emissions: Monitoring of Pollution (TEMPO), Surface Water and Ocean Topography (SWOT), and NASA-ISRO Synthetic Aperture Radar (NISAR). These missions remain on track.

As reported last year, the Interior Exploration using Seismic Investigations Geodesy and Heat Transport (InSight) mission to Mars, and NASA's contribution to the European Space Agency (ESA)'s Euclid mission, have exceeded their commitments. The James Webb Space Telescope (Webb) and the Ice, Cloud, and land Elevation Satellite (ICESat)-2 experienced previous cost growth, but none since they were re-baselined in 2013 and 2015 respectively.

WORK IN PROGRESS IN FY 2017

NASA is operating about 60 Science missions with over 70 spacecraft, most of which involve collaboration with international partners or other U.S. agencies. Work on over 40 missions in formulation and development continues. 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, NASA field Centers, industry, and other government agencies.

On December 9, 2016, NASA released an Announcement of Opportunity (AO) for the next New Frontiers mission. Two new Discovery missions (Lucy and Psyche) are now in formulation, after NASA selected them on January 4. On February 14, 2017, NASA released an AO for the third Earth Venture Suborbital competition. NASA will select the next Heliophysics Small Explorers (SMEX) mission during FY 2017, as well as releasing AOs for the Solar Terrestrial Probe (STP)-5 mission (called the Interstellar

Mapping and Acceleration Probe (IMAP)) and a Martian Moons eXploration (MMX) instrument. Work on these opportunities is ongoing.

The Cassini mission will conclude when the spacecraft plunges into Saturn on September 15, following many months of orbits passing between, and entirely inside of, Saturn's rings. The images and science return from these unprecedented orbits have been phenomenal, and there will be intense scientific and public interest in September.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

NASA plans to launch many new Science missions by the end of FY 2018, including ICON, GRACE-FO, InSight, ICESat-2, TESS, and SPP. The James Webb Space Telescope (Webb) will complete its assembly and testing, and NASA will ship Webb to the launch site in French Guiana for launch in October 2018.

NASA will award a Heliophysics Mission of Opportunity in FY 2018. NASA will also release AOs for a Heliophysics Explorer mission and Mission of Opportunity, and for Earth Venture Instruments (EVI-5).

Themes

EARTH SCIENCE

From space, NASA satellites can view Earth as a planet and enable the study of it as a complex, 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. Through partnerships with agencies that maintain forecasting and decision support systems, NASA improves national capabilities to predict climate, weather, and natural hazards; manages resources; and inform the development of environmental policy.

The primary recommendations of the National Academies' 2007 Decadal Survey for Earth Science and Applications from Space (ESAS), which informed the 2010 Climate-Centric Architecture plan, were:

- Complete the ongoing program. All legacy Earth Science missions identified in the 2007 ESAS Decadal [Jason-2 (2008), OCO (2009, 2014), Glory (2011), Aquarius (2011), Suomi-NPP (2011), Landsat 8 (2013)] have been developed and launched. OCO-1 and Glory suffered launch vehicle failures. OCO-2 was then developed and successfully launched. The FY 2018 request fully funds operations and science exploitation of these on-orbit missions.
- Continue the balance between flight and non-flight activities. The FY 2018 request fully supports this recommendation.
- Increase the scope and fraction of the Earth Science Technology program. The FY 2018 request fully supports this recommendation, in part through funding for the In-Space Validation of Earth Science Technologies (InVEST), which is part of the SMD-wide CubeSat/SmallSat initiative, leveraging technological progress across the science disciplines.
- Establish a robust program of competed Venture-class missions. The FY 2018 request fully supports this recommendation. It funds all EV missions selected under previous solicitations. It also fully

funds the planned future solicitations in all three strands on schedule (4-year cadence for EV-Suborbital and EV-Mission, 18-month cadence for EV-Instrument).

- Aggressively develop a number of future strategic missions. The 2007 ESAS Decadal identified four systematic Tier-1 missions [Soil Moisture Active Passive, ICESat-2, Deformation, Ecosystem Structure, and Dynamics of Ice (DESDynI), CLARREO] for launch by 2013. The Decadal also identified five Tier-2 missions [Hyperspectral Infrared Image (HyspIRI), Surface Water Ocean Topography (SWOT), GEOstationary Coastal and Air Pollution Events (GEO-CAPE), Active Sensing of CO2 Emissions over Nights, Days, and Seasons (ASCENDS), and Aerosol-Cloud-Ecosystem (ACE)] by 2016. Those Decadal recommendations assumed unrealistically low mission costs and overly optimistic budgets, rendering the target launch dates unachievable. NASA launched the Soil Moisture Active Passive mission in January 2015, and the Decadal-identified continuity SAGE-III mission in February 2017. The FY 2018 Budget request fully funds ICESat-2 (2018), and the radar portion of DESDynI (NISAR, 2022). The request also funds completion of high-priority, Decadal-identified, continuity missions: Landsat-9 (2021), GRACE-FO (2018, deferred to Tier-3 in the Decadal), and SWOT (2022). These dates are consistent with the latest Key Decision Point decisions and Agency commitments. The budget assumes termination of the PACE mission (previously planned for 2022) and technology demonstration instruments for risk reduction for CLARREO Pathfinder (previously planned for launch to the ISS in 2019).

NASA asks the Earth Science Advisory Committee for input regarding budget priorities, 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. NASA is continuing the exploration of Mars, and is planning the next Mars rover, which will launch in 2020 and address key questions about the potential for life on Mars. NASA plans to build on this and other missions as it continues to develop and pursue its science, technology and human exploration objectives. NASA is heading toward the first fly-by of a Kuiper Belt Object, operating spacecraft at Saturn, Jupiter, the largest asteroid Ceres, and the Moon, and has begun the journey to a potentially hazardous asteroid, Bennu, to capture and return 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. NASA adjusted the cost cap of the latest AO to $450 million FY2015 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. The out-year budget supports an approximate 30-month cadence for future launches.
- Continue New Frontiers with a $1 billion cost cap, and select two new missions by 2022. This budget supports the adjusted cost cap for the AO released in February 2017, which will select one new mission.
- 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.

- Continue missions in development and flight, subject to senior review. This budget fully supports all missions selected for development, all missions in prime operations, and all extended missions ranked highly in the latest senior review.
- Increase research and analysis (R&A) spending by 5 percent above the FY 2011 budget level, and then 1.5 percent above inflation thereafter. The total R&A budget in FY 2011 was $208 million. This budget funds R&A programs at $229 million in FY 2018.
- Increase Planetary Technology spending to six to eight percent of the total division budget, including completion of the advanced Stirling radioisotope generators. This budget funds technology at roughly 12 percent, including approximately $20 million for Planetary Science's contribution to the SMD CubeSat/SmallSat initiative.
- 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, 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 regarding budget priorities, to ensure that our proposed programs maximize scientific productivity, within the general framework established by the National Academies.

ASTROPHYSICS

The theories of the past century about the physical universe related to the origin of the universe, black holes, and dark matter and dark energy challenge scientists and NASA to use observations from space to test conventional understanding of fundamental physics. 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, New Worlds, New Horizons (Astro2010) 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 2018, continued operations of SOFIA at least through 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 spacecraft failure, this budget supports development of replacement hardware for 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 large missions, small 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 supports formulation of a 2.4-meter version of WFIRST, incorporating the Astrophysics Focused Telescope Assets (AFTA) with starshade compatibility and a potential coronagraph demonstration instrument. This request supports the continuation of Phase A formulation activities, the potential transition to Phase B in October 2017, and launch as early as 2025.
- 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 2014, 2016/2017, and 2018/2019.
- Launch the Laser Interferometer Space Antenna (LISA) by 2025. This budget supports studies 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 2028.
- Invest in a New Worlds technology development and precursor science program for a 2020s mission to image habitable rocky planets. This budget supports the development of technology and conduct of precursor science required for a potential future mission to directly image and characterize habitable rocky exoplanets.
- 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 has and 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 the availability of the AFTA, 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."

NASA asks the Astrophysics Advisory Committee for input regarding budget priorities, to ensure that our proposed programs maximize scientific productivity, within the general framework established by the National Academies.

SCIENCE

JAMES WEBB SPACE TELESCOPE (WEBB)

Webb is a large, space-based astronomical observatory. The mission is a successor to the Hubble Space Telescope, extending beyond Hubble's discoveries by looking into the infrared spectrum where unlike shorter wavelengths, the highly red-shifted early universe is observable, and relatively cool objects like protostars and protoplanetary disks strongly emit light unobscured by dust. Webb is progressing well toward its scheduled launch in October 2018, within the cost and schedule baseline NASA established in 2011.

HELIOPHYSICS

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. 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:

- <u>Maintain and complete the current program</u>. 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, SPP by 2018, and continued current funding of the Research program. Van Allen, IRIS, and MMS have launched, and SPP is on schedule. NASA will launch the ESA-led SOC mission in early FY 2019.
- <u>Implement the DRIVE (Diversify, Realize, Integrate, Venture, Educate) initiative</u>, 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.
- <u>Accelerate and expand the Heliophysics Explorer Program, resulting in an increase to the cadence of competed missions to one launch every 2-3 years, starting in roughly 2018</u>. This budget supports the launch of ICON and GOLD in 2017/2018 respectively, six years after the previous Explorer launch. The notional out-year budgets, if realized, would support the next launch around 2022.
- <u>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</u>. This budget assumes an AO release in 2017 for a launch of an IMAP mission in about 2024. NASA will initiate Science and Technology Definition Team (STDT) activities in preparation for two subsequent AOs for multi-spacecraft missions. NASA will competitively select these and all future STP strategic missions from principal investigator-led proposals. The program will also directly benefit from current investments in the CubeSat/SmallSat initiative.
- <u>Implement a large Living with a Star (LWS) mission to study Global Dynamic Coupling with a launch in 2024</u>. NASA will initiate an STDT to leverage technical advancements and enable cost-effective solutions, in anticipation of an AO in 2018.

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 regarding budget priorities 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 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Earth Science Research	477.7	--	**406.7**	435.1	441.1	459.7	477.8
Earth Systematic Missions	914.6	--	**778.0**	787.1	755.0	708.7	680.4
Earth System Science Pathfinder	233.6	--	**264.5**	243.8	256.0	271.5	268.3
Earth Science Multi-Mission Operations	192.4	--	**196.5**	194.1	200.7	208.6	218.6
Earth Science Technology	60.7	--	**60.4**	59.7	63.6	65.9	67.8
Applied Sciences	47.6	--	**47.9**	49.3	52.8	54.7	56.3
Total Budget	**1926.6**	**--**	**1754.1**	**1769.1**	**1769.1**	**1769.1**	**1769.1**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

Earth Science

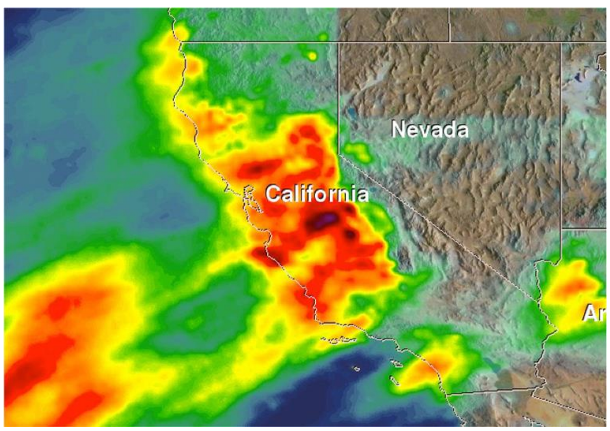
EARTH SCIENCE RESEARCH

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Earth Science Research and Analysis	347.2	--	**287.8**	296.5	299.6	313.7	309.1
Computing and Management	130.5	--	**118.9**	138.6	141.4	146.0	168.7
Total Budget	**477.7**	**--**	**406.7**	**435.1**	**441.1**	**459.7**	**477.8**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



An atmospheric river ("Pineapple Express") delivered over five inches of rainfall in parts of California during January 3-10, 2017 as viewed by Global Precipitation Measurement (GPM) data.

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 in order 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; and
- 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. NASA's Earth Science Research program is critical to the advancement of the interagency U.S. Global Change Research Program (USGCRP). NASA's Earth Science Research program also makes extensive contributions to international science programs, such as the World Climate Research Programme.

EXPLANATION OF MAJOR CHANGES IN FY 2018

NASA transferred $15M of FY 2018 High End Computing Capability (HECC) funds to the Construction and Environmental Compliance and Restoration (CECR) account in support of modular supercomputer facility construction. See the CECR section of this document for more information. In light of budget constraints and higher priorities within the Science budget, the request reduces funding for Earth Science competed research awards and eliminates funding for new Carbon Monitoring System awards.

ACHIEVEMENTS IN FY 2016

The Earth Science Subcommittee of the NASA Advisory Council Science Committee determined in September 2016 that NASA remained on track in its annual performance towards the achievement of the research goals relevant to the six science focus areas described in the previous section. Below are examples of the scientific progress reported in FY 2016.

The Global Ozone Chemistry and Related trace gas data records for the Stratosphere (GOZCARDS) provides information and access for the public on data on hydrogen chloride, water vapor, and ozone decline and recovery. This data set is a global long-term stratospheric Earth system data record, based on high-quality measurements from several NASA satellite instruments and the Canadian Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS) on SCISAT.

While emissions of nitrogen oxides have decreased over North America during the 2005-2010 period, the increased downwelling from the stratosphere and increased pollution from China offset the expected resulting tropospheric ozone decrease. A recent study reported that transport of ozone and its precursors from China had offset about 43 percent of the 0.42 Dobson unit reduction in free-tropospheric ozone over the western U.S. that was expected between 2005 and 2010, because of emissions reductions associated with federal, state, and local air quality policies.

With the use of satellite retrievals and surface observations of atmospheric methane, researchers found that U.S. methane emissions have increased by more than 30 percent over the 2002–2014 period. Researchers found the largest increase in the central part of the country; they could not attribute it to any specific source. The researchers concluded that these "top-down" derived emissions (i.e. emission estimates based on methane satellite observations) were far greater than estimated from the "bottom-up" approach that computes emissions as the product of activity rates.

EARTH SCIENCE RESEARCH

Earth's physical climate is changing and there are measurable impacts on Earth's biogeochemistry and ecosystems. Researchers used inputs from a variety of process-based biophysical models to examine the net balance of the three major gases that trap heat (carbon dioxide, methane, and nitrous oxide), which revealed that human-induced emissions of methane and nitrous oxide overwhelmingly surpass the ability of the land to absorb carbon dioxide emissions.

Researchers use remote sensing-derived tools and models to capture shifting climate and other ecosystem and habitat parameters, and improve natural resource management. For example, in order to build niche models of Atlantic Bluefin tuna habitats for use in better managing this species within a high-profile fishery, researchers used remote sensing-derived environmental data, such as chlorophyll-a fronts and concentration, sea surface current and temperature, and sea surface height anomaly. Defining key spatial and temporal habitats further helps in building spatially-explicit stock assessment models, thus improving the spatial management of bluefin tuna fisheries.

High-resolution lidar-derived biomass maps provided a valuable bottom-up reference to improve the analysis and interpretation of large-scale maps produced in carbon monitoring systems. Researchers developed a global gridded data product of agricultural carbon budgets, including crop- and animal-based food intake, crop biofuels, crop residues left on-field and used as feed, crop byproducts used as feed, livestock grazing, additions to food reserves, and food supply chain losses and waste.

Researchers used the Normalized Difference Vegetation Index (NDVI) data set to constrain estimates of net biome production (NBP) over Europe between 1982 and 2012, which revealed links to anomalies in heat and water transport controlled by interactions between the North Atlantic Oscillation and the East Atlantic Pattern. These results suggest that human alterations of land cover and management practices over the past century have resulted in a substantial increase of carbon exported from the land to the ocean.

The loss of Arctic sea ice and its effect on sea levels has important implications for defense and economic activity. The September 2015 seasonal minimum extent was the fourth lowest on record and reinforced the long-term downward trend. The nine lowest September sea ice extents in the satellite record have all occurred in the last nine years. Arctic winter maximum sea ice extents have also experienced a long-term downward trend, though smaller in magnitude. However, Antarctic sea ice has experienced a small increasing trend, with recent years experiencing record highs. The contrasting behavior of sea ice in the Antarctic is at a much lower level than the strong decrease observed in the Arctic, and is due to a stronger influence of natural variability in the region.

The processes controlling ice loss from the Greenland ice sheet continue to be the subject of intense focus. Multi-beam echo sounding observations revealed that marine-terminating glaciers are grounded deeper below sea level than previously measured, and are undercut by warm, salty Atlantic water, increasing iceberg calving, impacting ice front stability and, in turn, glacier mass balance. Researchers used ice-penetrating radar and a subglacial flow model to show that the connectivity of different regions influences how glacier velocity responds to variations in surface melting.

Landslide inventories are critical to support investigations of where and when landslides have and, may occur in the future; however, there is little information on the historical occurrence of landslides at the global scale. NASA scientists presented a new publicly available global landslide catalog (GLC), based on media reports, online databases, and other sources. Researchers also compared reported landslide events to precipitation estimates from Tropical Rainfall Measuring Mission (TRMM) to evaluate the co-occurrence of extreme precipitation and landslide activity. Of the 3,550 points considered in a subset of the GLC, approximately 60 percent of the reported landslides have daily precipitation exceeding the 95th percentile of precipitation calculated over a 14-year TRMM record for the same location.

Researchers used in-situ and satellite data to review the surface temperature of 235 lakes, on six continents, and discovered that threats to more than half of the world's freshwater supply by rising water temperatures. They found that lake temperatures are increasing at an average of 0.34°C each decade, which is a higher rate than seen in either the ocean or the atmosphere. The study projected that lakes will produce 4 percent more methane per decade over the next century and lake algal bloom outbreaks may increase by 20 percent.

Earth Surface and Interior (ESI) focus area investigators continued to advance understanding of interactions between hydraulic systems and solid-Earth deformation. Researchers used Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) data acquired in June 2009 and July 2012 to measure ongoing subsidence (gradual caving in or sinking of an area of land) near New Orleans, Louisiana. Researchers identified primary drivers of subsidence as groundwater withdrawal, and surficial drainage/dewatering activities, with high subsidence rates, also observed around some major industrial facilities and due to shallow compaction in highly localized areas. UAVSAR also captured subsidence in California's Sacramento-San Joaquin Delta. The study measured subsidence rates across Sherman Island averaging 1.3 cm/year with a systematic uncertainty of 0.3 cm/year, consistent with previous measurements at electric transmission line towers. Results have important implications for maintaining a reliable water supply for California and protecting the Delta ecosystem.

Key field campaigns implemented in FY 2016 include:

The Korea U.S.-Air Quality Study (KORUS-AQ) used observations from three research aircraft, eight ground sites, ships, and satellites to test air quality models and remote sensing methods, to prepare for future geostationary observations from satellite instruments focused on air quality over Asia, North America, and Europe.

The GPM-sponsored Olympic Mountains Experiment (OLYMPEX) collected precipitation observations in the Olympic Mountains in Washington from November 2015 through January 2016. OLYMPEX was one of the most comprehensive campaigns for GPM for validating rain and snow measurements in mid-latitude frontal systems moving from ocean to coast to mountains. Researchers will use OLYMPEX observations to investigate the optimal use of GPM precipitation observations in a range of hydrologic, weather forecasting, and climate process studies and products. For more information, go to https://pmm.nasa.gov/OLYMPEX.

The Salinity Processes in the Upper Ocean Regional Study 2 (SPURS-2) is a field campaign in a low salinity, rainy area of the eastern Tropical Pacific, and is a follow-up study to SPURS-1. SPURS-1 focused on a high salinity area in the North Atlantic Ocean during 2012-13. The purpose of both SPURS campaigns is to identify ocean processes that lead to the salinities observed by NASA's Aquarius and SMAP missions. As part of SPURS-2, a 20m schooner rigged sailing vessel called Lady Amber sailed June 2016 from Mexico to Honolulu, deploying 10 surface salinity drifters. In addition to this schooner, the Scripps Institution of Oceanography's research vessel R/V Roger Revelle, which sailed during August 2016, deployed three moorings, floats, gliders, as well as Conductivity-Temperature-Depth (CTD) and air-sea flux measurements.

During FY 2016, HECC started a pilot facility project to examine the feasibility to use ambient air to cool the computing systems. HECC is able to expand the computing facility using a modular system approach.

EARTH SCIENCE RESEARCH

The pilot project demonstrated higher energy efficiency, with the measured Power Usage Effectiveness of 1.06 compared to 1.7 for traditional cooling systems. The benchmarked computing throughput is 1.09 petaFlops (1.06 x 1,015 floating-point operations per second).

Scientific Computing significantly increased their operational capabilities to support key NASA science projects. The project installed an additional computational unit consisting of over 18,000 processor cores with a peak computing capacity of 0.72 petaFlops (0.72 x 1,015 floating-point operations per second). Scientific computing requires large amounts of storage, and to meet these needs, NASA integrated an increase in the overall storage capacity of 10 petabytes into the operational environment. To supplement the large-scale computational environment, Scientific Computing introduced the Advanced Data Analytics Platform (ADAPT), which is a high-performance NASA science cloud designed specifically for “Big Data” applications. Finally, Scientific Computing began to prototype the next generation combination of storage and computing systems designed for the future of data analytics.

Airborne Science conducted over 4,200 flight hours in support of Earth Science. Major campaigns included AfriSAR, GPM OLYMPEX/RADEX, KORUS-AQ, and Operation IceBridge, as well as the start of Earth Venture Suborbital-2 (EVS-2) investigation campaigns for Act-America, ATom, CORAL, NAAMES, OMG, and ORACLES.

WORK IN PROGRESS IN FY 2017

NASA and the European Space Agency (ESA) are co-sponsoring the next Ice-sheet Mass Balance Intercomparison Exercise (IMBIE-2). In the original exercise, a series of workshops brought together experts in various remote-sensing techniques in an attempt to reconcile estimates for the mass balance for the Greenland and Antarctic ice sheets. Based on the success of that effort researchers established the scope, structure and timeline for IMBIE-2 with open participation to anyone with ice-sheet mass balance estimates to contribute, and a one-month registration period opened on July 1, 2016.

Following the NASA airborne campaign in 2016 in the Hawaiian Islands for volcano and coral reef research, NASA solicited and recently initiated research to utilize data collected during the campaign. Data collected with the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) and the MODIS/ASTER Airborne Simulator (MASTER) instruments will serve as precursor datasets in advance of the Hyperspectral Infrared Imager (HyspIRI) mission.

The EXport Processes in the Ocean from RemoTe Sensing (EXPORTS) is a science plan for a future NASA field campaign to develop a predictive understanding of the export and fate of the global ocean’s primary production and its implications for the Earth’s carbon cycle in present and future climates. NASA plans to execute the EXPORTS field campaign, likely in the Atlantic and Pacific Oceans, during the next five to seven years following a 2016/2017 open competition. NASA’s satellite ocean-color data record has revolutionized our understanding of global marine systems by providing synoptic and repeated global observations of phytoplankton stocks and rates of primary production.

The Arctic-Boreal Vulnerability Experiment (ABoVE) is a major NASA field campaign in Alaska and western Canada over the 2015 to 2023 timeframe. ABoVE seeks a better understanding of the vulnerability and resilience of ecosystems and society to environmental changes in this region. Following the selection of the initial science team in 2015, the team has produced the first version of the ABoVE Science Implementation Plan, and field-based investigations began in January 2016. NASA has finalized

Memorandums of Agreement with our Canadian partner Polar Knowledge Canada, and with the Department of Energy's Next Generation Ecosystem Experiment – Arctic.

NASA will continue the SnowEx multi-year airborne snow campaign, a ground and aerial field campaign underway in the fall of 2016 and winter of 2017. SnowEx will study how much water is stored in Earth's terrestrial snow-covered regions. The data will help researchers investigate the distribution of snow-water equivalent (SWE) and the snow energy balance in different canopy types and densities and terrain. It employs a unique combination of sensors, including lidar, active and passive microwave, an imaging spectrometer, and infrared to determine the sensitivity and accuracy of different remote sensing techniques for measurement of SWE. Future plans include ground-based instruments, snowfield measurements, and modeling.

HECC plans to add the second pilot module and additional computing racks to the existing supercomputing systems. Scientific Computing will continue to add both computing and storage to its operational high-performance environment during FY 2017. The next generation Advanced Data Analytics Platform (ADAPT) prototyped during FY 2016 will be put into operations. The projects plans a significant increase in the ADAPT system (both in computing and storage). In addition, Scientific Computing will begin to explore the use of computing systems specialized in machine executable learning algorithms to solve problems in climate and weather applications. As the model and observational data continue to grow at increasing rates, leveraging the capabilities of machine learning systems for science will be necessary for future research.

Major airborne campaigns will continue in FY 2017 to include ABoVe, Operation Icebridge, HyspIRI Tropics, and the continuation of all EVS-2 investigations.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

NASA will perform the Clouds, Aerosol, and Monsoon Processes-Philippines Experiment (CAMP2Ex) in partnership with Philippine research and operational weather communities. Currently scheduled for the summer of 2018, it will characterize the role of anthropogenic and natural aerosol particles in modulating the frequency and amount of warm and mixed phase precipitation near the Philippines during the Southwest Monsoon.

NASA will conduct the Fire Impacts on Regional Emissions and Chemistry (FIREChem) mission, a cooperative biomass burning and air quality field study, in the continental United States from late June to mid-September 2018. FIREChem will focus on the links between satellite and ground-based measurements of both fresh and aged biomass burning plumes generated from both wildfires and prescribed burns (e.g., agriculture and forest management). The FIREChem mission will include in situ measurements and remote sensing observations from the NASA DC-8 to sample upwind and downwind of natural and managed fires.

As part of a broader cooperative effort in Earth science research and applications, NASA and the Indian Space Research Organization (ISRO) agreed to operate the NASA AVIRIS – Next Generation (AVIRIS – NG) instrument aboard the ISRO National Remote Sensing Centre King Air B-200 aircraft. This airborne campaign will generate data products relevant to Earth science research and applications activities in a number of topic areas by capturing spectra from terrestrial, freshwater, and marine sites throughout India. The products will provide ISRO with important baseline spectroscopy data for a wide variety of Indian environments and offer NASA researchers an opportunity to use an important new dataset. Both NASA and ISRO will have access to all scientific data coming from the AVIRIS-NG instrument. This campaign marks the first step in a potential multiyear effort between NASA and ISRO to advance imaging spectroscopy of the Earth.

In FY 2018, HECC plans to build a one-acre concrete pad to support the modular computing facility expansion. They will add three new computing modules to the facility.

Scientific Computing will continue to increase its high-performance compute and storage capacities to meet emerging NASA science requirements. Expansions to Scientific Computing's primary services in ADAPT and the next generation data analytics systems will continue. Additional investment into deep learning capabilities will occur during FY 2018.

In FY 2018, major airborne campaigns planned include Operation IceBridge, CAMP2Ex, FIREChem, and the continuation of EVS-2 investigations.

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.

GLOBAL MODELING AND ASSIMILATION OFFICE

The Global Modeling and Assimilation Office creates global climate and Earth system component models using data from Earth science satellites and aircraft. Investigators can then use these products worldwide to further their research.

AIRBORNE SCIENCE

The Airborne Science project is responsible for providing manned and unmanned aircraft systems that 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.

EARTH SCIENCE RESEARCH

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 (SGP) 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 (GSFC) and Jet Propulsion Laboratory (JPL) 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

Global Learning and Observations to Benefit the Environment (GLOBE) is a worldwide hands-on primary and secondary school-based science and education program that promotes collaboration among students, teachers, and scientists to conduct inquiry-based investigations about our environment. NASA works in close partnership with NOAA and NSF 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 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 HECC 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 248,000 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 (SLS) at different attach angles and different air speeds. The systems also analyze the Kepler mission observation data to search for habitable exoplanets.

DIRECTORATE SUPPORT

The Directorate Support project funds the Science Mission Directorate's (SMD) 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
Q2 FY 2017	Research Opportunities in Earth and Space Science (ROSES)-2017 solicitation release
Q1 FY 2018	ROSES-2017 selection within six to nine months of receipt of proposals
Q2 FY 2018	ROSES-2018 solicitation release
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

Program Management & Commitments

Program Element	Provider
Carbon Cycle Science Team	Provider: Various and defined in the acquisition strategy Lead Center: Headquarters (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): Armstrong Flight Research Center (AFRC), Ames Research Center (ARC), GSFC Wallops Flight Facility (WFF), Glenn Research Center (GRC), Johnson Space Center (JSC), Langley Research Center (LaRC) Cost Share Partner(s): Federal Aviation Administration (FAA), Department of Defense (DoD), Department of Energy (DOE), NOAA, NSF
Scientific Computing	Provider: GSFC Lead Center: HQ Performing Center(s): GSFC Cost Share Partner(s): N/A

EARTH SCIENCE RESEARCH

Program Element	Provider
Ozone Trends Science	Provider: Various and defined in the acquisition strategy 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 and defined in the acquisition strategy Lead Center: HQ Performing Center(s): All NASA Centers Cost Share Partner(s): USGCRP and SOST agencies
High-End Computing Capability	Provider: ARC Lead Center: HQ Performing Center(s): ARC Cost Share Partner(s): N/A
Directorate Support	Provider: HQ Lead Center: HQ Performing Center(s): Cost Share Partner(s); None
Fellowships and New Investigators	Provider: Various Lead Center: HQ Performing Center(s): All NASA Centers Cost Share Partner(s): N/A
Space Geodesy	Provider: Various Lead Center: GSFC Performing 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): N/A

Acquisition Strategy

NASA implements the Earth Science Research program via competitively selected research awards. NASA releases research solicitations each year in the ROSES NASA Research Announcements. All proposals in response to NASA ROSES are peer reviewed and selected based on defined criteria. The program competitively awards funds to investigators from academia, the private sector, NASA Centers and other government agencies.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Relevance	NASA Advisory Council Earth Science Subcommittee	2016	To review progress towards Earth Science objectives in the NASA Strategic Plan	All six science focus areas were rated green as documented in the FY 2016 Performance and Accountability Report	2017; annually

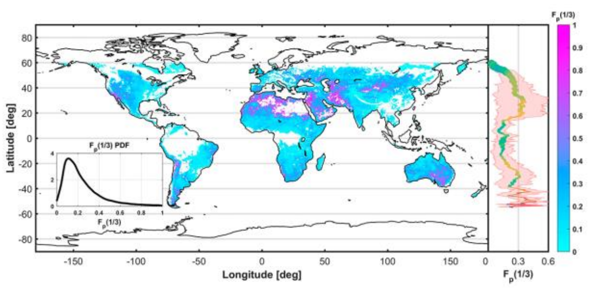
EARTH SYSTEMATIC MISSIONS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Ice, Cloud, and land Elevation Satellite (ICESat-2)	117.4	86.5	**92.3**	14.2	14.2	14.4	14.7
GRACE FO	59.9	33.7	**20.5**	11.3	12.3	12.2	14.4
Surface Water and Ocean Topography Mission (SWOT)	114.1	61.7	**90.9**	121.3	85.0	63.9	32.8
NASA-ISRO Synthetic Aperature Radar (NISAR)	72.4	101.4	**55.4**	128.1	125.4	101.2	83.9
Sentinel-6	38.2	42.5	**53.4**	67.5	64.5	40.4	14.9
Landsat 9	56.0	--	**175.8**	167.4	127.9	121.2	8.8
Other Missions and Data Analysis	456.7	--	**289.7**	277.4	325.8	355.5	510.9
Total Budget	**914.6**	**--**	**778.0**	**787.1**	**755.0**	**708.7**	**680.4**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



Global map and associated averages, by zone, of a new measure of how long it takes for soil moisture from rainfall to dissipate (estimated soil moisture water cycle fraction), produced from one year of data from NASA's Soil Moisture Active Passive (SMAP) mission.

Earth Systematic Missions (ESM) 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 in support of the research and applications communities.

Interagency and international partnerships are a central element throughout the ESM program. Several on-orbit missions provide data products in near-real time for use by U.S. and international meteorological agencies and disaster responders. Five missions involve significant international or interagency collaboration in development. The Landsat Data Continuity Mission (LDCM), now operating on orbit as Landsat 8, involves collaboration with the U.S Geological Survey (USGS). The GPM mission, now operating on orbit, is a partnership with the Japanese Aerospace Exploration Agency (JAXA), and the GRACE Follow-On (GRACE-FO) mission is a partnership between NASA and the German Research Centre for Geosciences (GFZ). The Surface Water and Ocean Topography (SWOT) mission includes significant collaborations with the Centre National d'Etudes' Spatiales (CNES), the Canadian Space Agency (CSA), and the United Kingdom Space Agency (UKSA). The NISAR mission is a major collaboration between NASA and ISRO. Sentinel-6 is a four-partner collaboration between NASA, 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 2018

ICESat-2 experienced delays in the Advanced Topographic Laser Altimeter System (ATLAS) instrument development, driving a delay of launch from June 2018 to no earlier than September 2018.

The request includes no funding for the Radiation Budget Instrument (RBI), which is experiencing cost growth and continues to experience technical challenges. RBI was to fly on the Joint Polar Satellite System 2 (JPSS-2) mission to make measurements of the Earth's radiation budget. RBI's predecessor instruments – the Clouds and the Earth's Radiant Energy System (CERES) series of instruments – continue to operate on existing NASA and NOAA satellites (Terra, Aqua, S-NPP). The sixth flight model of CERES will launch on JPSS-1 to extend the data record.

The request includes no funding for the Pre-Aerosol, Clouds, and ocean Ecosystem (PACE) mission. The PACE mission incorporated selected ocean color and atmospheric aerosol measurement capabilities of the Decadal Survey-recommended Tier-2 Aerosol, Cloud, and ocean Ecosystem (ACE) mission, ensuring continuity and additional capability in the measurement record, particularly for ocean color. Ocean color measurements are or will be acquired by the MODIS instrument on Aqua and the VIIRS instruments on S-NPP and JPSS-1.

The request includes no funding for the CLARREO Pathfinder mission. CLARREO Pathfinder was to validate the high accuracy radiometry approaches required for early detection of long-term climate trends in support of other decadal survey missions, in particular the Decadal Survey Tier-1-recommended CLARREO mission.

The request includes no funding for the NASA-provided instruments on the Deep Space Climate Observatory (DSCOVR) mission (the Earth Poly-Chromatic Imaging Camera (EPIC) and the National Institute of Standards and Technology (NIST) Advanced Radiometer (NISTAR)). The Earth Science Decadal Survey did not mention these instruments.

ICE, CLOUD, AND LAND ELEVATION SATELLITE (ICESAT-2)

Formulation	Development	Operations

FY 2018 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022	BTC	Total
Formulation	249.1	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	249.1
Development/Implementation	480.6	117.4	86.4	**79.4**	0.0	0.0	0.0	0.0	0.0	763.8
Operations/Close-out	0.0	0.0	0.0	**12.9**	14.2	14.2	9.4	0.0	0.0	50.7
2017 MPAR LCC Estimate	**729.7**	**117.4**	**86.4**	**92.3**	**14.2**	**14.2**	**9.4**	**0.0**	**0.0**	**1063.6**
Total Budget	**729.5**	**117.4**	**86.5**	**92.3**	**14.2**	**14.2**	**14.4**	**14.7**	**0.0**	**1083.2**
Change from FY 2017				**5.8**						
Percentage change from FY 2017				**6.7%**						

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

ICESat-2 will use a multi-beam micropulse laser altimeter to measure the topography of the Greenland and Antarctic ice sheets as well as the thickness of Arctic and Antarctic sea ice. The satellite LIDAR also will measure vegetation canopy heights and support other NASA environmental monitoring missions. By discovering the anatomy of ice loss, researchers may be able to forecast how the ice sheets will melt in the future and what impact this will have on sea-levels.

PROJECT PURPOSE

The ICESat-2 mission will serve as an ICESat follow-on satellite to continue the assessment of polar ice changes. ICESat-2 will also 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 mission is a Tier 1 mission, recommended by the National Academies. It entered formulation in FY 2010 and entered implementation in FY 2013.

For more information, go to http://icesat.gsfc.nasa.gov/icesat2.

ICE, CLOUD, AND LAND ELEVATION SATELLITE (ICESAT-2)

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2018

Repairs to the ATLAS instrument lasers have delayed the project schedule. The project now plans to launch in September 2018.

PROJECT PARAMETERS

The ICESat-2 observatory employs a dedicated spacecraft with a multi-beam photon-counting surface elevation lidar, which measures distance by illuminating the Earth's surface with a laser and analyzing the reflected light. ICESat-2 will continue the measurements begun with the first ICESat mission, which launched in 2003, and will improve upon ICESat by incorporating a micro-pulse multi-beam laser to provide dense cross-track sampling, improving elevation estimates over inclined surfaces and very rough (e.g., crevassed) areas and improving lead detection for above-water sea ice estimates.

ACHIEVEMENTS IN FY 2016

The project completed the spacecraft and addressed issues identified by risk reduction testing. The final ATLAS instrument subsystems were completed, delivered, and integrated during early FY 2016. Final ATLAS Dynamics and Electromagnetic Interference/Electromagnetic Compatibility (EMI/EMC) testing was completed. An issue developed with one of the two onboard lasers during thermal vacuum testing requiring the removal of the laser from the ATLAS instrument and subsequent troubleshooting and repair.

WORK IN PROGRESS IN FY 2017

The project installed a mass simulator in the ATLAS instrument in place of the removed laser and delivered the instrument to the spacecraft manufacturer. The spacecraft manufacturer will mate the instrument to the spacecraft and test the resultant observatory during FY 2017. In parallel, the laser vendor will repair the broken laser component and refurbish similar high-risk internal components in the flight laser and the spare laser to reduce the risk of a repeat failure going forward. Upon completion of the laser refurbishment, the spacecraft manufacturer will remove the ATLAS instrument from the spacecraft and ship it back to NASA. The project will install the reworked laser within the instrument and will prepare for its KDP-D review.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

After instrument-level testing has assured proper performance of the replaced laser, the Project will deliver the ATLAS instrument back to the spacecraft manufacturer for the second time, but in its final flight configuration. The spacecraft vendor will re-integrate ATLAS with the spacecraft and complete additional testing. After observatory testing concludes, there will be a series of reviews leading up to launch including the Mission Pre-Ship review, the Operational Readiness Review (ORR), and the Key Decision Point-E (KDP-E).

ICE, CLOUD, AND LAND ELEVATION SATELLITE (ICESAT-2)

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

NASA plans to launch ICESat-2 in September 2018 to begin a three-year prime mission. The following timeline shows the development agreement schedule per the rebaseline plan from May 2014, and the current schedule estimates.

Milestone	Confirmation Baseline Date	FY 2017 PB Request
KDP-C	Dec 2012	Dec 2012
Critical Design Review (CDR)	Feb 2014	Feb 2014
New Baseline	Feb 2015	Feb 2015
Launch	Jun 2018	Sep 2018
End of Prime Mission	Sep 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)
2015	763.7	>70	2017	763.7	0	Launch	Jun 2018	Sep 2018	+3

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. The 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 ICESat-2 in 2013, it was re-baselined in 2015. 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:	**763.8**	**763.7**	**-0.1**
Aircraft/Spacecraft	106.0	112.2	6.2

ICE, CLOUD, AND LAND ELEVATION SATELLITE (ICESAT-2)

Formulation	Development	Operations

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
Payloads	239.1	280.0	40.9
Systems Integration and Test (I&T)	21.6	4.5	-17.1
Launch Vehicle	118.8	118.3	-0.5
Ground Systems	55.4	63.6	8.2
Science/Technology	31.0	35.8	4.8
Other Direct Project Costs	191.9	149.3	-42.6

Project Management & Commitments

GSFC has project management responsibility for ICESat-2.

Element	Description	Provider Details	Change from Baseline
ATLAS Instrument	Advanced Topographic Laser Altimeter System	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Launch Vehicle	Provides launch service and entry into proper Earth orbit	Provider: United Launch Alliance (ULA) Lead Center: GSFC Performing Center(s): KSC Cost Share Partner(s): N/A	N/A
Ground System	Provides control of observatory operations, science data processing and distribution	Provider: Orbital ATK Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Spacecraft	Platform provides thermal and attitude control, power, and communications with the instrument	Provider: Orbital ATK Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A

ICE, CLOUD, AND LAND ELEVATION SATELLITE (ICESAT-2)

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: Observatory integration and testing reveals any issues Then: The delivery of the observatory back to GSFC will be delayed.	GSFC and Orbital ATK management are closely monitoring staffing and workloads, and have scheduled Saturday work during round 1 observatory testing. Project-level schedule reserves will be used in the event of a delay.

Acquisition Strategy

GSFC is responsible for the design and testing of the ATLAS instrument. NASA competitively selected the spacecraft vendor, Orbital ATK, which will provide the ground system element through a contract option. NASA competitively selected ULA as the launch services vendor.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Ground System	Orbital ATK	Dulles, VA
Spacecraft	Orbital ATK	Gilbert, AZ
Launch Service	ULA	Decatur, AL

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board (SRB)	Dec 2012	KDP-C	Mission was approved to enter development	Feb 2014
Performance	SRB	Feb 2014	Mission CDR	Mission CDR was successfully completed	Sep 2017
Performance	SRB	Sep 2017	KDP-D	TBD	Aug 2018
Performance	SRB	Aug 2018	ORR	TBD	N/A

GRACE FOLLOW-ON

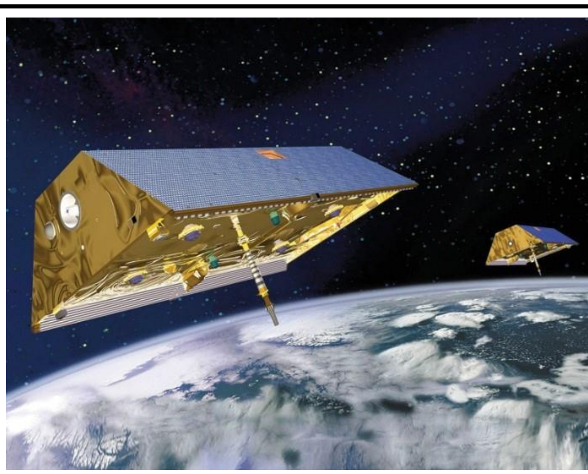
Formulation	Development	Operations

FY 2018 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022	BTC	Total
Formulation	107.4	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	107.4
Development/Implementation	160.3	59.9	33.7	**9.5**	0.0	0.0	0.0	0.0	0.0	263.4
Operations/Close-out	0.0	0.0	0.0	**11.0**	11.3	12.2	12.2	10.2	4.2	61.1
2017 MPAR LCC Estimate	**267.7**	**59.9**	**33.7**	**20.5**	**11.3**	**12.2**	**12.2**	**10.2**	**4.2**	**431.9**
Total Budget	**267.6**	**59.9**	**33.7**	**20.5**	**11.3**	**12.3**	**12.2**	**14.4**	**0.0**	**431.8**
Change from FY 2017				**-13.2**						
Percentage change from FY 2017				**-39.2%**						

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



GRACE-FO is a successor to the original GRACE mission, which began orbiting Earth in 2002. The two GRACE-FO satellites will use the same kind of microwave ranging system as GRACE, and so can expect to achieve a similar level of precision. But they will also test an experimental instrument using lasers instead of microwaves, which promises to make the measurement of their separation distance at least 20 times more precise.

PROJECT PURPOSE

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 will obtain the same extremely high-resolution global models of Earth's gravity field, including how it varies over time, as in the original GRACE mission (launched in 2002). GRACE-FO data is vital to ensuring there is a minimal gap in gravitational field measurements following the decommissioning of the currently operating GRACE mission. GRACE-FO includes a partnership with the German Research Centre for Geosciences.

GRACE FOLLOW-ON

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2018

The International Space Company Kosmostras informed the German Research Centre for Geosciences (GFZ) that they would be unable for provide a Dnepr launch vehicle for GRACE-FO. GFZ has subsequently negotiated a ride-share agreement with Iridium Communications, Inc. GFZ plans to launch GRACE-FO from Vandenberg Air Force Base with five Iridium NEXT satellites on a SpaceX Falcon 9 launch vehicle.

PROJECT PARAMETERS

The GRACE-FO observatory employs two dedicated spacecraft, launched into a near-circular polar orbit. As the two spacecraft orbit Earth, slight variations in gravity will alter the spacecraft speed and distance relative to each other. Scientists use the speed and distance changes to extrapolate and map Earth's gravitational field.

The GRACE-FO instrument suite includes the Microwave Instrument, which accurately measures changes in the speed and distance between the two spacecraft. The accelerometer instrument measures all non-gravitational accelerations (e.g., atmospheric drag, solar radiation pressure, attitude control, and thruster operation) on each GRACE-FO satellite. The Laser Ranging Interferometer is a technology demonstration and is a partnership between the United States and Germany. NASA will use the science data from the GRACE-FO mission to generate an updated model of Earth's gravitational field approximately every 30 days for the 5-year lifetime of the prime mission.

ACHIEVEMENTS IN FY 2016

The project completed the accelerometers, the microwave instruments, and the laser ranging interferometers and completed integration of the science instruments and spacecraft subsystems in FY 2016.

WORK IN PROGRESS IN FY 2017

The project completed final observatory integration and testing of the two GRACE-FO spacecraft and shipped them to Munich, Germany for environmental testing. Both spacecraft will complete environmental testing and be prepared for shipment to the launch site in FY 2017. As part of its contribution to the mission, GFZ is procuring the Multi-Satellite Dispenser (MSD) from Airbus/CASA Espacio. The MSD design, production, and testing will be completed in FY 2017.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

The project will launch the GRACE FO satellites in February 2018.

GRACE FOLLOW-ON

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2017 PB Request
KDP-C	Feb 2014	Feb 2014
CDR	Feb 2015	Feb 2015
KDP-D	Aug 2015	Aug 2015
Launch (or equivalent)	Feb 2018	Feb 2018
Start Phase E	May 2018	May 2018
End of Prime Mission	Feb 2023	Feb 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)
2015	264	70	2017	263.4	0	Launch	Feb 2018	Feb 2018	0

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

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**264.0**	**263.4**	**-0.6**
Aircraft/Spacecraft	118.7	127.5	8.8
Payloads	32.1	39.5	7.4
Systems I&T	0	0	0

GRACE FOLLOW-ON

Formulation	Development	Operations

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
Launch Vehicle	0	0	0
Ground Systems	0	0	0
Science/Technology	12.3	15.6	3.3
Other Direct Project Costs	100.9	80.8	-20.1

Project Management & Commitments

The Earth Systematic Missions Program at GSFC manages GRACE-FO. NASA has assigned responsibility for implementation to JPL.

Element	Description	Provider Details	Change from Baseline
Spacecraft	Provides platform for the instruments	Provider: Airbus Defence & Space (Germany) Lead Center: N/A Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
Microwave Instrument	Measures the distance between the spacecraft as a function of time	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
Accelerometers	Measures all non-gravitational accelerations of the satellite(s)	Provider: French Office National d’Etudes et Recherches Aérospatiales (ONERA) Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
Laser Ranging Interferometer	Heterodyne interferometric laser will measure the distance between the two spacecraft as a function of time	Provider: JPL and GFZ Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): GFZ	N/A

GRACE FOLLOW-ON

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Launch Vehicle	Delivers observatory into Earth orbit	Provider: Iridium Communications, SpaceX, Airbus/CASA Espacio Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): GFZ	N/A

Project Risks

Risk Statement	Mitigation
If: The SpaceX Falcon 9 launch manifest is delayed due to recent launch failures, Then: There would be a delay to the GRACE FO launch date.	NASA will closely monitor the SpaceX Falcon 9 launch manifest, and will work with our ride share partner, Iridium, to negotiate the most appropriate launch date in the event of a delay.

Acquisition Strategy

The acquisition strategy for GRACE-FO leveraged GRACE heritage by using sole source procurement to the same vendors for major components. NASA has completed all major acquisitions.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Spacecraft	Airbus Defence & Space	Germany
Microwave Instrument Ultra Stable Oscillator	Applied Physics Laboratory-Johns Hopkins University	Laurel, MD
Microwave Assemblies	Space Systems/Loral	Palo Alto, CA
Accelerometers	ONERA	France

GRACE FOLLOW-ON

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Feb 2014	KDP-C Milestone Review	Project approved to proceed into development	Aug 2015
Performance	SRB	Aug 2015	KDP-D Milestone Review	Project approved to enter the integration and test phase	Nov
Performance	SRB	Nov 2017	Flight Readiness Review (FRR)	TBD	N/A

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

FY 2018 Budget

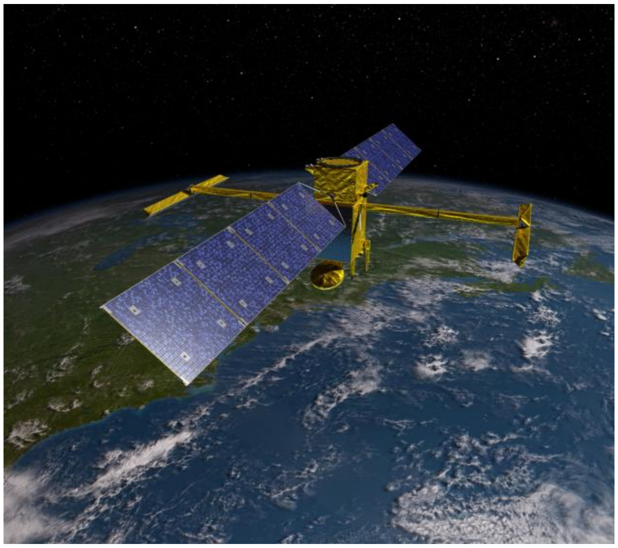
		Actual	Enacted	Request	Notional					
Budget Authority (in $ millions)	**Prior**	**FY 2016**	**FY 2017**	**FY 2018**	**FY 2019**	**FY 2020**	**FY 2021**	**FY 2022**	**BTC**	**Total**
Formulation	136.8	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	136.8
Development/Implementation	23.6	114.0	61.7	**90.9**	121.3	85.0	59.9	15.0	0.0	571.4
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	4.0	17.8	24.9	46.7
2017 MPAR LCC Estimate	**160.4**	**114.0**	**61.7**	**90.9**	**121.3**	**85.0**	**63.9**	**32.8**	**24.9**	**754.9**
Total Budget	**160.4**	**114.1**	**61.7**	**90.9**	**121.3**	**85.0**	**63.9**	**32.8**	**24.9**	**754.9**
Change from FY 2017				**29.2**						
Percentage change from FY 2017				**47.3%**						

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations



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 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 the informed control of this resource.

The 2007 National Academies decadal survey of Earth Science endorsed SWOT. The mission will complement the Jason oceanography missions, as well as other NASA missions currently in operation and development to measure the global water cycle (GPM, SMAP, and GRACE-FO). NASA will collaborate with CNES, CSA, and UKSA to accomplish this mission.

EXPLANATION OF MAJOR CHANGES IN FY 2018

NASA confirmed the SWOT project to proceed into implementation and this budget represents the Agency commitment.

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. The mission has a prime mission of three years.

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

ACHIEVEMENTS IN FY 2016

The SWOT project successfully completed its preliminary design review in April 2016, and NASA approved the project to enter the implementation phase.

WORK IN PROGRESS IN FY 2017

In FY 2017, the project will complete the critical design for the KaRIn instrument and conduct the KaRIn CDR as well as the critical design of the integrated payload module and Payload Critical Design Review. In addition, NASA plans to make the launch vehicle selection for SWOT.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

In FY 2018, the project will complete the mission CDR.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2017 PB Request
KDP-C	May 2016	May 2016
CDR	Feb 2018	Feb 2018
KDP-D	Oct 2019	Oct 2019
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 April 2021. Consistent with NASA policies regarding commitments to time and schedule, the SWOT launch will occur no later than April 2022.

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

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 Milestone Data	Milestone Change (mths)
2017	571.5	>70	2017	571.5	0	Launch Readiness Date (LRD)	Apr 2022	Apr 2022	0

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

Development Cost Details

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:	521.5	571.5	50
Aircraft/Spacecraft	0	0	0
Payloads	181.5	200.0	18.5
Systems I&T	4.9	4.9	0
Launch Vehicle	131.3	107.8	-23.5
Ground Systems	35	35.9	0.9
Science/Technology	47.1	46.3	-0.8
Other Direct Project Costs	121.7	176.6	54.9

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

Project Management & Commitments

JPL has project management responsibility for SWOT.

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
Advanced Microwave Radiometer (AMR)	Provides wet tropospheric delay correction of KaRIn	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
GPSP	Provides orbit determination	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
LRA	Provides orbit determination	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
X-band Telecom	Provides downlink of science data	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
Nadir Altimeter	Measures Jason-heritage ocean surface topography at nadir	Provider: CNES Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): CNES	N/A
DORIS	Provides orbit determination	Provider: CNES Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): CNES	N/A

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Spacecraft Bus	Provides instrument platform	Provider: CNES Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): CNES	N/A
Launch Vehicle	Delivers spacecraft to orbit	Provider: NASA Lead Center: JPL Performing Center(s): KSC Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: KaRIn critical path contributions from the multiple partners are not timely, Then: It will delay delivery of the KaRIn instrument.	Project worked with CNES to mature key interfaces early, conduct multiple model exchanges between CSA, JPL, and CNES, and conduct a full instrument integration and test campaign for the KaRIn Engineering Model.

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

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 will be a competitive procurement.

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

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	May 2014	SRR/Mission Definition Review (MDR)	Project met all review success criteria	Apr 2016
Performance	SRB	Apr 2016	PDR	Successful	May 2016
Performance	SRB	May 2016	KDP-C	Successful	Feb 2018
Performance	SRB	Feb 2018	CDR	TBD	Jan 2019
Performance	SRB	Jan 2019	SIR	TBD	Oct 2019
Performance	SRB	Oct 2019	KDP-D	TBD	Aug 2021
Performance	SRB	Aug 2021	ORR	TBD	N/A

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

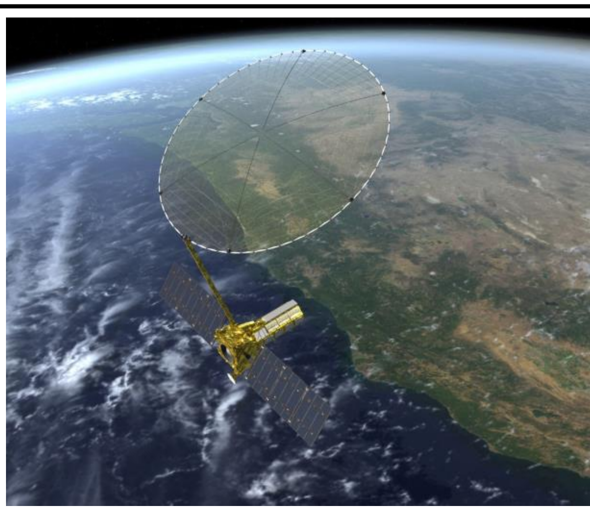
Formulation	Development	Operations

FY 2018 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022	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	13.2	72.4	101.4	**55.4**	128.0	125.4	101.2	64.0	0.0	661.0
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	19.9	69.0	88.9
2017 MPAR LCC Estimate	**130.2**	**72.4**	**101.4**	**55.4**	**128.0**	**125.4**	**101.2**	**83.9**	**69.0**	**866.9**
Total Budget	**130.2**	**72.4**	**101.4**	**55.4**	**128.1**	**125.4**	**101.2**	**83.9**	**69.0**	**866.9**
Change from FY 2017				**-46.0**						
Percentage change from FY 2017				**-45.4%**						

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



The NISAR satellite, a joint mission between NASA and the 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 NISAR mission will provide an unprecedented, detailed view of the Earth using advanced radar imaging. The NISAR satellite will observe and take measurements of some of the planet’s most complex processes, including ecosystem disturbances; ice sheet collapse; and natural hazards, such as earthquakes, tsunamis, volcanoes, and landslides. NISAR is a dual frequency (L- and S-band) Synthetic Aperture Radar (SAR) mission and data collected by the NISAR satellite will reveal information about the evolution and state of Earth’s crust, help scientists understand more about our planet's changing processes and its effect in changing climate, and aid future resource and hazard management. The mission is currently in the implementation phase in partnership with the ISRO.

Scientists have proposed L-band SAR missions in various forms for over a decade. Scientists derived the L-band SAR science of the NISAR

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

mission from Deformation, Ecosystem Structure, and Dynamics of Ice (DESDynI, a 2007 Decadal Survey Tier 1 mission recommended by the National Academies).

EXPLANATION OF MAJOR CHANGES IN FY 2018

NASA confirmed the NISAR project to proceed into implementation and this budget represents the Agency commitment. The LRD is September 2022.

PROJECT PARAMETERS

NASA will provide the L-band SAR, the engineering payload, the payload integration, and payload operations. ISRO will provide the S-band SAR, the spacecraft bus, the launch vehicle, observatory integration and testing, and spacecraft operations. NASA/JPL will be providing the L-band SAR instrument and associated engineering payload elements, including L-band electronics, radar feed, reflector and boom assembly, solid state recorder, GPS receiver, high-rate telecom system, power distribution unit and payload data subsystem.

ACHIEVEMENTS IN FY 2016

In FY 2016, the NISAR project completed the preliminary design review of the observatory, and NASA approved the mission to enter the implementation phase in September 2016. The project selected the contractor for the reflector and the solid state recorder, and developed the mission operations concept jointly with ISRO.

WORK IN PROGRESS IN FY 2017

In FY 2017, the NISAR project will continue detailed design work on the reflector and boom, and will start to build the flight models as the subsystem critical design reviews are completed.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

In FY 2018, the NISAR project will complete all planned engineering models and begin to build flight hardware. The project will start to build the reflector and boom, and will mature the mission operations concept jointly with ISRO.

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2017 PB Request
KDP-C	Aug 2016	Aug 2016
CDR	Oct 2018	Oct 2018
KDP-D	Dec 2019	Dec 2019
Payload delivery to ISRO	Feb 2021	Feb 2021
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%	2017	661	0	LRD	Sep 2022	Sep 2022	0

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

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:	661.0	661.0	0
Aircraft/Spacecraft	77.1	87.3	10.2
Payloads	211.1	228.9	17.8
Systems I&T	23.0	26.6	3.6

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
Launch Vehicle	0.6	0.5	-0.1
Ground Systems	72.6	60.8	-11.8
Science/Technology	28.2	30.7	2.5
Other Direct Project Costs	226.2	226.2	0

Project Management & Commitments

JPL has project management responsibility for NISAR.

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
Launch Vehicle	Delivers observatory to orbit	Provider: ISRO Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ISRO	N/A

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

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	NASA and ISRO jointly defined five success criteria for the NISAR launch to proceed and both NASA and ISRO have documented and agreed to these criteria. On August 27, 2015, and September 8, 2016 ISRO completed successful GSLV launches and so has met two of the five criteria.
If: The NISAR boom does not deploy in-orbit properly, then the mission success criteria cannot be satisfied	The project is addressing the single point failure in the boom electronics. NASA will extensively test the NISAR boom in the flight configuration before delivering it to 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

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Dec 2014	SRR/MDR	Project met all review success criteria	June 2016
Performance	SRB	Jun 2016	PDR	Successful	Oct 2018
Performance	SRB	Oct 2018	CDR	TBD	Dec 2019
Performance	SRB	Dec 2019	SIR	TBD	Oct 2021
Performance	SRB	Oct 2021	ORR	TBD	N/A

SENTINEL-6

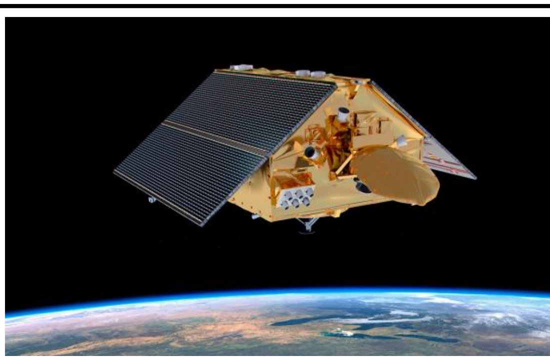
Formulation	Development	Operations

FY 2018 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022	BTC	Total
Formulation	0.0	16.3	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	16.3
Development/Implementation	0.0	21.9	42.5	**53.4**	67.5	64.5	37.5	12.0	165.6	464.9
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	2.9	2.9	32.7	38.5
2017 MPAR LCC Estimate	**0.0**	**38.2**	**42.5**	**53.4**	**67.5**	**64.5**	**40.4**	**14.9**	**198.3**	**519.7**
Total Budget	**0.0**	**38.2**	**42.5**	**53.4**	**67.5**	**64.5**	**40.4**	**14.9**	**0.0**	**321.4**
Change from FY 2017				**10.9**						
Percentage change from FY 2017				**25.6%**						

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



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.

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), OSTM/Jason-2 (2008), and Jason-3 (2016) missions. The Sentinel-6 mission consists of two satellites, Sentinel-6A and -6B, that will launch approximately five years apart 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) 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

Formulation	Development	Operations

NASA will develop and operate Sentinel-6 as an international collaboration with the NOAA, ESA, and EUMETSAT. NASA contributions include the Advanced Microwave Radiometer, the Global Positioning System (GPS) Radio Occultation, the Laser Reflector Array (LRA), and the launch vehicle for both spacecraft.

EXPLANATION OF MAJOR CHANGES IN FY 2018

NASA confirmed the Sentinel-6 mission to enter into implementation and this budget represents the Agency commitment.

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 an 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 US 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 on top of mission data product archiving and distribution.

ACHIEVEMENTS IN FY 2016

The Sentinel-6 project successfully completed the combined MCR/SRR/MDR.

WORK IN PROGRESS IN FY 2017

NASA approved the project to enter formulation, Phase B. The project will complete its preliminary design review, enter implementation, Phase C, and complete its critical design review.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

The project will complete its pre-ship review for the Sentinel-6A payload.

SENTINEL-6

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2017 PB Request
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	465.0		2017	465.0	0	LRD of Setinel-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 (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

SENTINEL-6

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:	465.0	465.0	0
Aircraft/Spacecraft	0	0	0
Payloads	64.9	64.9	0
Systems I&T	8.8	8.8	0
Launch Vehicle	280.7	280.7	0
Ground Systems	9.7	9.7	0
Science/Technology	4.4	4.4	0
Other Direct Project Costs	96.6	96.6	0

Project Management & Commitments

NASA assigned project management of this mission to JPL.

Element	Description	Provider Details	Change from Baseline
AMR-C Quality	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
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): KSC Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: Negotiations with S6 Partners fail to agree on a delivery date consistent with baseline plan Then: The project will need to accelerate, compress or descope implementation activities, or accept higher mission risks to meet mission delivery dates	Project worked with ESA to expedite long lead procurements for the NASA-supplied instruments, negotiate a revised delivery due date and resolve the risk by PDR.

SENTINEL-6

Formulation	Development	Operations

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.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
GNSS-RO Electronics	MOOG	Golden, CO
AMR-C Antenna	ATK	San Diego, CA
LRA	ITE	Laurel, MD

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Aug 2016	MCR/SRR/MDR	Project met all review success criteria	Feb 2017
Performance	SRB	Feb 2017	PDR	TBD	Oct 2017
Performance	SRB	Oct 2017	CDR	TBD	Sep 2018
Performance	SRB	Sep 2018	Sentinel-6A U.S. Payload Pre-Ship Review (PSR-A)	TBD	July 2019
Performance	SRB	July 2019	Sentinel-6B U.S. Payload Pre-Ship Review (PSR-B)	TBD	Aug 2021
Performance	SRB	Aug 2021	Sentinel-6A ORR	TBD	Aug 2026
Performance	SRB	Aug 2026	Sentinel-6B ORR	TBD	N/A

LANDSAT 9

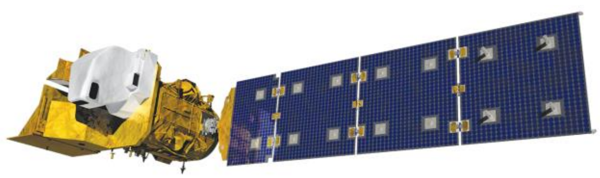
Formulation	Development	Operations

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	**56.0**	**--**	**175.8**	**167.4**	**127.9**	**121.2**	**8.8**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



Landsat 9 will continue the Sustainable Land Imaging program's critical role in monitoring, understanding, and managing the land resources needed to sustain human life by observing land use and land use change. Landsat 9 will provide data to drive informed decisions across local, regional, and global scales, and within many disciplines.

PROJECT PURPOSE

The purpose of Landsat 9 is to extend the record of multi-spectral, moderate resolution Landsat-quality data and to meet government and other user communities' operational and scientific requirements for observing land use and land change.

Unprecedented changes in land cover and use are having profound consequences for weather, climate, ecosystem function and services, carbon cycling and sequestration, resource management, the national and global economy, human health, and society. The Landsat data series, begun in 1972, is the longest continuous record of changes in Earth's surface as seen from space and the only U.S. satellite system designed and operated to make repeated observations of the global land surface at moderate resolution. Landsat data are now available at no cost, providing a unique resource for people who work in agriculture, geology, forestry, regional planning, education, mapping, and climate research.

The Landsat 9 mission is a partnership between NASA and the USGS. NASA will build, launch, and perform the initial check-out 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.

Landsat 9 is the first flight project in 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 that will provide researchers and other users with high quality, global, continuous land imaging measurements that are compatible with the existing 44-year Landsat record and that will evolve through investment in, and introduction of, new sensor and system technologies.

LANDSAT 9

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2018

None.

PROJECT PRELIMINARY PARAMETERS

Landsat 9 consists of two science instruments, the Operational Land Imager 2 (OLI-2) and the Thermal Infrared Sensor 2 (TIRS-2), a spacecraft, and a mission operations element. Landsat 9 is designed to provide 16-day repeat 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, such as the currently operating Landsat 8 satellite, Landsat 9 would contribute to increased repeat coverage for U.S. users.

ACHIEVEMENTS IN FY 2016

The Landsat 9 Project conducted its SRR/MDR in FY 2016. Subsequently the project completed its KDP-B to continue to mission design.

WORK IN PROGRESS IN FY 2017

The project awarded the spacecraft contract to Orbital ATK. The Project will conduct its PDR in FY 2017.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

The Landsat 9 Project will conduct KDP-C and its CDR in FY 2018.

ESTIMATED PROJECT SCHEDULE

Milestone	Formulation Authorization Document	FY 2017 PB Request
SRR/MDR	Jun 2016	
KDP-B	Aug 2016	
PDR	Aug 2017	Sep 2017
KDP-C	Oct 2017	Nov 2017
CDR		Mar 2018

LANDSAT 9

Formulation	Development	Operations

Milestone	Formulation Authorization Document	FY 2017 PB Request
SIR		Aug 2019
KDP-D		Sep 2019
ORR		Aug 2020
KDP-E		Nov 2020
Launch (or equivalent)		Dec 2020 – Nov 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 PDR.

KDP-B Date	Estimated Life Cycle Cost Range ($M)	Key Milestone	Key Milestone Estimated Date Range
August 2016	851- 928	Launch Readiness	Dec 2020 - Nov 2021

Project Management & Commitments

GSFC has project management responsibility for Landsat 9. The Landsat 9 mission is a partnership between NASA and the USGS. NASA will build, launch, and perform the initial check-out 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.

Element	Description	Provider Details	Change from Formulation Agreement
Operational Land Imager 2	Provide moderate resolution, multi-channel, wide swath visible imaging of Earth's surface, consistent with previous Landsat missions.	Provider: Ball Aerospace Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	

LANDSAT 9

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
Thermal Infrared Sensor 2	Provide moderate resolution thermal infrared imaging of 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: Orbital ATK Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	
Ground System	Collect, process, archive, and freely distribute Landsat data.	Provider: TBD Lead Center: USGS EROS Performing Center(s): USGS EROS Cost Share Partner(s): USGS	
Mission Operations Element	Provide software and system for capability for command and control, mission scheduling, long-term trending and flight dynamics analysis.	Provider: TBD Lead Center: USGS EROS Performing Center(s): USGS EROS Cost Share Partner(s): USGS	

Project Risks

Risk Statement	Mitigation
There is a potential impact to the Landsat 9 launch readiness date if USGS is unable to obtain sufficient funding to develop the Landsat 9 ground system in a timely manner.	USGS will work to maintain the development schedule for the ground system and support the earliest possible launch readiness date.

LANDSAT 9

Formulation	Development	Operations

Acquisition Strategy

The acquisition strategy for Landsat 9 is identical to that for Landsat 8 (formerly known as LDCM). NASA selected Ball Aerospace to provide the OLI-2 instrument through a sole source procurement in FY 2016. Ball Aerospace will build the OLI-2 instrument and deliver it for observatory integration and test. NASA selected Orbital ATK to provide the Landsat 9 spacecraft through the GSFC Rapid Spacecraft Development Office (RSDO) selection process. Orbital ATK will build the spacecraft and provide observatory integration and test. NASA assigned the TIRS-2 instrument as a directed development to GSFC. GSFC will build it in-house and deliver it for observatory integration and test.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
OLI-2	Ball Aerospace	Boulder, Colorado
TIRS-2	GSFC	Greenbelt, Maryland
Spacecraft	Orbital ATK	Gilbert, Arizona
Launch Vehicle	TBD	TBD

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	July 2016	SRR	Successful	Aug 2017
Performance	SRB	Aug 2017	PDR	TBD	March 2018
Performance	SRB	March 2018	CDR	TBD	Aug 2019
Performance	SRB	Aug 2019	SIR	TBD	Dec 2020
Performance	SRB	Dec 2020	ORR	TBD	

OTHER MISSIONS AND DATA ANALYSIS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Earth Systematic Missions (ESM) Research	17.6	--	**17.6**	22.3	24.1	25.5	26.2
Ocean Surface Topography Science Team (SWOT)	6.2	--	**5.7**	5.7	5.9	5.9	6.1
Earth Observations Systems (EOS) Researc	24.1	--	**17.2**	14.2	13.8	14.7	14.8
Sage III	10.3	--	**4.8**	4.8	4.6	4.6	4.6
Radiation Budget Instrument (RBI)	78.8	--	**0.0**	0.0	0.0	0.0	0.0
Sustainable Land Imaging	3.3	--	**6.0**	6.1	31.0	59.9	135.0
Earth from ISS	2.6	--	**3.2**	2.6	2.6	2.1	1.7
Plankton,Aerosols,Clouds,ocean Ecosystem	75.0	--	**0.0**	0.0	0.0	0.0	0.0
Total Solar Irradiance Sensor-2 (TSIS-2)	0.1	--	**0.6**	8.3	26.9	35.2	25.3
Earth Radiation Budget Science	13.2	--	**13.7**	13.6	13.8	14.0	14.3
Ozone Mapping and Profiler Suite (OMPS)	5.7	--	**6.9**	7.0	7.0	6.2	4.5
Total Solar Irradiance Sensor-1 (TSIS-1)	21.9	--	**20.5**	4.8	4.7	4.9	4.7
CLARREO Pathfinder	1.3	--	**0.0**	0.0	0.0	0.0	0.0
Decadal Survey Missions	18.3	--	**13.2**	16.3	15.8	2.6	90.6
Earth Science Program Management	31.9	--	**35.4**	35.2	36.4	36.7	37.1
Precipitation Science Team	7.5	--	**6.9**	6.9	7.1	7.2	7.4
Ocean Winds Science Team	4.6	--	**4.2**	4.2	4.3	4.4	4.5
Land Cover Science Project Office	1.6	--	**1.5**	1.5	1.6	1.6	1.6
Ocean Salinity Science Team	0.0	--	**7.8**	7.8	8.0	8.1	8.3
Soil Moisture Active and Passive (SMAP)	5.9	--	**11.3**	11.3	11.5	11.7	12.0
Quick Scatterometer	1.6	--	**1.0**	0.0	0.0	0.0	0.0
Tropical Rainfall Measuring Mission	4.8	--	**0.0**	0.0	0.0	0.0	0.0
Deep Space Climate Observatory	3.2	--	**0.0**	0.0	0.0	0.0	0.0
Global Precipitation Measurement (GPM)	21.1	--	**20.4**	20.4	20.7	20.9	20.9
Landsat 8	2.3	--	**2.4**	0.0	0.0	0.0	0.0
Ocean Surface Topography Mission (OSTM)	2.3	--	**2.3**	2.3	2.3	2.4	2.4
Suomi National Polar-Orbiting Partnershi	3.4	--	**3.1**	3.5	3.6	3.7	3.8
Terra	25.9	--	**25.3**	25.3	25.9	26.3	27.0
Aqua	27.8	--	**27.3**	27.3	27.8	28.3	29.0
Aura	26.6	--	**25.9**	25.9	26.4	28.6	29.0
SORCE	5.2	--	**5.5**	0.0	0.0	0.0	0.0
Earth Observing-1	2.8	--	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**456.7**	**--**	**289.7**	**277.4**	**325.8**	**355.5**	**510.9**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

OTHER MISSIONS AND DATA ANALYSIS

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

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 missions in formulation, such as Landsat 9 and Sentinel-6; and smaller missions in formulation and development, such as TSIS (Total Solar Irradiance Sensor)-1 and TSIS-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

Members of the Suomi-NPP science team compared the monthly mean Aerosol Optical depth time series between March 2012 and May 2014 from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) and the Visible Infrared Imaging Radiometer Suite (VIIRS) sensors. Their analysis addresses how issues of calibration, as well as instrument spatial resolution may be affecting the ability to create a consistent MODIS to VIIRS aerosol climate data record spanning MODIS observations (aboard NASA satellites) to more recent VIIRS observations (aboard S-NPP and future NOAA JPSS satellites). Scientists compared ozone observations from hyperspectral infrared sounders, such as the Aqua AIRS and Suomi NPP CrIS instruments and developed total ozone combined products. The Short-term Prediction Research and Transition Center has facilitated its transition to forecasters at the Weather Prediction Center, Ocean Prediction Center, and National Hurricane Center. A product evaluation with forecasters at these centers has confirmed operational utility in identification of stratospheric air intrusions associated with rapid mid-latitude cyclone development and extratropical cyclone transition.

Science team members have been able to perform successful retrievals of geophysical variables, such as temperature and humidity profiles, from the Atmospheric Infrared Sounder instrument on Aqua and the Cross-track Infrared Sounder instrument on S-NPP radiances using a unified retrieval algorithm. This is a major step forward towards climate continuity datasets across different infrared sounding platforms. The team is currently testing this unified version of the retrieval algorithm for operational implementation.

The Short-term Prediction Research and Transition Center has begun integration of retrieved soil moisture observations from the SMAP satellite into the NASA Land Information System (LIS). Inclusion of SMAP data provides more direct measurement of important near-surface soil moisture conditions that users determined primarily by precipitation in land surface models in the past. Researchers expect the SMAP data inclusion to result in improved representation of the land surface for situational awareness and initialization of regional numerical weather prediction and hydrology models. A high-resolution, real-time LIS soil moisture and temperature analysis product for the continental United States has been transitioned to several National Weather Service (NWS) forecast offices and was used as part of a targeted assessment to make decisions on drought categories, issuance of areal flood guidance, and detection of locations with higher risk for wildfire.

NASA scientists continued to expand the number of users for its suite of high-resolution imagery and derived products from instruments on the Suomi NPP satellite. Numerous NWS Weather Forecast Offices (WFOs) around the country and national weather forecast centers now use the data to address a variety of forecast problems. Multispectral (i.e., red-green-blue or RGB) composite imagery from VIIRS combines information from several channels to aid forecasters in quickly identifying cloud and atmospheric features. The 24-hour Microphysics RGB product helps diagnose restrictions in surface visibility that affect aviation across the country and in Alaska during both daytime and nighttime conditions. The NWS WFOS used the Dust RGB in the southwest to provide public warnings for dust storms that impact visibility and respiratory health. The Air Mass RGB allows forecasters to identify the interaction of different air mass types in the formation of extratropical and tropical cyclones. Instead of using infrared data alone, an RGB composite derived from the Day Night Band (DNB) on VIIRS provides significantly improved feature detection at night in these regions when monitoring low clouds and fog.

OCEAN SURFACE TOPOGRAPHY SCIENCE TEAM (OSTST)

Ocean Surface Topography Science Team (OSTST) uses scientific data from the Ocean Surface Topography Mission (OSTM) and Jason satellites to measure global sea surface height.

Recent Achievements

OSTST completed studies on the stability of atmospheric water vapor measurements required in the Jason-series of missions. It has recommended new approaches to calibration of the water vapor radiometer in order to maintain knowledge of sea level rise estimates with 1 millimeter per year.

NOAA launched Jason-3 in January 2016 and completed a tandem mission with OSTM/Jason-2 for cross calibration. After calibration, OSTST recommended moving Jason-2 into an interleaved (arranged in alternate layers) orbit with Jason-3. The project completed the orbit in October 2016. OSTST has analyzed data from the joint CNES/ISRO SARAL/AltiKa satellite and Sentinel 3-A.

EARTH OBSERVATION SYSTEMS (EOS) RESEARCH

EOS Research funds science for the EOS missions, currently Terra, Aqua, Aura, Landsat, and ICESat missions. The project competitively selects individual investigators to undertake research projects that analyze data from specific missions. Whereas, overall, the selected activities focus on science data analyses and the development of Earth system data records, including climate data records relevant to NASA’s research program, some funded activities continue algorithm improvement and validation for the EOS instrument data products.

Recent Achievements

Scientists developed a new approach to use time-series Landsat data to study vegetation greening and browning trends in the Arctic and boreal regions of North America for the 1984 – 2012 timeframe. Since this information is at a much finer spatial scale than data from other satellites, it provides new insights on vegetation changes in this region.

OTHER MISSIONS AND DATA ANALYSIS

Researchers combined Landsat and MODIS data in a land model to assess the impact of urbanization on U.S. surface climate. For cities built within forests, daytime urban land surface temperature is much higher than that of vegetated lands. For example, in Washington, D.C. and Atlanta, daytime mean temperature differences between urbanized and vegetated lands reach 3.3 and 2.0 °C, respectively. Conversely, for cities built within arid lands, such as Phoenix, urban areas are 2.2 °C cooler than surrounding shrub. The study also showed that the carbon lost to urbanization represents 1.8 percent of the continental total, a striking number considering urbanization occupies only 1.1 percent of the U.S. land.

A team of researchers examined a method of analyzing forest disturbance and extended the method to the forests and grasslands of the North Island of New Zealand. Forest disturbances are events that cause a change in the structure and composition of a forest ecosystem, such as fires, floods, invasive species, storms and pollution. The results of the study indicate that the method of analyzing disturbance was effective for both forests and grasslands. Additionally, the adapted grassland method had comparable or higher accuracy than the analyses of the forest disturbance. A different team developed an approach to merge Landsat-based maps of forest disturbance to estimate the change in canopy height in re-growing forests.

Though researchers have mapped snow-covered area at high resolutions for decades, they do not have a good assessment of Snow Water Equivalent, especially in mountainous regions. Recent work has helped to recreate past Snow Water Equivalent values in the Sierra Nevada Mountains. This approach combines very high-resolution Landsat snow mapping with a mesoscale model via data assimilation. Using this innovative approach and in combination with longer term in situ data, analysis of the U.S. Sierra Nevada snowpack indicates that water year 2015 was a truly extreme dry year. The 2015 conditions, occurring on top of three previous drought years, led to an accumulated (multiyear) snowpack deficit of about 264 billion gallons, the highest over the 65 years analyzed. Runoff from the overall Sierra snowpack provides arid California with a third of its water in a good year, a critical resource for the State.

Researchers used observations from the Ozone Monitoring Instrument (OMI) on the NASA Aura satellite to locate nearly 40 unreported and major human-made sources of toxic sulfur dioxide emissions. These missing sources are scattered throughout the developing world, with over a third clustered around the Persian Gulf. The authors note that conventional, bottom-up emissions inventories used to assess impacts are often incomplete or outdated, particularly for developing nations that lack comprehensive emission reporting requirements and infrastructure. This new inventory will help eliminate gaps in these bottom-up inventories, independent of geopolitical borders and source types.

Satellite measurements of tropospheric carbon monoxide enable a wide array of applications, including studies of air quality and pollution transport. The Measurements of Pollution in the Troposphere (MOPITT) instrument on the NASA Terra satellite has been measuring carbon monoxide concentrations globally since March 2000. A recent study used the GEOS-Chem assimilation system to quantify North American carbon monoxide emissions during the period of June 2004–May 2005 by assimilating new retrievals of MOPITT carbon monoxide. They found that the annual total anthropogenic carbon monoxide emission from the continental United States showed a 14 percent increase from the prior estimate. This increase was mainly due to enhanced emissions around the Great Lakes region and along the west coast.

Recent publications have highlighted the unique capabilities of the AIRS instrument to observe atmospheric processes that are notoriously difficult to measure from space. Scientists showed that AIRS is capable of providing useful information on the structure of the cloudy boundary layer, and in some

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regions can be superior to the European Centre for Medium-Range Weather Forecast re-analysis. In addition, they discuss detailed observations of cloud properties from AIRS. Additionally, other studies highlight the unique capabilities of AIRS in detecting atmospheric gravity waves.

In a recent study, researchers addressed a key question on weather and climate, namely the link between extreme tropical convection changes and sea surface temperature variability. They found that over the tropical ocean, the more extreme convective events – as measured by AIRS brightness temperatures - are particularly sensitive to sea surface temperature changes, and the average intensity storm events are fairly insensitive. This finding suggests that extreme convective events may occur more frequently in the future, in particular over regions where the monsoon and tropical storms often occur.

Scientists at NASA’s Jet Propulsion Laboratory used a combination of satellite and aircraft data, combined with modeling, to determine the amount of melting occurring at Antarctic ice shelves. They also explained why glaciers discharge ice differently in response to the same ocean forcing, which is a critical step in improving projections of sea level rise.

Using IceBridge (and earlier) airborne lidar surveys of Alaskan glaciers, scientists found that tidewater glaciers are currently losing mass at slower rates than land-terminating glaciers, signifying a dramatic reversal of a trend that had persisted since the Little Ice Age ended. The results suggest that surface melt and accumulation, rather than ice-ocean interactions, will drive future sea-level contributions; this is critical to projecting near-term sea level rise.

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 44-year Landsat record and will address near- and longer-term issues of continuity risk. They will also evolve flexibly and responsibly through investment in, 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 Landsat-10; 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.

To minimize the risk of gaps while taking advantage of cost savings and capability enhancements owing to the technology development activity outlined above, the Administration will make key strategic decisions on Landsat 10 payload/instrument approaches by the end of the decade, with the goal of beginning development of the Landsat 10 mission prior to the launch of Landsat 9.

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Additional SLI activities support efforts to minimize costs and maximize the overall utility for U.S. users by engaging responsibly 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

NASA selected six projects in FY 2016 under the SLI-T program to demonstrate improved, innovative, full-instrument concepts for potential infusion into the architecture and design of Landsat 10 and to develop and mature technologies that have long-term potential to improve future land imaging instruments and systems through substantial architecture changes.

TOTAL SOLAR IRRADIANCE SENSOR-2 (TSIS-2)

TSIS-2 will be the follow-on instrument to the TSIS-1 instrument. The TSIS-2 instrument will maintain and extend the measurements of total solar irradiance and spectral solar irradiance provided by TSIS-1. TSIS-2 is a mission of opportunity, to be ready for integration onto a host spacecraft in 2022. The TSIS-2 project will begin formulation in FY 2018.

EARTH RADIATION BUDGET SCIENCE

The goal of the Earth Radiation Budget Science (ERBS) Project is to produce 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 CERES instruments measuring broadband radiative fluxes from the Terra, Aqua, and Suomi NPP platforms, the data products utilize coincident imager measurements from Terra, Aqua, Suomi NPP, and operational geostationary satellite observations. In total, 13 instruments on eight 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

This year, the CERES team successfully incorporated data into their processing stream from the next generation of advanced geostationary imagers, starting with the Himawari-8 geostationary imager. The ERBS team continues to produce the most accurate continuous long-term Earth Radiation Budget climate data record, fusing the observational record collected over time from five NASA polar orbiting broadband radiometers, two NASA polar orbiting imagers, one NOAA polar orbiting imager and a total of 17 current and former geostationary imagers. The project is preparing to incorporate data from the CERES Flight Model 6 scheduled for launch on NOAA's Joint Polar Satellite System (JPSS) 1 spacecraft in 2017.

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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 consists of three spectrometers: a downward-looking nadir mapper, nadir profiler, and limb profiler. The entire OMPS suite currently operates on the Suomi NPP spacecraft, and to ensure data continuity, a copy of this suite will fly on NOAA's JPSS-2 mission, planned for launch in 2021. NASA is responsible for providing the OMPS-Limb profiler for integration on the OMPS instrument.

Recent Achievements

The project continues with development activities and remains on track for integration with the OMPS instrument in FY18.

TOTAL SOLAR IRRADIANCE SENSOR-1 (TSIS-1)

The TSIS-1 mission will provide absolute measurements of the total solar irradiance (TSI) and spectral solar irradiance (SSI), important for accurate scientific models of climate change and solar variability. TSIS is comprised of two instruments, the Total Irradiance Monitor (TIM), and the Spectral Irradiance Monitor (SIM). Both instruments are in storage at the University of Colorado's Laboratory for Atmospheric and Space Physics awaiting flight. Currently, the data from an earlier NASA-managed TIM instrument, flying on the aging SORCE spacecraft, launched in 2003, provides the TSI data record as part of an unbroken 35-year long data record. The Total Solar Irradiance Calibration Transfer Experiment (TCTE) instrument, a joint mission with NOAA and the U.S. Air Force, launched in 2013 and currently augments the data record. The TSIS-1 project transferred fully to NASA in FY 2016 and it is on the manifest for installation on the ISS in FY 2017 in time to overlap with the TCTE mission in order to maintain continuity of the solar irradiance measurement.

Recent Achievements

The TSIS-1 project completed assembly of the Thermal Pointing System (TPS), a highly sensitive pointing apparatus that will enable the collecting of the minuscule measurements of TSI and SSI. The project integrated the TIM and the SIM onto the TPS. The project will begin environmental testing in early 2017, and will launch TSIS-1 on SpaceX-13, currently scheduled for November 2017.

DECADAL SURVEY MISSIONS

The Decadal Survey project contains missions recommended by the National Academies Earth Science decadal survey. All the missions within this project are in a pre-formulation phase conducting mission concept studies. The next Decadal Survey will be released in late 2017, and will guide the selection of pre-formulation studies in FY18 and out. The current portfolio of missions under study includes:

- CLARREO;
- Active Sensing of CO2 Emissions over Nights, Days, and Seasons (ASCENDS);
- GEOstationary Coastal and Air Pollution Events (GEO-CAPE);
- ACE; and
- Hyperspectral Infrared Imager (HyspIRI).

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Recent Achievements

Mission teams continue to make progress in requirements refinement and modeling, instrument concept and technology maturation, and algorithm development. The ACE Science Working Group implemented and tested advances in multi-frequency Doppler radar, high spectral resolution lidar as well as aerosol and cloud polarimetry.

EARTH SCIENCE PROGRAM MANAGEMENT

The Earth Science Program Management budget supports critical flight project management functions executed by the ESM Program Office at GSFC, the Earth System Science Pathfinder Program Office at LaRC and the Earth Science Flight Project Office at 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, TRMM launched in November 1997 and nearing its end of life, the GPM Core Observatory launched February 2014, and GPM mission constellation partner spacecraft (partners include NOAA, DoD, CNES, JAXA, and 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

Global Precipitation Measurement (GPM) Microwave Imager (GMI) data continue to be used as an integral part of the tropical cyclone analysis and forecasting effort by both the NOAA National Hurricane Center and the U.S. Navy, exemplified in NHC and Joint Typhoon Warning Center discussions of tropical cyclone activity, and in integral posting for GMI data on the Naval Research Laboratory (NRL) Tropical Cyclone Page.

As pioneered by the legacy NASA Tropical Rainfall Measuring Mission (TRMM), quasi-global, long-record, fine-scale precipitation estimates based on a merged combination of all precipitation-relevant satellites from around the world have rapidly become the go-to product for many precipitation-based applications in the U.S. and internationally. GPM provides the Integrated Multi-satellitE for GPM (IMERG) products at temporal scales of 30 minutes and spatial resolutions of 10 km by 10 km, and is in the process of unifying the TRMM and GPM precipitation estimates to create a 20+ year record. Near-real-time data are key to short-fuse applications, including the Global Flood Monitor for flood analysis and the Potential Landslide Areas site for precipitation-driven landslides. These data continue to be widely used in the disaster response community, including the NASA disaster response activity, World Bank, and International Red Cross.

OCEAN WINDS SCIENCE TEAM

The Ocean Winds Science Team (OWST) 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. The sparse wind data from ships and buoys serve to calibrate the satellite data.

Recent Achievements

OWST has analyzed RapidScat data for diurnal wind variability over the ocean, with particular focus on the tropical areas of the Earth. On the applications side, more than a decade of high quality global ocean wind data has already yielded important insights into tropical and extra-tropical cyclones. NASA forwards his work directly to marine forecasters.

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 improvements in the Landsat 7 long-term acquisition plan and provision of preprocessed data sets for land-cover change analysis, and facilitates use of international data sets for improved land cover monitoring.

Recent Achievements

A recent focus of the LCPSO has been to prepare the U.S. land cover research community for the integration of European Sentinel-1 and Sentinel-2 datasets into land monitoring activities. The LCPSO recently delivered a prototype dataset that harmonizes data from Landsat and Sentinel-2 sensors to create a seamless temporal record for the research and applications community. LCPSO continues to facilitate access to commercial high-resolution imagery procured by the National Geospatial-Intelligence Agency for NASA-funded investigators. The LCPSO has also supported activities of the Committee on Earth Observation Satellites (CEOS) Land Surface Imaging Virtual Constellation (LSI-VC) working group, including definition of Analysis Ready Data (ARD) products from moderate-resolution imaging systems.

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 plans to produce a SMAP salinity product that is consistent with the Aquarius salinity product, which ended in June 2015.

Recent Achievements

In August 2016, OSST began a yearlong field program, Salinity Processes in the Upper-ocean Regional Study-2 (SPURS-2), in the eastern tropical Pacific Ocean to increase its understanding of the surface salinity patterns under the Intertropical Convergence Zone – one of the rainiest regions on Earth. Researchers are studying the new upper-ocean phenomena revealed by the Aquarius and SMOS missions in detail to help scientists understand the role of the ocean in the planetary water cycle. This experiment is a "bookend" to the SPURS-1 experiment conducted in 2012 - 2013 in the subtropical North Atlantic. The experiments focus on the surface salinity signature of evaporation and precipitation. This work has already led to the discovery of potential forecasting of African continental and USA mid-west rainfall patterns from salinity patterns in the North Atlantic.

Operating Missions

SOIL MOISTURE ACTIVE AND PASSIVE (SMAP)

The SMAP mission 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. The radar and radiometer share a single feed and deployable six-meter reflector antenna system. Although the active radar instrument failed in July 2015, the radiometer is operating nominally, and continue to provide global mapping of soil moisture with accuracy, resolution and coverage that exceeds the capability of other on-orbit systems. The prime mission will end in May 2018. The project may propose a mission extension through the senior review process. NASA will conduct the next Earth Science Senior Review for Mission Extension in the spring of 2017.

SMAP measurements will be used to understand the processes that link the terrestrial water, energy and carbon cycles; to estimate the global water and energy fluxes at the land surface; to enhance weather and climate forecasts, and to develop improved flood prediction and drought monitoring capabilities.

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

Recent Achievements

Since last year's loss of the radar instrument, recovery efforts have been underway to augment the residual capability through (1) enhanced processing of the radiometer-only dataset to achieve global spatial resolution down to 25km, and (2) collaborative data collection campaigns with the ESA Sentinel 1 radar missions to achieve 3km radar-radiometer datasets over key U.S. regions.

A new study of the first year of observational data from NASA's Soil Moisture Active Passive (SMAP) mission is providing significant surprises that will help in modeling Earth's climate, forecasting our weather and monitoring agricultural crop growth. Scientists from the Massachusetts Institute of Technology (MIT), Cambridge; and NASA's Jet Propulsion Laboratory, Pasadena, California, published the findings in the journal Nature Geosciences in January 2017. They used SMAP measurements to estimate soil moisture memory (how long it takes for soil moisture from rainfall to dissipate) in the top two inches (five centimeters) of Earth's topsoils. The estimates improve upon earlier ones that were predicted from models or based on sparse data from ground observation stations.

The team found that, on average, about one-seventh of the amount of rain that falls is still present in the topmost layer of soils three days later. This persistence is greatest in Earth's driest regions. Although the top two inches of topsoil on Earth's land masses contains an infinitesimal fraction of our planet's water, that tiny amount plays a disproportionately critical role in the cycling of water, which has major impacts in everything from agriculture, weather, climate and even the spread of disease. This thin layer is a key part of the global water cycle over the continents and is also a key factor in the global energy and carbon cycles. Among the study's other findings, the team found that SMAP data identify regions where soil moisture memory has the potential to influence weather and affect and amplify droughts and floods. When moisture evaporates from wet soil, it cools the soil in the process, but when the soil gets too dry, that cooling diminishes. This, in turn, can lead to hotter weather and heat waves that extend and deepen drought conditions. Scientists had speculated about such effects, but had not directly studied them until now.

GLOBAL PRECIPITATION MEASUREMENT (GPM)

The GPM mission will advance the measurement of global precipitation. A joint mission with JAXA, GPM will provide the first opportunity to calibrate measurements of global precipitation (including the distribution, amount, rate, and associated heat release) across tropical, mid-latitude, and Polar Regions. The Global Precipitation Measurement (GPM) Microwave Imager (GMI) and the Dual-frequency Precipitation Radar (DPR) are the two primary instruments on the GPM Core Observatory. The prime mission of GPM ends in "fill in blank here". The project may propose a mission extension through the senior review process. NASA will conduct the next Earth Science Senior Review for Mission Extension in the spring of 2017E

The GPM mission has several scientific objectives:

- Advance precipitation measurement capability from space through combined use of active and passive remote-sensing techniques;
- Advance understanding of global water/energy cycle variability and fresh water availability;
- Improve climate prediction by providing the foundation for better understanding of surface water fluxes, soil moisture storage, cloud/precipitation microphysics, and latent heat release in Earth's atmosphere;
- Advance numerical weather prediction skills through more accurate and frequent measurements of instantaneous rain rates; and
- Improve high-impact natural hazard event (flood and drought, landslide, and hurricanes) and fresh water-resource prediction capabilities through better temporal sampling and wider spatial coverage of high-resolution precipitation measurements.

Recent Achievements

During its third year of operations in 2016, GPM's vigorous program of snow research has yielded important results on how various combinations of the GMI channels affect snowfall detection at the Earth's surface and in the atmosphere. The project released two new data visualization tools, including the Global Viewer for viewing near real-time global precipitation data, and the Precipitation and

Applications Viewer for recent (30 minute, one day, three day, and seven day) precipitation, flood, and landslide data. GPM provided short, informative featured articles about current weather events as depicted in GPM data products that are aimed at the general public, as well as weather and application specialists. The mission will be completing its prime operations phase in a few months and expects to demonstrate that all Level 1 requirements have been satisfied.

LANDSAT 8

Landsat 8 is the most recent in the Landsat series of satellites that have been continuously observing Earth's land surfaces by recording data since 1972. In addition to widespread routine use for land use planning and monitoring on regional to local scales, support of disaster response and evaluations, and water use monitoring, Landsat 8 measurements directly serve NASA research in the focus areas of climate, carbon cycle, ecosystems, water cycle, biogeochemistry, and Earth surface/interior. USGS performs mission operations for Landsat 8, but NASA provides science activities in support of the USGS and the Landsat Science Team during prime mission operations.

Recent Achievements

Since 1984, scientists have analyzed more than three million Landsat images and relied heavily on Landsat data to quantify how global surface water has changed over time. Their findings show that overall surface water has increased—180,000 square kilometers of new permanent water bodies have been created--while elsewhere half that amount has disappeared. In 2016, the project developed a new Landsat 8-based semi-automatic tool to map the speed of ice sheets and outlet glaciers around the globe in near-real time. NASA, together with the Universities of Colorado and Alaska, has created the Global Land Ice Velocity Extraction project (GoLIVE), which uses Landsat 8's frequent imagery and excellent mapping capability to detect subtle ice surface changes and thereby measure flow and melt patterns. Landsat 8 continues to support operational agricultural monitoring within the USDA, including generation of the annual Cropland Data Layer—a field-scale map of crop types across the United States. NASA made significant progress to improve ongoing technical issues with the Thermal Infrared Sensor (TIRS). Landsat operational processing will now include correction for Landsat-8 TIRS stray light and provide consistent Landsat-4 TM to Landsat-7 ETM+ radiometric calibration tied to the Landsat-8 OLI reflectance calibration.

OCEAN SURFACE TOPOGRAPHY MISSION (OSTM)

OSTM, or Jason-2, measures sea surface height and enables scientists to assess climate variability and change, and water and energy cycles. This mission is the third in a series of ocean surface topography missions (following Jason-1 and TOPEX/Poseidon) and is the only one currently operating. OSTM is a joint mission with NOAA, CNES, and the European Organisation for the Exploitation of Meteorological Satellites. OSTM will provide cross-calibration with Jason-3 (launching in 2016). It will also serve to increase the spatial and temporal resolution of altimetry measurements in 2017 when OSTM is maneuvered into the interweaved five-day repeat orbit that was previously occupied by Jason-1. The 2015 Earth Science senior review endorsed the OSTM mission for continued operations through 2017. The next senior review will occur in the spring of 2017 and will re-evaluate the OSTM mission extension in terms of scientific value, national interest, technical performance, and proposed cost.

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Recent Achievements

The OSTM/Jason-2 mission successfully completed a comprehensive six-month tandem calibration and validation phase with the Jason-3 satellite, which launched in January 2016. Data from these missions enabled scientists to continue their analysis of the heat, water mass, nutrient, and salt transport by our Earth's oceans. Various domestic agencies utilized data from OSTM/Jason-2 to improve marine, fishery, and naval operations, help forecast the intensity of tropical hurricanes/cyclones, and monitor large lake/reservoir water levels in remote and/or inhospitable regions. The year also included observations of a large El Niño event in the Pacific Ocean, and ongoing measurements of variations in regional and global mean sea level.

SUOMI NATIONAL POLAR-ORBITING PARTNERSHIP (SUOMI NPP)

Suomi NPP successfully launched in 2011is operated by 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 and NOAA continue to collaborate during the mission's five-year prime operations phase to ensure meeting the shared objectives of both agencies. Prime mission operations officially ended in March 2017. The project may propose a mission extension through the senior review process. NASA will conduct the next Earth Science Senior Review for Mission Extension in the spring of 2017

Recent Achievements

In 2016, VIIRS Nighttime imagery became routinely produced and available through NASA's public web portals. A substantial community of users including scientists, commercial companies, and the media use these data for a wide range of purposes, from detecting illegal fishing in restricted waters to supporting both natural and manmade disaster response activities. The VIIRS active fire product, combining S-NPP/VIIRS 375m and 750m data, is now available in near real-time through Worldview as well as through NASA's Fire Information for Resource Management System (FIRMS). The VIIRS science team developed a new approach to detect small fires by a combined use of visible light and infrared radiation detected at night in non-urban regions. The Ozone Mapping and Profiler (OMPS) Science Team has characterized and validated the performance of both the OMPS nadir and limb sensors. Scientists used the OMPS data to monitor the location and dispersion of ash from volcanic eruptions such as the March 2016 eruption of Pavlof.

TERRA

Terra is one of the 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. Terra, launched in 1999, is a joint mission with Japan and Canada. The Terra mission has now provided more than 17 years of continuous data collection, providing 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 Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)

Shortwave Infrared (SWIR) bands). The 2015 Earth Science senior review endorsed the Terra mission for continued operations through 2017. The next senior review will occur in the spring of 2017 and will re-evaluate the Terra mission extension in terms of scientific value, national interest, technical performance, and proposed cost.

Recent Achievements

Recent Terra data product accomplishments include ASTER-based high-resolution global surface composition dataset to find undiscovered mineral deposits, to locate volcanically altered rocks, and to observe environmental effects of mining. Scientists produced near-real-time aerosol, fire, and carbon monoxide products to understand health and safety impacts, and near real time wind and cloud data that improves operational weather forecasts. The Terra project developed an agreement between ASTER, CERES, MISR, and MODIS that will allow the Terra project to accurately track variations and changes in the climate system as well as improving ocean color, land vegetation, aerosol, and cloud science.

AQUA

Aqua, another of the Earth Observing System flagship missions, also operates in the afternoon constellation of satellites, known as the A-Train. Aqua improves our understanding of Earth's water cycle and the intricacies of the climate system by monitoring atmospheric, land, ocean, and ice variables. Aqua, launched in 2002, is a joint mission with Brazil and Japan. Four of its Earth observing instruments – the Atmospheric Infrared Sounder (AIRS), the Advanced Microwave Sounding Unit (AMSU), CERES, and MODIS – continue to collect valuable data about the atmosphere, oceans, land, and ice, and these data are widely used by the science and applications communities. The 2015 Earth Science senior review endorsed the Aqua mission for continued operations through 2017. The next senior review will occur in the spring of 2017 and will re-evaluate the Aqua mission extension in terms of scientific value, national interest, technical performance, and proposed cost.

Recent Achievements

Aqua data enabled new insight on climate feedback and climate sensitivity. In 2016, this included showing that reflection of the Sun's radiation by low clouds over the tropical oceans decreases when the underlying surface warms. Scientists combined Aqua ocean data with earlier satellite records to create a consistent 36-year sea surface temperature record, extending back to 1981. These long-term records assist scientists in examining oscillations and trends within the Earth system. Aqua atmosphere data led to new discoveries regarding gravity waves in the atmosphere and have been used to create the first global maps of convectively generated concentric gravity waves, showing that these waves in the atmosphere are far more common than previously realized. Scientists use Aqua data in a wide range of applications of direct immediate importance to the nation and the world.

AURA

The Aura mission enables study of atmospheric composition, climate variability, and weather by measuring atmospheric chemical composition, tropospheric/stratospheric exchange of energy and chemicals, chemistry-climate interactions, and air quality. Launched in 2004, Aura is also part of the A-Train. It is a joint mission with the Netherlands, Finland, and the United Kingdom. Three of Aura's four instruments are operational: the Microwave Limb Sounder (MLS), the Ozone Monitoring Instrument (OMI), and the Tropospheric Emission Spectrometer (TES). Additional measurements include clouds, aerosols, solar spectral irradiance, and water vapor. The 2015 Earth Science senior review endorsed the Aura mission for continued operations through 2017. The next senior review will occur in the spring of 2017 and will re-evaluate the Aura mission extension in terms of scientific value, national interest, technical performance, and proposed cost.

Recent Achievements

Aura data benefit society by contributing to public health research and decision-making in the US and worldwide. Researchers are using the ongoing Aura record to document the rapid evolution of air pollution in many world regions. In 2016, researchers used Aura data to demonstrate clearly the success of pollutant emission controls such as the US Clean Air Act, as well as to show dramatic pollution growth in developing countries. Scientists used Aura data in 2016 to successfully identify unreported and under-reported worldwide sources of pollutants (e.g., sulfur dioxide) that impact global air quality and climate. Researchers used the Aura stratospheric column ozone data to assess the health impact of exposure to harmful ultraviolet (UV) radiation in 2016 and use the data in the operational ozone assimilation at the NOAA National Centers for Environmental Prediction (NCEP) for weather and UV Index forecasts.

SOLAR RADIATION AND CLIMATE EXPERIMENT (SORCE)

The SORCE mission measures the total and spectral solar irradiance incident at the top of 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. SORCE, launched in 2003, is in extended operations. SORCE's solar observations have significantly advanced our understanding of solar radiative forcing of Earth's environment.

In order to maintain the 38-year long total solar irradiance (TSI) record, the TSI Calibration Transfer Experiment (TCTE) was launched in 2013 to be the bridge for the TSI record between the aging SORCE satellite and the future NASA Total Spectral Irradiance Sensor (TSIS) mission. NASA is developing TSIS-1 for the International Space Station (ISS), and its solar observations will begin in early 2018. NASA will end the SORCE mission in 2018, after a 15-year operating life.

Recent Achievements

In 2016, the SORCE mission made significant improvements in TSI accuracy. The project established a new solar spectral irradiance (SSI) record for the near ultraviolet, visible, and near infrared wavelength ranges that together comprise almost 95% of the Sun's total energy. Important in these solar records is the amount that the TSI and SSI increase and decrease over an 11-year period; this is known as the solar activity cycle.

STRATOSPHERIC AEROSOL AND GAS EXPERIMENT III (SAGE-III)

The Stratospheric Aerosol and Gas Experiment III (SAGE-III) will provide 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

SAGE III launched on SpaceX-10 on February 19, 2017.

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.

ISS-RapidScat, installed on ISS in October 2014, is a space-based scatterometer that replaces the inoperable SeaWinds payload aboard the QuikSCAT satellite. Scatterometers are radar instruments that measure wind speed and direction over the ocean, and are useful for weather forecasting, hurricane monitoring, and observations of large-scale climate phenomena, such as El Niño. The ISS RapidScat instrument enhances measurements from other international scatterometers by crosschecking their data, and demonstrates a unique way to replace an instrument aboard an aging satellite. The RapidScat instrument used spare parts from QuikSCAT to provide a demonstration of the earth observing capabilities of the ISS as a platform for Earth observations.

The ISS Cloud Aerosol Transport System (CATS) instrument launched on January 10, 2015 aboard a SpaceX Dragon spacecraft, and astronauts installed it on ISS on January 23, 2015. CATS is generating data useful for improving our understanding of aerosol and cloud properties and interactions. In addition, the project will use data from CATS to advance operational aerosol forecast models to improve air quality prediction and monitoring and to improve hazard-warning capabilities for natural events (e.g., dust storms and volcanic eruptions).

The ISS Lightning Imaging Sensor (LIS) will make space-based lightning observations, and will provide important continuity in the lightning data record obtained by the TRMM spacecraft (1997–2015). LIS observations continue to support and 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.

Recent Achievements

In its 18 months of operation to-date, CATS has generated an unprecedented 1.5 billion laser pulses on-orbit. In the long term, CATS is generating data useful for improving our understanding of aerosol and cloud properties and interactions. In addition, the ISS platform allows near-real time data availability, allowing use of CATS data in operational aerosol forecast models to improve air quality prediction and monitoring and to improve hazard-warning capabilities for natural events (e.g., dust storms and volcanic eruptions). The modeling and research community is actively engaged in using CATS data as a means to complement and extend the CALIPSO data set.

After a power system anomaly, ISS-RapidScat ceased functioning in August 2016. The nearly two year data set from the instrument is valuable in providing a cross-calibration with various polar-orbiting wind missions and providing a look at the diurnal variability of wind over the tropical and mid-latitude oceans. Initial analysis of the RapidScat data has provided evidence of diurnal variability of wind jets near coasts.

Space-X launched the ISS-LIS instrument on SpaceX-10 on February 19, 2017 and delivered it to the ISS for integration.

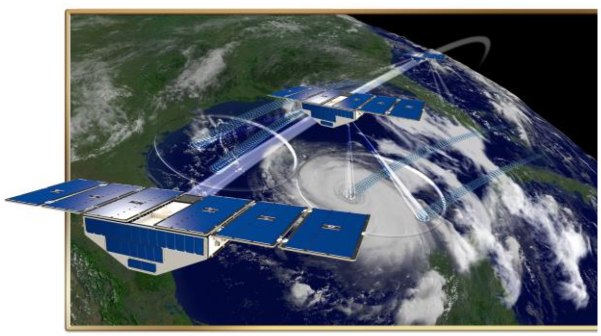
EARTH SYSTEM SCIENCE PATHFINDER

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Venture Class Missions	151.1	--	**199.1**	174.0	184.0	199.7	202.5
Other Missions and Data Analysis	82.5	--	**65.4**	69.7	72.0	71.9	65.7
Total Budget	**233.6**	**--**	**264.5**	**243.8**	**256.0**	**271.5**	**268.3**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



Launched on 15 December 2016 CYGNSS consists of a constellation of eight micro-satellites, each carrying a 4-channel radar receiver that measures GPS navigation signals scattered by the ocean surface. The radars are measuring surface winds with high temporal resolution, under all precipitating conditions, and over the full dynamic range of wind speeds. The system will be calibrated and ready to measure hurricane inner core surface winds during the upcoming 2017 Atlantic Hurricane season.

The 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 whose scientific objectives support a variety of studies lead these missions, including studies of the atmosphere, oceans, land surface, polar ice regions, or solid Earth.

ESSP projects include space missions and remote sensing instruments for space-based missions of opportunity or extended duration airborne science missions. The ESSP program also supports the conduct of science research utilizing data from these missions. ESSP projects often 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 2018

In March 2016, NASA selected MAIA and TROPICS from the third Earth Venture Instrument (EVI-3) Announcement of Opportunity. NASA also selected GeoCarb from the second Earth Venture Mission (EVM-2) Announcement of Opportunity.

In light of budget constraints and higher priorities within the Science budget, no funding is requested for the Orbiting Carbon Observatory-3 (OCO-3), which was not recommended in the last Earth Science

Decadal Survey. OCO-3 was to investigate the distribution of carbon dioxide on Earth as it relates to growing urban populations and changing patterns of fossil fuel combustion. These measurements are currently being taken by NASA's OCO-2 mission as well as the Japanese satellite GOSAT. Future measurements of carbon dioxide are planned by Japan (GOSAT-2) and the European Space Agency (Carbonsat). NASA will complete the instrument and deliver to storage.

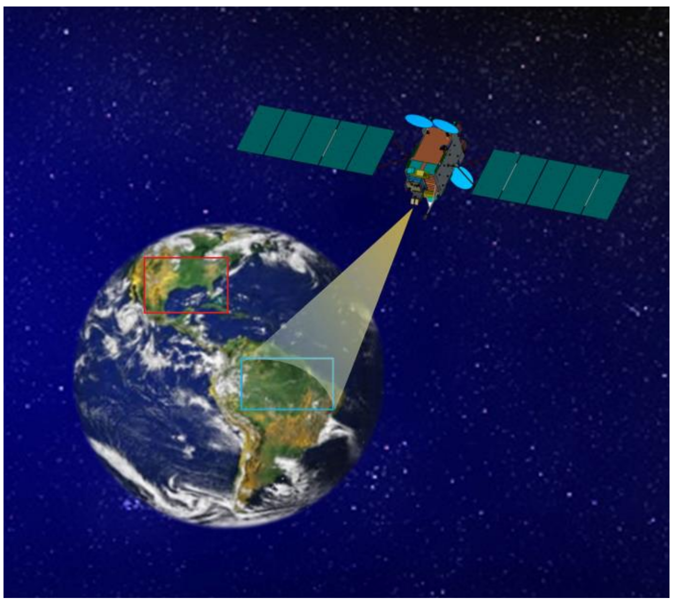
VENTURE CLASS MISSIONS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	151.1	--	199.1	174.0	184.0	199.7	202.5

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



Measurements from NASA's new Earth Venture Mission-II, GeoCarb, will change our understanding of the carbon cycle's terrestrial source/sink dynamics by providing high-spatial resolution daily mapping from geostationary orbit of the carbon dioxide, methane and carbon monoxide over much of the Americas. GeoCarb will help us understand why the global Carbon Cycle is changing, how gas emissions that trap heat vary with population, and how variations in the biosphere affect the natural uptake and emissions of carbon dioxide and methane.

NASA's Earth Venture Class project provides frequent flight opportunities for high-quality earth science investigations that are low cost and that can be developed and flown in five years or less. NASA will select the investigations through open competitions to ensure broad community involvement and encourage innovative approaches. Successful investigations will enhance our capability to understand the current state of the Earth system and to enable continual improvement in the prediction of future changes. Solicitations will alternate between space-borne and airborne/suborbital opportunities.

NASA established the Venture Class project in response to recommendations in the National Academies' report, "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond."

The Earth Venture Class project consists of three types of activities:

- Earth Venture Suborbital (EVS) are sustained suborbital science investigations. NASA caps each solicitation at $150 million in FY 2014 dollars, and selects multiple investigations within each call, individually capped at $30 million. The EVS solicitations will be made at four-year intervals;
- Earth Venture small Missions (EVM) are small space-based missions. Each solicitation is cost capped at $166 million in FY 2018 dollars. The EVM solicitations will be made at four-year intervals; and

VENTURE CLASS MISSIONS

- Earth Venture Instruments (EVI) will fly on space-borne platforms, which NASA will select. Each solicitation is cost capped at $97 million in FY 2018 dollars. NASA will release EVI solicitations at no more than 18-month intervals.

EXPLANATION OF MAJOR CHANGES IN FY 2018

None.

ACHIEVEMENTS IN FY 2016

Under the EVS-1 portfolio, the Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS), Airborne Tropical TRopopause Experiment (ATTREX), Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE), and Hurricane and Severe Storms Sentinel (HS3) missions all successfully completed the KDP-F review process and closed out in FY 2016.

Under the EVS-2 portfolio, the Atmospheric Carbon and Transport America (ACT-America), Atmospheric Tomography Mission (ATom), COral Reef Airborne Laboratory (CORAL), Oceans Melting Greenland (OMG), and ObseRvations of Aerosols above CLouds and their intEractionS (ORACLES) missions all moved into data collection phase and completed first airborne deployments in FY 2016. Deployments for ACT-America took place in the eastern U.S., ATom with a global transit, CORAL over the Great Barrier Reef in Australia, OMG in Greenland, and ORACLES in Namibia, Africa. Additionally, the North Atlantic Aerosols and Marine Ecosystems Study (NAAMES) mission completed a second airborne deployment over the North Atlantic during FY 2016.

TEMPO held a successful Critical Design Review in May 2016 for the ground system elements (Instrument Operations Center and Science Data Processing Center). Development began on the major instrument subsystems and on the science data processing code. The project successfully held the instrument Test Readiness Review in August 2016. The USAF Space and Missile Systems Center continued to work on the Statement of Work for the TEMPO hosting contract.

The ECOSTRESS project is in full development after passing CDR in April 2016.

The GEDI project successfully completed both their PDR and their confirmation review in 2016.

MAIA and TROPICS held their kick-off meetings after NASA selection announcement and began staffing their projects.

WORK IN PROGRESS IN FY 2017

The EVS-2 missions will all deploy during FY 2017: ACT-America to the northeast U.S. during Q2, ATom on a global transit during Q2, CORAL to Hawaii in Q2 and to the Marianas Islands and Palau in Q3, NAAMES to the North Atlantic in Q4, OMG to Greenland in Q2 and in Q4, and ORACLES to Namibia in Q4. Data from the first deployments are available now or will become available to the public during FY 2017. NASA plans to release the NASA Research Announcement for EVS-3 in FY 2017.

The development of the TEMPO instrument will continue upon the completion and integration of subsystems. Additionally, the project will begin instrument-level testing and continue to work on the data processing code development. NASA plans to complete and release the hosting Request for Proposals (RFP).

The ECOSTRESS project is working towards payload completion by June 2017.

The GEDI project held its CDR in February 2017, and started hardware procurement and manufacturing. Integrating and testing will follow in late 2017 and continue through 2018.

MAIA plans to hold the SRR and conduct KDP-B to move into the design phase.

TROPICS is currently in formulation and will hold their SRR and KDP-B review.

NASA selected the Geostationary Carbon Cycle Observatory (GeoCarb) from the EVM-2 solicitation and it is currently in formulation.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

CORAL will complete data analysis, complete the KDP-F review, and close out. The remaining five EVS-2 missions will continue data collection.

NASA plans to complete the TEMPO instrument for integration onto a host spacecraft, release the RFP for procuring a host, and award the contract.

NASA will install ECOSTRESS on the ISS.

Integration and test of GEDI will continue through 2018.

MAIA project will conduct its PDR and hold the confirmation review to enter implementation.

TROPICS will conduct its PDR and hold its confirmation review prior to entering implementation.

GeoCarb will hold its SRR and conduct KDP-B.

Program Elements

CYGNSS (EVM-1, SELECTED IN 2012)

CYGNSS will make accurate measurements of ocean surface winds throughout the life cycle of tropical storms and hurricanes, leading to better weather forecasting. CYGNSS data will enable scientists to probe from space key air-sea interaction processes that take place near the inner core of the storms, which are rapidly changing, and play large roles in the genesis and intensification of hurricanes. The CYGNSS measurements will also provide 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 will receive both direct and reflected signals from GPS satellites. The direct GPS signals pinpoint CYGNSS observatory positions, while the reflected signals are indicative of ocean surface roughness. Scientists will use both measurements to derive the critical measurement of wind speed. CYGNSS has completed development and launched in December 2016. CYGNSS has entered the operational phase and will conduct its prime mission for 24 months.

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 later 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.

The project will procure the commercial host spacecraft service through the USAF 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 2021.

ECOSYSTEM SPACEBORNE THERMAL RADIOMETER EXPERIMENT ON SPACE STATION (ECOSTRESS) (EVI-2, SELECTED IN 2014)

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.

ECOSTRESS will fill a key gap in our observing capability, advance core NASA and societal objectives, and allow 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.

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 instrument will be the first to systematically probe the depths of the forests from space by using a lidar instrument from the ISS and will provide a unique 3D view of Earth's forests and provide information about their role in the carbon cycle. The GSFC will build and manage the instrument.

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, coarse, sulfate, nitrate, organic and black carbon, and mineral dust particles in major urban areas around the globe on a one kilometer grid. The MAIA instrument uses multi-angle and multispectral radiometry and polarimetry to retrieve aerosol optical depths of different particle types, and then uses these data to correlate with birth, death, and hospital records. Additionally, MAIA will use established epidemiological methodologies to correlate the exposure to particulate matter with adverse health outcomes.

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 nearly all-weather observations of 3D temperature and humidity, as well as 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 12 CubeSat's 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).

GEOSTATIONARY CARBON CYCLE OBSERVATORY (GEOCARB) (EVM-2, SELECTED IN 2016)

NASA selected Geostationary Carbon Cycle Observatory (GeoCarb) in December 2016 as part of the agency's second Earth Venture Mission announcement of opportunity.

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 and 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 PI-led 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.

EARTH VENTURE MANAGEMENT

The Earth Venture Management project provides for the development of AO solicitations and the Technical, Management, and Cost (TMC) evaluations of proposals received in response to the AO solicitations. Additionally, this project supports Common Instrument Interface activities to identify a common set of earth science instrument-to-spacecraft interface guidelines that will improve the likelihood that these instruments can take advantage of future hosted payload opportunities.

In addition, as funding and opportunities permit, NASA supports a small number of technology studies, in an effort to prepare these technologies to compete in future Earth Venture solicitation. In 2015, NASA selected two technology demonstration efforts from EVI-2:

- Green OAWL (GrOAWL): The GrOAWL Demonstrator effort is reducing risk for a potential future ATHENA-OAWL Doppler Wind Lidar mission by providing validated airborne wind profiles measured with a 532-nanometer version of the Optical Autocovariance Wind Lidar instrument. The University of Colorado managed this work, and Ball Aerospace Corporation built the GrOAWL instrument. NASA conducted flight tests in the third quarter of FY 2016 and expects data analysis to complete in the first quarter of FY 2017.
- Temporal Experiment for Storms and Tropical Systems-Demonstrator (TEMPEST-D): As a technology demonstration effort, a TEMPEST-Demonstrator is reducing the risk for a potential future TEMPEST mission that will provide the first global observations of the time evolution of precipitation. TEMPEST-D provides for a single six-unit CubeSat with the required set of five millimeter-wave frequencies from 89 to 183 GHz. With launch scheduled for the third quarter of FY 2018, TEMPEST-D will validate existing airborne and satellite-based millimeter-wave radiometer data through geolocation, calibration, and intercalibration of brightness temperatures with the GMI and other available satellite radiometers. Colorado State University is leading this work, and JPL is building the 5-frequency radiometer instrument.

VENTURE CLASS FUTURE MISSIONS

Earth Venture Class Future Mission funding supports future Earth Venture Suborbital, Earth Venture small Missions, and Earth Venture Instruments through AO solicitations.

EARTH VENTURE SUBORBITAL-2 (EVS-2; SELECTED IN 2014) INVESTIGATIONS INCLUDE:

- 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).
- 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.

- ACT-America quantifies the sources of regional carbon dioxide, methane and other gases, and documents how weather systems transport these gases in the atmosphere.
- 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.
- 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 (selected in FY 2015) investigation will analyze 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.

Program Schedule

Date	Significant Event
Jun 2016	GEDI Confirmation Review
Jul 2016	EVI-4 (instrument) solicitation released
May 2017	CYGNSS launch readiness
2017	EVS-3 (suborbital) solicitation released
2017	ECOSTRESS Instrument Delivery to ISS
2019	GEDI Instrument Delivery to ISS
2018	EVI-5 (instrument) solicitation released
2019	EVM-3 (mission) solicitation released
2019	GEDI launch readiness
2019	ECOSTRESS launch readiness
2020	EVI-6 (instrument) solicitation released
2021	TEMPO launch readiness
2021	MAIA launch readiness

VENTURE CLASS MISSIONS

Program Management & Commitments

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
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
EVM-1: CYGNSS	Provider: University of Michigan Lead Center: LaRC Performing Center(s): N/A 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

VENTURE CLASS MISSIONS

Program Element	Provider
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
EVI-3: MAIA	Provider: JPL Lead Center: JPL Performing Center(s): JPL 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

Acquisition Strategy

NASA anticipates issuing a solicitation for a Venture Class element at least once a year. 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

VENTURE CLASS MISSIONS

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Apr 2016	GEDI PDR	Successful	Jun 2016
Performance	SRB	Apr 2016	ECOSTRESS CDR	Successful	FY 2019 Q4
Performance	SRB	Jun 2016	GEDI KDP-C Milestone Review to determine readiness to enter development	Successful	Feb 2017
Performance	SRB	Aug 2016	CYGNSS ORR	Successful	N/A
Performance	SRB	Feb 2017	GEDI CDR	TBD	FY 2018 Q2
Performance	SRB	FY 2017 Q2	TROPICS SRR	TBD	FY 2017 Q2
Performance	SRB	FY 2017 Q2	TROPICS KDP-B	TBD	FY 2017 Q4
Performance	SRB	FY 2017 Q2	MAIA SRR/IDR	TBD	FY 2017 Q3
Performance	SRB	FY 2017 Q3	MAIA KDP-B Milestone review to determine readiness to begin design	TBD	FY 2018 Q1
Performance	SRB	FY 2017 Q4	TROPICS PDR	TBD	FY 2017 Q4
Performance	SRB	FY 2017 Q4	TROPICS KDP-C	TBD	TBD
Performance	SRB	FY 2018 Q1	MAIA PDR	TBD	FY 2018 Q2
Performance	SRB	FY 2018 Q2	TEMPO KDP-C Milestone Review to establish hosting costs	TBD	FY 2021 Q3
Performance	SRB	FY 2018 Q3	MAIA KDP-C Milestone review to determine readiness to enter development	TBD	FY 2019 Q1
Performance	SRB	FY 2018 Q2	GEDI ORR	TBD	N/A
Performance	SRB	FY 2019 Q1	MAIA CDR	TBD	FY 2021 Q4
Performance	SRB	FY 2019 Q4	ECOSTRESS ORR	TBD	N/A
Performance	SRB	FY 2021 Q3	TEMPO ORR	TBD	N/A
Performance	SRB	FY 2021 Q4	MAIA ORR	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
ESSP Missions Research	16.7	--	**11.9**	13.6	16.3	20.5	21.2
Orbiting Carbon Observatory-3	33.1	--	**0.0**	0.0	0.0	0.0	0.0
Small Satellite Constellation Initiative	0.0	--	**25.6**	25.2	25.8	25.4	25.0
OCO-2	9.4	--	**10.1**	10.4	10.0	10.2	10.4
Aquarius	2.7	--	**0.0**	0.0	0.0	0.0	0.0
GRACE	5.6	--	**2.4**	4.7	3.8	0.0	0.0
CloudSat	9.1	--	**8.8**	9.1	9.4	9.6	4.4
Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO)	6.0	--	**6.5**	6.6	6.7	6.2	4.8
Total Budget	**82.5**	**--**	**65.4**	**69.7**	**72.0**	**71.9**	**65.7**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

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.

Recent Achievements

NASA research continues to improve the methods for incorporating GRACE information into Land Surface models. Scientists have refined the assimilation approach combining GRACE Terrestrial Water Storage into the NASA Catchment model, run in the North American Land Data Assimilation Systems framework. The resulting assimilation shows improved modeling of variability of unconfined groundwater across the eastern United States, when evaluated with in situ observations, and small improvements of modeled snow depth fields.

GRACE studies of the 2012 Indian Ocean magnitude 8.6 and 8.2 earthquakes revealed coseismic (points on the earth's surface at which an earthquake wave arrives simultaneously) compression and dilatation within the oceanic crust and upper mantle and vertical motion after the earthquakes, demonstrating the potential for satellite gravity missions to contribute to earthquake research.

In order to better assess the water cycle, scientists have investigated the hemispheric (half of the globe) energy balance using radiative flux (amount of power radiated through an area) and ocean heat data, as well as recent simulations with fully coupled climate models. They found more energy is absorbed in the Southern Hemisphere resulting in a northward, cross equatorial heat transport by the oceans and a southward heat flow in the atmosphere. Hemispheric precipitation was also found to be approximately balanced, with slightly more precipitation falling in the Northern Hemisphere than in the Southern Hemisphere. Because CloudSat observations show that it rains more frequently in the Southern Hemisphere, this implies that it rains more intensely in the Northern Hemisphere.

The marine boundary layer (MBL) is the layer of air over the ocean in close contact with the surface, and important processes involving the exchange of heat, momentum, and moisture between the oceans and the lower atmosphere occur within it. A layer of low clouds often caps the MBL, playing an important role in the heat balance of the Earth. A recent study utilized observations from the CALIPSO satellite to examine for the first time the climatology and seasonal variations of the MBL structure over the eastern Pacific region, successfully identifying and characterizing the behavior of both the top of the boundary layer and details of its internal structure. Specifically, the study found that strong vertical mixing within the MBL often did not extend to its top, but it tends to be better mixed under overcast conditions. This study demonstrated that satellite lidar measurements could be used to characterize the MBL over global oceans, which is not possible using other techniques.

SMALL SATELLITE CONSTELLATIONS INITIATIVE

The Small Satellite Constellation Initiative focuses on increasing the use and utility of constellations of small satellites to acquire Earth observation data required for Earth system science research. NASA designed the initiative to enable, foster, and encourage spaceflight solutions for Earth science missions that involve the use of multiple, instrumented small satellites flying in various tight or loose formations, to achieve the quality and quantity of data required by the research and applications communities. The project will capitalize on the increasing availability of low-cost, miniaturized small satellites and instruments to investigate and demonstrate the science capabilities and programmatic robustness of small satellite constellations in comparison with traditional single-mission, multi-instrument satellite observatories.

Potential small satellite constellation activities include on-orbit technology validation and risk reduction for small instruments; fostering commercial launch services dedicated to transporting small payloads into orbit; funding competitive grants for small satellite proposals; and exploring governance models to incentivize Center involvement in small satellite constellation proposals.

Recent Achievements

NASA released an RFI in July 2016 with an initial focus on GPS radio occultation and land imaging data. The RFI also requested that responders address any data constraints that would be levied on NASA (to include access to NASA-funded researchers and distribution of purchased data) and share the present and near-term (three to five year) planned availability of data products for purchase and evaluation by NASA. Responses addressed a broad set of data (not just GPS radio occultation and Land imaging). NASA will release a request for proposals in 2017.

OTHER MISSIONS AND DATA ANALYSIS

Operating Missions

OCO-2

Since the beginning of the industrial age, the concentration of carbon dioxide in the Earth's atmosphere increased more than 38 percent. Scientific studies indicate that carbon dioxide is one of several gases that trap heat near the Earth's surface. Most scientists have concluded that substantial increases in carbon dioxide in the atmosphere will increase the Earth's surface temperature.

From its vantage point in low Earth orbit, OCO-2 collects hundreds of thousands of precise carbon dioxide measurements across the globe each day. With these data, scientists are gaining greater insight into how much of carbon dioxide the Earth emits by natural sources and human activities, and into 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.

Recent Achievements

OCO-2 successfully reached the conclusion of the two-year prime operating mission in October 2016. It continues to produce high science quality data in extended mission. Several studies have used the data from OCO-2 to describe the balance between terrestrial and oceanic processes, as was evidenced by the effects from the significant El Nino event that occurred right after the launch of OCO-2. Additionally, there are other studies documenting the effects of more localized emissions of CO2 using OCO-2 data.

GRAVITY RECOVERY AND CLIMATE EXPERIMENT (GRACE)

Gravity Recovery and Climate Experiment (GRACE) measures minute changes in Earth's gravity field by measuring micron-scale variations in the separation between the two spacecraft that fly in formation 220 kilometers apart in low Earth orbit. Local changes in Earth's mass cause the variations in gravitational pull. GRACE demonstrated a new paradigm of observations that utilizes ultra-small variations of Earth's gravity field, as small as one-billionth the surface force of gravity. With this capability, GRACE was the first mission to provide a comprehensive measurement of the monthly change in the ice sheets and major glaciers. GRACE provided significant new information on changes in water resources within river basins and aquifers worldwide, and measured the effects of major earthquakes around the world. NASA developed the twin GRACE satellites in collaboration with German Aerospace Center (DLR).

The 2015 Earth Science senior review endorsed the GRACE mission for continued operations through 2017 and preliminarily through 2019, or until re-entry, currently projected to occur in 2018. The next senior review will occur in 2017, and will re-evaluate the GRACE mission extension in terms of scientific value, national interest, technical performance, orbit status, and proposed cost in relation to NASA Earth Science strategic plans. Assuming re-entry in 2018, the FY 2019-20 funding would support final data processing and closeout activities.

Recent Achievements

Since launch in 2002, GRACE provided unprecedented insights into changes in ground and surface water, polar ice sheet and glacier melt and its contribution to sea level change, ocean mass and circulation changes, and earthquakes. Since 2014, GRACE helped reveal the true extent of the California drought, and beginning in 2016, GRACE monitored in real-time the recovery of the California drought. GRACE observations are also providing crucial information for early flood detection and flood prediction around the world, as documented in 2016 publications. Based on the significant advances in both measurement capability and the analytical framework during the mission life span of 15 years, GRACE data is now an essential asset for a number of hazard assessment efforts. With the development of the capability to deliver data products soon after taking the measurement, it is now an essential input to operational drought forecasting within the framework of the US National Drought Monitor. In 2016, several international efforts were initiated that use GRACE gravity observations operationally for disaster prevention and forecasting (e.g., the multination European Gravity Service for Improved Emergency Management - EGSIEM). Furthermore, Land Data Assimilation System ingested data from GRACE that led to significant improvements in the quality of the total terrestrial water storage estimates (higher spatial and time resolution). In turn, this results in more accurate and reliable estimates of the surface, soil and ground water components. The near real-time provision of these products can support forecast and planning activities related to water use for agricultural and consumption purposes.

The planned launch of GRACE Follow-On in late 2017 will continue the valuable and successful data record, and provide data users and agencies with vital observations of Earth's water cycle.

CLOUDSAT

CloudSat measures cloud characteristics to increase understanding of the role of clouds in Earth's radiation budget. This mission specifically 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 condensates. CloudSat collects information about the vertical structure of clouds and aerosols that other Earth-observing satellites do not collect. This data improves models and provides a better understanding of the human impact on the atmosphere. CloudSat launched in 2006, and is currently in extended operations.

The 2015 Earth Science senior review endorsed the CloudSat mission for continued operations through 2017 and preliminarily through 2019. The next senior review will occur in 2017, and will re-evaluate the CloudSat mission extension in terms of scientific value, national interest, technical performance, and proposed cost in relation to NASA Earth Science strategic plans.

Recent Achievements

The CloudSat data record revealed new and unique information about cloud and precipitation processes around Earth. In 2016, CloudSat successfully reached its 10th year in orbit and laid the foundation for a long-term climate data record of the vertical distribution of clouds on Earth. More recently, the CloudSat team has developed new products that utilized data from other members of the A-Train. A new cloud product blending data from the Orbiting Carbon Observatory (OCO)-2 is near completion, which will provide precise estimates of cloud base height. The CloudSat project is currently working with the NASA Global Precipitation Measurement mission to develop a new data product of coincident satellite overpasses in order to improve estimates of precipitation around the globe.

CLOUD-AEROSOL LIDAR AND INFRARED PATHFINDER SATELLITE OBSERVATION (CALIPSO)

CALIPSO 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 provides an indirect estimate of the contribution of clouds and aerosols to atmospheric temperature. Since its launch in 2006, CALIPSO has been part of the A-Train constellation (with CloudSat, Aura, Aqua, CNES's Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar [PARASOL], JAXA's Global Change Observation Mission 1st - Water [GCOM-W1], and now OCO-2). It is in extended operations.

Atmospheric aerosols can affect Earth's radiation balance, the formation of clouds and precipitation, the chemical composition of the atmosphere, and pose a health risk when pollution levels rise. CALIPSO 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 2015 Earth Science senior review endorsed the CALIPSO mission for continued operations through 2017 and preliminarily through 2019. The next senior review will occur in 2017, and will re-evaluate the CALIPSO mission extension in terms of scientific value, national interest, technical performance, and proposed cost in relation to NASA Earth Science strategic plans.

Recent Achievements

In 2016, the CALIPSO mission produced and released new versions of standard and near real-time lidar profile data products that encompass the more than 10-year data record. These versions include extensive improvements that significantly enhance the content and quality of science data products. The mission further supported the calibration and validation of the Cloud-Aerosol Transport System lidar on the International Space Station, field campaigns investigating air quality in South Korea, the impact of smoke particles on clouds off the coast of southwest Africa, and phytoplankton ecosystems in the North Atlantic Ocean.

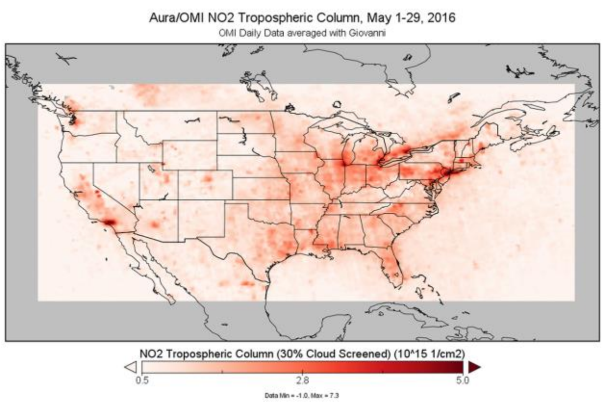
EARTH SCIENCE MULTI-MISSION OPERATIONS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	**192.4**	**--**	**196.5**	**194.1**	**200.7**	**208.6**	**218.6**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



Tropospheric Nitrogen Dioxide (NO2) measured by the Ozone Measuring Instrument (OMI) on the EOS Aura satellite, averaged over the period May 1-29, 2016. NO2 results from combustion processes, including vehicular transportation, power generation, and wildfires. NO2 is a major component of acid rain and can lead to breathing difficulties. In this image, higher NO2 concentrations primarily correspond to major urban areas.

The Earth Science Multi-Mission Operations (MMO) program acquires, processes, preserves, and distributes observational data from operating spacecraft to support Earth Science research focus areas. The MMO program primarily accomplishes this via the Earth Observing System Data and Information System (EOSDIS), which has been in operations since 1994. The EOSDIS team creates earth science data products from satellite, airborne and field campaign data that grows at the rate of up to 16 terabytes per day.

The archiving of NASA Earth Science information happens at Distributed Active Archive Centers (DAACs) located across the United States. The DAACs specialize by science discipline, and make their data available to researchers and industry around the world.

The MMO program supports the data archive and distribution for upcoming Earth Science missions. It recently began acquiring and distributing data from the European Space Agency's Sentinel missions under a bilateral agreement with the European Union. EOSDIS data centers also support Earth Ventures Suborbital campaigns. In response to the National Academies decadal survey, a system plan for 2017 and beyond will take into account evolutionary needs for new missions in development, including ICESat-2, NISAR, and SWOT. These investments will enable the system to keep technologically current, and incorporate new research data and services.

ACCESS supports the evolution of EOSDIS by investing in technology to enhance the analysis, delivery, and preservation of Earth science. 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.

EARTH SCIENCE MULTI-MISSION OPERATIONS

MMO guides a broad effort to leverage the federal government's extensive, freely available earth science data resources to stimulate innovation and private-sector entrepreneurship. This effort works closely with many federal agencies to make Earth science datasets and resources discoverable through data.gov.

For more information, go to http://science.nasa.gov/earth-science/earth-science-data.

EXPLANATION OF MAJOR CHANGES IN FY 2018

The program will expand its capabilities to support data from new missions, including GRACE Follow-on and ECOSTRESS.

ACHIEVEMENTS IN FY 2016

The EOSDIS archives grew to over 17 Petabytes in FY 2016. EOSDIS distributed over 1.5 billion data products to 2.9 million users around the world. The 2016 EOSDIS American Customer Satisfaction Index (ASCI) score was 77 – considered in the "very good" range. The EOSDIS was awarded the 2015 William T. Pecora Award, in recognition of outstanding contributions toward understanding the Earth by means of remote sensing.

The EOSDIS Common Metadata Repository (CMR) became operational in February 2016. This effort consolidated multiple metadata systems, providing a single source of unified, high-quality, reliable Earth science metadata. The EOSDIS project has dramatically improved search performance of the metadata repository; it generally returns search results in less than one second.

The EOSDIS Worldview web application allows users to browse global satellite imagery interactively within hours of image acquisition. It continued to evolve to support many new data layers through a new product navigation interface. Worldview also added a "natural events feed," which enables users to select current events, such as hurricanes and volcanic eruptions, as seen by NASA satellites. The Global Imagery Browse Services (GIBS) system, which underlies Worldview, was transitioned to a more robust, scalable operational environment as well as adding over 200 new imagery products.

EOSDIS expanded the NASA Sentinel Gateway to support data from multiple European Space Agency Sentinel missions. It is now acquiring data from Sentinel-1A, 1-B and 3-A. The gateway transfers data to the appropriate DAACs for archive and distribution to the NASA science user community.

The EOSDIS expanded the distribution of near-real-time data (within less than three hours of observation), by adding near-real-time products from the MISR, AMSR-2 and VIIRS instruments.

With agreement from the Japanese Ministry of Economy, Trade, and Industry (METI), EOSDIS opened the Terra Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data collection to everyone. Previously, only approved U.S. investigators had access to data covering the United States. Otherwise, all users had to pay a nominal fee to METI.

EOSDIS support to the Big Earth Data Initiative (BEDI) continued in FY 2016. NASA Earth Science Data Systems continued to promote community-driven, open standards for data formats, interfaces, and protocols to achieve interoperability of Earth science data products across U.S. federal agencies. To improve data discoverability, the EOSDIS DAACs continued to register their data products via Digital Object Identifiers (DOIs). The DAACs also continued their push to make data available via open standards. By the end of FY 2016, over 800 data sets were with the Open Source Project for a Network Data Access Protocol (OPenDAP), an additional way to make NASA data accessible to the community. In addition, NASA allowed any user access, via open-source, to, the EOSDIS Earthdata Search Client.

EOSDIS also initiated a comprehensive prototyping plan to evaluate the relative cost, technical performance, and security implications of utilizing commercial Cloud Computing technology. These prototypes address infrastructure/security, core functions including data archive and distribution from a Cloud, and hosting of cross-EOSDIS applications on a commercial cloud.

MMO guided efforts to increase the discoverability of earth observations through data.gov for use by local and regional communities and institutions through a public-private partnership known as the Partnerships for Resilience and Preparedness (PReP). MMO co-developed a customizable platform to integrate federal earth observations, data, and tools with regional/local users of these resources. Two key events in FY 2016 include the development of a Memorandum of Understanding between NASA and the World Resources Institute – the lead private partner in PREP, and the release of the beta platform through prepdata.org.

WORK IN PROGRESS IN FY 2017

The EOSDIS is completing interface testing with the JPSS, in preparation for support of JPSS-1 instruments, to provide continuity with EOS and Suomi NPP data records. EOSDIS DAACs are preparing to support several instruments planned to deploy on the International Space Station, including LIS, SAGE-3, and TSIS-1, as well as the CYGNSS and TEMPO missions.

Prototypes to evaluate commercial cloud technology are continuing. The project deployed the Earthdata Search Client to the Cloud in FY16, and will test the GIBS in the Cloud environment in FY 2017. NASA will continue to archive and distribute Sentinel-1A data from a commercial Cloud as we continue to evaluate performance and cost efficiency.

Support for BEDI objectives continues, as DAACs are making additional data sets compatible with OPenDAP, and adding additional data layers via GIBS. The project will continue to enhance GIBS, including adding the ability to natively support vector products, such as ocean currents and wind velocities. Worldview has created an animation capability to enable visualization of dynamic changes over time.

ACCESS proposals started in the summer of 2016 are in early stages of development. First annual reports from the two-year projects will be due in mid-summer 2017. The project will continue to make new data sets available through the PReP and data.gov effort.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

The program will support ICESat-2, GRACE Follow-on, and ECOSTRESS with increased capacity and new capabilities at the National Snow & Ice Data Center (NSIDC), Physical Oceanography, and Alaska Satellite Facility (ASF) DAACs. The program will also implement and test capabilities required for archive and distribution of the data from the NISAR and SWOT missions.

EARTH SCIENCE MULTI-MISSION OPERATIONS

Program Elements

EARTH SCIENCE MULTI-MISSION OPERATIONS

This project funds the evolution of EOSDIS elements, aimed at improving the efficiency and effectiveness of EOSDIS while reducing the cost. It also supports the twelve nationwide DAAC installations that collect, disseminate, and archive earth science data. Each DAAC focuses on a specific Earth system science discipline and provides users with data products, services, and data-handling tools unique to that specialty.

- The Alaska Synthetic Aperture Radar Facility collects data and information on sea ice, polar processes, and geophysics;
- The GSFC Earth Sciences Data and Information Services Center collects information on atmospheric composition, atmospheric dynamics, global precipitation, ocean biology, ocean dynamics, and solar irradiance;
- The LaRC DAAC collects data on Earth's radiation budget, clouds, aerosols, and atmospheric chemistry;
- The Land Processes DAAC collects land processes and land cover change data;
- The National Snow and Ice Data Center collects snow and ice data, as well as environmental information about the cryosphere and climate;
- The Oak Ridge National Laboratory DAAC collects data on biogeochemical dynamics and ecological data for studying environmental processes;
- The Physical Oceanography DAAC collects information on oceanic processes and air-sea interactions;
- The Socioeconomic Data and Applications Center collects information on human dimensions including population, sustainability, multilateral environmental agreements, natural hazards, and poverty;
- The Crustal Dynamics Data Center collects information focused on solid earth and geodesy data;
- The Ocean Biology Progressing Group produces and distributes ocean biology and biogeochemistry products;
- The Global Hydrology Research Center provides hydrological cycle and severe weather research data and information; and
- The Level 1 and Atmosphere Data Center provides a comprehensive suite of MODIS and VIIRS atmospheric products.

EARTH OBSERVING SYSTEM DATA AND INFORMATION SYSTEM (EOSDIS)

The EOSDIS project provides science data to a wide community of users, including NASA, Federal agencies, international partners, academia, and the public. EOSDIS provides users with the services and tools they need in order to use NASA's earth science data in research and creation of models. EOSDIS archives and distributes data through standardized science data products, using algorithms and software developed by Earth Science investigators.

The EOSDIS project also funds research opportunities related to EOSDIS. ACCESS projects increase the interconnectedness and reuse of key information-technology software and services in use across the spectrum of earth science investigations. ACCESS also supports the deployment of data and information systems and services that enable the freer movement of data and information. ACCESS researchers develop needed tools and services to aid in measurable improvements to earth science data access and usability.

MAKING EARTH SYSTEM DATA RECORDS FOR USE IN RESEARCH ENVIRONMENTS (MEASURES)

Researchers investigate new types of sensors to provide three-dimensional profiles of Earth's atmosphere and surface through the MEaSUREs project. There is an emphasis on linking data from multiple satellites, and then facilitating the use of this data in the development of comprehensive Earth system models. MEaSUREs may include infusion or deployment of applicable science tools that contribute to data product quality improvement, consistency, merging or fusion, or understanding. Through the MEaSUREs activity, researchers investigate the development of new high-level data products and clusters of data sets to provide information to a broad community of earth science researchers as well as other users.

NASA competitively selects MEaSUREs projects for up to five years. NASA will release a new solicitation via ROSES 2017 in February 2017. NASA will award efforts based on that solicitation in FY 2018. The last year of implementation of the 29 projects selected through the ROSES 2012 competition is FY 2017.

Program Schedule

MMO solicits research opportunities approximately every two years for ACCESS and every five years for MEaSUREs.

Date	Significant Event
Q2 FY 2017	ROSES MEaSUREs Solicitation Released
Q2 FY 2017	ROSES ACCESS Solicitation Released
Q1 FY 2018	ROSES ACCESS Solicitation Released
Q1 FY 2020	ROSES ACCESS Solicitation Released
Q2 FY 2022	ROSES MEaSUREs Solicitation Released

Program Management & Commitments

Program Element	Provider
EOSDIS core system, and Evolution of EOSDIS upgrades	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A

EARTH SCIENCE MULTI-MISSION OPERATIONS

Program Element	Provider
DAACs	Provider: Various Lead Center: GSFC Performing Center(s): GSFC, LaRC, Marshall Space Flight Center (MSFC), JPL Cost Share Partner(s): N/A

Acquisition Strategy

Research opportunities related to EOSDIS are available through NASA's ROSES announcements.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
EOSDIS Evolution & Development	Raytheon	Riverdale, MD

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	American Customer Satisfaction Index	2016	Survey current EOSDIS users to assess current status and improve future services	EOSDIS scored 77 out of 100	2017 annually

EARTH SCIENCE TECHNOLOGY

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	60.7	--	60.4	59.7	63.6	65.9	67.8

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

Developed at JPL, this Ka-band Doppler scatterometer instrument, or DopplerScatt, is an Instrument Incubator Program (IIP) effort. Pictured here with some of the project team members, DopplerScatt conducted several validation flights onboard a Department of Energy B200 aircraft in mid-September 2016, over coastal Oregon and Washington. The goal of the flights was to demonstrate the instrument's ability to take simultaneous measurements of ocean surface vector winds and currents, a fundamentally new science capability.

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 2018

None.

ACHIEVEMENTS IN FY 2016

The ESTP worked on 139 technology projects in FY 2016. Thirty-four percent of these projects advanced at least one Technology Readiness Level (TRL) during the fiscal year. In addition, NASA infused several new technologies into science measurements, airborne campaigns, data systems, or other follow-on activities during the year. As an example, in March 2016 NASA announced the selection of two proposals under the third EV-I solicitation. Both selections included significant ESTP technology: the Multi-Angle Imager for Aerosols (MAIA) instrument is a direct descendent of the Airborne Multi-angle Spectropolarimetric Imager. The Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) investigation benefits from microwave receiver technology development and the Microwave Radiometer Technology Acceleration effort. The ESTP paves the way for new and unique science measurement techniques. In FY 2016, an airborne instrument called DopplerScatt conducted several validation flights over coastal Oregon and Washington and demonstrated the first-ever simultaneous measurements of ocean surface vector winds and currents. Within the Advanced Information Systems Technology (AIST) program element, a new effort kicked off in FY 2016 to bring a secure, NASA-compliant cloud-computing platform online for research and collaboration.

WORK IN PROGRESS IN FY 2017

The ESTP began FY 2017 with 97 active projects. In early FY 2017, the program released the Advanced Information Systems Technology (AIST) program element solicitation, and selected 17 awards through the 2016 Instrument Incubator Program element solicitation, released in April 2016. The new awards under both programs will commence during FY 2017.

The In-Space Validation of Earth Science Technologies (InVEST) program element plans four launches of technology demonstrations in FY 2017. The first, launched in November 2016, is the Radiometer Assessment using Vertically Aligned Nanotubes (RAVAN) CubeSat. RAVAN will demonstrate new technology for measurements of Earth's radiation budget and features a small, accurate radiometer to measure the strength of the Earth's outgoing radiation across the entire spectrum of energy, from the ultraviolet to the far infrared.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

There will be new strategic direction in the form of the latest Decadal Survey for Earth Science and Applications from Space. This document is currently under formulation by the National Research Council of the National Academies; NASA anticipates its release in 2017. As was the case with the 2007 decadal survey, NASA expects that investments made through the ESTP will be available immediately to address the measurement goals outlined in the updated version. In addition, new solicitations are planned for FY 2018 and beyond that will aid in fully realizing the updated direction.

NASA plans four additional technology demonstration launches in FY 2018 within the InVEST program element.

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 help reduce the risk of new technologies in future Earth Science missions.

EARTH SCIENCE TECHNOLOGY

INSTRUMENT INCUBATOR

This project develops instrument and measurement techniques at the system level, including laboratory breadboards and operational prototypes for airborne validation. NASA currently funds 17 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 climate science. Instrument Incubator supports the development of instrument design, prototype 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.

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, Advanced Information Systems Technology (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.

EARTH SCIENCE TECHNOLOGY

Program Schedule

Date	Significant Event
Q1 FY 2017	ROSES-2016 selection no earlier than six months of receipt of proposals
Q2 FY 2017	ROSES-2017 solicitation
Q1 FY 2018	ROSES-2017 selection no earlier than six months of receipt of proposals
Q2 FY 2018	ROSES-2018 solicitation
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

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

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.

EARTH SCIENCE TECHNOLOGY

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Perform-ance	NASA Advisory Council Earth Science Subcommittee	2012	Review for success in infusion of new technologies and participation of universities in developing the new generation of technologists.	The committee was pleased with the technology program; it recommended focusing on reducing cost in missions and enabling specific measurements.	2017, 2019

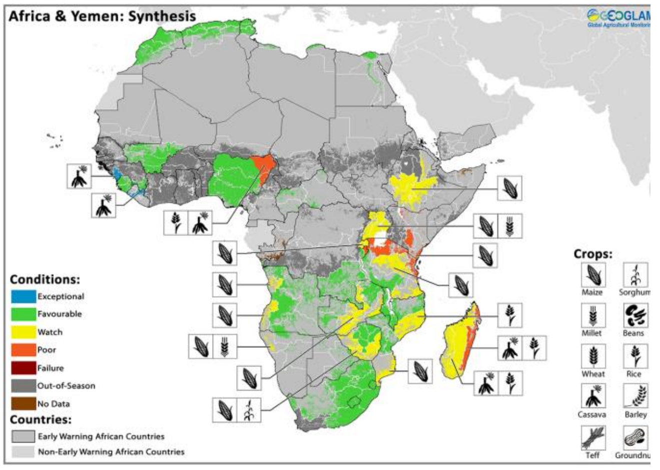
APPLIED SCIENCES

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	**47.6**	**--**	**47.9**	**49.3**	**52.8**	**54.7**	**56.3**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



The Global Agricultural Monitoring initiative (GEOGLAM), initially launched by the Group of Twenty (G20) Agriculture Ministers in June 2011, uses NASA satellite data and strengthens the international community's capacity to produce and disseminate timely forecasts of agricultural production at multiple scales with Earth observations. On a monthly basis, the GEOGLAM Crop Monitor provides transparent, in-season assessments of crop growing conditions and outputs, which helps stabilize markets and reduce price volatility. In 2016, GEOGLAM introduced a new Early Warning Crop Monitor for countries at risk of food insecurity (image for February 2017 shown above).

The NASA 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, private, and academic organizations.

Examples of these applications include:

- Use of satellite observations of volcanic ash to inform air traffic controllers and the aviation industry for hazards along major airplane routes;
- Development of drought indicators with the National Drought Mitigation Center to support end users' conservation and agriculture decisions;
- 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;
- Application of land cover information by the Nature Conservancy to conduct a reverse auction, pay landowners, and increase prime habitat for migrating wild birds;
- 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;

- Provision of satellite-based precipitation information to support flooding response and aid in decisions whether to close rivers to shipping;
- Support early warnings and risk maps of infectious diseases to help health officials anticipate outbreaks and take timely actions for disease control and prevention; and
- Improved forecasts of crop water needs in California's Central Valley to account for optimal irrigation rates when scheduling irrigation.

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 2018

None.

ACHIEVEMENTS IN FY 2016

An Applied Sciences project with the National Oceanic and Atmospheric Administration (NOAA) transitioned an application on the agricultural Evaporative Stress Index (ESI) into operational use. ESI shows the beginning of a drought 2-4 weeks before plant stress appears in current drought indicators, giving farmers considerable added lead-time to offset the effects of drought. NOAA will provide continued operational support and maintenance for the product system and provide operational data feeds to project stakeholders.

The first NASA Air Quality Applied Sciences Team (AQAST) provided new tools to air quality managers to improve forecasting and planning decisions. For example, one project worked closely with the Environmental Protection Agency, California air districts, and Western States to quantify ozone entering from outside the United States, and to learn about its effects on air quality in Western United States.

The Health and Air Quality applications area solicited proposals for a Health and Air Quality Applied Sciences Team (HAQAST), expanding the scope of AQAST to include public health topics. The Water Resources applications area issued a two-step solicitation on uses of satellite observations to detect and mitigate threats to water security and sustainability, and on water quality and agricultural water use. The Ecological Forecasting applications area issued a solicitation on uses of Earth observations for conservation and marine ecosystem management. The Disaster applications area organized strong NASA support to the response and recovery of multiple disasters, including Hurricane Matthew, Mississippi River flooding, and the Fort McMurray wildfires in Canada. NASA data enabled a Conservation International wildfires project to provide near-real-time fire information to local authorities and regional managers, helping them manage and protect forests and endangered species.

Applied Sciences conducted 11 webinars and 7 in-person workshops through Applied Remote SEnsing Training (ARSET), designed to increase the use of NASA Earth science data and models by managers, policy makers, analysts, and other applied science professionals in the areas of health, air quality, water resources, land management, and disaster response. Overall, the training reached people in all 50 states, and one five-week webinar series involved 770 people from 560 organizations across 90 countries.

APPLIED SCIENCES

The SERVIR program (managed jointly with the U.S. Agency for International Development) officially launched its new regional hub in Western Africa to enhance uses of Earth observations for decision-making and environmental monitoring with Ghana, Burkina Faso, Senegal, and Niger. SERVIR continued to streamline access to Earth science applications, tools, and data through its SERVIR product catalogue.

Applied Sciences completed the scoping study phase for the Western Water Applications Office, which involves multiple NASA Centers, to characterize the needs of water managers in Western states and to apply their scientific knowledge and NASA observations to support the managers and water districts.

Applied Sciences continued its engagement with the applications community to support NASA Earth science missions. The program supported workshops for TEMPO, OCO-2, HyspIRI, NISAR, ICESat-2, and other missions and sensors. It expanded the Early Adopter effort to promote applications research to provide a fundamental understanding of how organizations can integrate these mission data products into their policy, business, and management activities to improve decision-making efforts.

WORK IN PROGRESS IN FY 2017

The second SERVIR Applied Sciences Team will have its first full year of activities, and 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, including several focused on joint efforts with the National Park Service. 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.

The HAQAST team will hold its first team meetings in Atlanta and Seattle, expanding efforts to engage stakeholders and air quality and public health managers. They will scope their first round of tiger team projects.

The Earth Science Division takes over the NASA International Space Apps Challenge from the Office of the Chief Information Officer in FY 2017, and the Applied Sciences Program will manage this effort. The focus of the Challenge will be on Earth science data.

Applied Sciences will continue its engagement with the applications community as part of current and future NASA earth science missions, and it will support implementation of the forthcoming guidance on the inclusion of applications in flight mission concepts.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

Applied Sciences will deliver results in projects focused on water resource decisions with an emphasis on drought. The projects address advances in the long-term (30-180 day) outlooks of water supply anomalies and their effective use by water managers, their organizations, and decision-makers. The program will deliver results in projects focused on use of Earth observations in health and air quality, and HAQAST will deliver results from its tiger team projects.

APPLIED SCIENCES

FY 2018 will be the first full year for work on agriculture and food security, for work supporting the Group on Earth Observations' Work Programme, and for work on the Sustainable Development Goals. The Program will have the first results from the consortium on socioeconomic impact assessments.

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 for supporting developing countries, ARSET for professional-level training on Earth observations, and DEVELOP for workshop development through hands-on internships with state and local governments.

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. The Mission and Applied Research project enables end user engagement to identify applications early and throughout mission life cycle, integrate end-user needs in design and development, enable user feedback, and broaden 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 the mission 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 to ensure timely, valuable support to responders when disasters occur. The Disaster Support project sponsors the use and integration of Earth observations in disaster-related organizations' decisions and actions, 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. This project pursues partnerships with disaster groups that can carry forward NASA-developed information and tools to support the responders they serve.

APPLICATIONS

The Applications project organizes its development activities on priority themes related to societal and economic topics important to end user communities and their management, policy, and business activities. The Applications project sponsors the integration of Earth observations in community organizations' decisions and actions. Specific topics within an area evolve to reflect new priorities and opportunities. There are four formal applications areas in Ecosystems, Health, and Water and Wildfires. The project will conduct ad hoc activities on other themes and formalize areas when warranted or additional resources are available. Each applications area supports 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.

Program Schedule

Date	Significant Event
2016 Q1	ROSES-2015 solicitation
FY 2016 Q2	ROSES-2016 selection no earlier than six months of receipt of proposals
FY 2017 Q2	ROSES-2017 selection no earlier than six months of receipt of proposals
FY 2018 Q2	ROSES-2018 selection no earlier than six months of receipt of proposals
FY 2019 Q2	ROSES-2019 selection no earlier than six months of receipt of proposals
FY 2020 Q2	ROSES-2020 selection no earlier than six months of receipt of proposals
FY 2021 Q2	ROSES-2021 selection no earlier than six months of receipt of proposals

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, 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: HQ Performing Center(s): ARC, GSFC, JPL, LaRC, MSFC, Cost Share Partner(s): USAID
Disaster Support	Provider: Various Lead Center: HQ Performing Center(s): 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

None.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Relevance	Applied Sciences Advisory Committee	Mar 2016	Review strategy and implementation. Reports to NASA SMD/Earth Science Division Director.	Decision to pursue Applications topic in NAS Continuity Study	Dec 2016; semi-annual

PLANETARY SCIENCE

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Planetary Science Research	274.0	--	**291.5**	295.1	298.4	298.9	304.7
Discovery	189.0	--	**306.1**	425.4	488.3	376.8	375.2
New Frontiers	194.0	--	**82.1**	121.7	169.4	227.8	307.0
Mars Exploration	513.0	--	**584.7**	562.5	530.4	356.9	450.7
Outer Planets and Ocean Worlds	261.0	--	**457.9**	318.1	229.3	446.2	267.2
Technology	197.0	--	**207.2**	198.6	200.6	204.8	206.6
Total Budget	**1628.0**	**--**	**1929.5**	**1921.4**	**1916.4**	**1911.4**	**1911.4**

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Planetary Science

PLANETARY SCIENCE RESEARCH

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Planetary Science Research and Analysis	163.2	--	**197.9**	201.2	201.2	201.2	201.2
Directorate Management	3.3	--	**0.0**	0.0	0.0	0.0	0.0
Near Earth Object Observations	50.0	--	**50.0**	50.0	50.0	50.0	50.0
Other Missions and Data Analysis	57.5	--	**43.6**	43.9	47.2	47.7	53.5
Total Budget	**274.0**	**--**	**291.5**	**295.1**	**298.4**	**298.9**	**304.7**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

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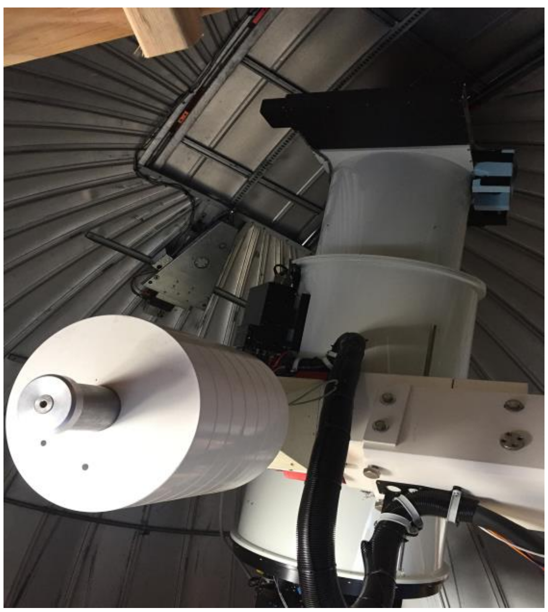

Asteroid Terrestrial-impact Last Alert System (ATLAS 2) on Maunaloa, Hawai'i. ATLAS is an asteroid impact early warning system developed by the University of Hawaii and funded by NASA. It consists of two telescopes, 100 miles apart, which automatically scan the whole sky every night looking for nearby small asteroids. The ATLAS system has found 29 previously unknown Near Earth Asteroids as of March 2017. ATLAS will provide one day's warning for impact of a 30-kiloton equivalent event, a week for a 5-megaton event, and three weeks for a 100-megaton impact event.

The Planetary Science Research program provides the scientific foundation for data sets 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:

- Explore and observe the objects in the solar system to understand how they formed and evolved;
- Advance the understanding of how the chemical and physical processes in our solar system operate, interact, 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

PLANETARY SCIENCE RESEARCH

- Identify and characterize objects in the solar system that pose threats to Earth or offer resources for human exploration.

EXPLANATION OF MAJOR CHANGES IN FY 2018

The requested increase for Research and Analysis includes a transfer of responsibility and funding from the Joint Robotics Program for Exploration (see page PS-9), and maintains balance between research and flight program elements within Planetary Science.

ACHIEVEMENTS IN FY 2016

NASA's Planetary Science Research Program produced a number of exciting results in FY 2016:

A new study by NASA scientists suggests that Venus—a hot, volcanically active planet, with an atmosphere consisting primarily of carbon dioxide—may have been the first habitable planet in the solar system. Researchers created a suite of three-dimensional climate simulations using topographic data from the Magellan mission, solar spectral irradiance estimates for 2.9 and 0.7 billion years ago, present day Venus orbital parameters, an ocean volume consistent with current theory and measurements, and an atmospheric composition estimated for early Venus. Using these parameters, scientists found that such a world could have had moderate temperatures if Venus had a rotation period slower than about 16 Earth days, despite an incident solar flux 46 to 70 percent higher than modern Earth receives. At its current rotation period of 243 days, Venus's climate could have remained habitable until at least 715 million years ago, if it hosted a shallow primordial ocean. These results demonstrate the vital role that rotation and topography play in understanding exoplanetary Venus-like worlds scientists are now discovering.

Several planetary satellites have shown evidence of subsurface seas, making them interesting for their possible habitability. Scientists have used data from NASA's Cassini mission to determine that Saturn's moon, Enceladus, has a subsurface ocean. Enceladus vigorously vents liquid water and vapor from fractures within a south polar depression, indicating that it must have a liquid reservoir or active melting. Using measurements of control points across the surface of Enceladus accumulated over seven years, scientists found a forced physical libration (oscillation motion in its orbit) too large to be consistent with a rigid connection between Enceladus's core and its surface. This implies the presence of a global ocean, rather than a localized polar sea.

The Solar System Exploration Research Virtual Institute (SSERVI) had a highly productive third year of operations, producing over 140 peer-reviewed publications by its nine domestic teams, hosting numerous in-person and virtual scientific events and conducting a wide range of research projects at the intersection of human space exploration and planetary science. The SSERVI dust accelerator, housed at the University of Colorado, studies important impact phenomena relevant to both human exploration and space weathering (damage that occurs to any object exposed to the harsh environment of outer space). It has developed two new facilities that allow researchers to 1) study micrometeoroid ablation in our upper atmosphere and 2) investigate impact dynamics into icy substrates (analogs to permanently shadowed lunar craters). To demonstrate synergies between human and robotic exploration of other worlds, NASA conducted geologic fieldwork at two volcanic structures and one impact basin in both the U.S. and Canada. Researchers are testing new handheld geophysical tools developed at these remote field sites, which led to new protocols for discovery, characterization, and utilization of water volatiles. A SSERVI scientist discovered evidence that the Moon's rotational axis has "wandered" approximately six degrees, which could provide new clues on where water ice could exist around the poles of the Moon. Another SSERVI scientist developed a new simulated asteroid regolith that will allow for more accurate testing of future operations on the surfaces of small bodies and the moons of Mars. SSERVI increased its international presence through new partnerships with both South Korea and France in FY 2016.

In FY 2016, asteroid search teams funded by NASA's Near Earth Object Observation (NEOO) Program found another eight asteroids larger than one kilometer in size with orbits that come close to Earth's vicinity. Asteroid search teams also found 1,850 smaller asteroids less than one kilometer in size, along with three additional Earth-approaching comets. This brings the total known population of Near Earth Objects (NEOs) to 14,996 (as of September 30, 2016). The high-precision orbit predictions computed by the Center for Near-Earth Object Studies at NASA's Jet Propulsion Laboratory (JPL) show that none of these objects is likely to strike Earth in the next century. However, 1,733 small bodies (of which 156 are larger than one kilometer in diameter), with 120 found this year, are in orbits that could become a hazard in the more distant future and warrant continued monitoring.

WORK IN PROGRESS IN FY 2017

In pursuit of fundamental science that guides planetary exploration, the Planetary Science Research program continues to select highly rated research and analysis (R&A) proposals that support planetary missions and goals. Planetary science is also archiving and distributing relevant mission data to the science community and the public in a timely manner.

The NEOO project supports a network of university- and space institute-owned and operated 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 Wide-field Infrared Survey Explorer (WISE) mission, and support increased follow-up and analysis of this data;
- Increase collection of NEO detection and characterization data by the University of Hawaii operated Panoramic Survey Telescope and Rapid Reporting System (Pan-STARRS) with the start of operations of the Pan-STARRS-2 telescope;
- Standup operations of the two new sites of ATLAS by University of Hawaii for detection of smaller asteroids days to weeks before possible impact;
- Fully integrate the operations, analysis and archive of small body data by the Minor Planet Center into the Small Bodies Node of the NASA Planetary Data System;
- Support the continued and enhanced operation of planetary radar capabilities at the National Science Foundation's Arecibo and NASA's Goldstone facilities; and
- Investigate both ground and space-based capabilities for increasing capacity to detect, track, and characterize NEOs of all sizes.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

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.

The NEOO project will continue to collaborate with a network of university and privately owned and operated observatories to conduct search and characterization, and the subsequent data processing and analysis required to understand the near-Earth population of small bodies. The NEOO project will continue to fund the operation of the planetary radar capabilities at the National Science Foundation's Arecibo and NASA's Goldstone facilities. The NEO project will continue to investigate both ground and space-based capabilities for increasing capacity to detect, track, and characterize NEOs of all sizes.

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.

Recent Achievements

Researchers used new Cassini data to model the ocean water on Enceladus to estimate the acidity or basicity (pH) of its ocean, answering a fundamental question in determining whether Saturn's icy moon Enceladus could support life. Cassini's mass spectra observations of the plume gas indicate that the ocean is a sodium-chloride-carbonate solution with an alkaline pH. The dominance of sodium chloride, or salt, is similar to oceans on Earth, but the dissolved sodium carbonate concentrations mean that the ocean composition is similar to that of soda lakes on Earth. The alkaline pH results from serpentinization (a geological low-temperature metamorphic process involving heat and water in which rocks are oxidized and hydrolyzed with water into serpentinite), a geochemical fuel that can support both abiotic and biological synthesis of organic molecules, such as those detected in Enceladus's plume from Cassini. The detection of native hydrogen gas in the plume today would indicate current serpentinization, and thus a source of energy for possible life.

When its poles tilt more toward the Sun, ice accumulates near Mars's mid-latitude, due to the transfer of water from polar ice to mid-latitude cold traps. When the tilt is less, the warmer mid-latitudes lose water to the colder polar regions. NASA's Mars Reconnaissance Orbiter (MRO) has detected a layer of relatively pure ice up to 300 meters thick on top of the north polar cap. Models indicated this result makes sense if the last Martian ice age ended 400 thousand years ago. Data reveal four such layers in the one-mile thick north polar ice cap, indicating the occurrence of at least four major ice age episodes during the 5-10 million-year lifetime of the current cap.

PLANETARY SCIENCE RESEARCH

NEAR EARTH OBJECT OBSERVATIONS (NEOO)

NASA formally established a NEOO Research Program with a goal to detect and track at least 90 percent of the asteroids and comets greater than 140 meters in diameter that come within 1.3 astronomical units of the Sun (within about 30 million miles of Earth's orbit).

NASA and its partners, using ground and space-based assets maintain a watch for NEOs, asteroids and comets that pass close to the Earth, as part of an ongoing effort to discover, catalog, and characterize these bodies. 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.

Since NASA's search started in 1998, the program has found over 93 percent of these objects that are 1 kilometer and larger, and about 28 percent of all those larger than 140 meters in size. The program will also discover and characterize NEOs that could be viable targets for robotic and crewed exploration. This is part of NASA's contribution to the effort to find all asteroid threats to human population and know what to do about them.

NASA formalized the ongoing NEOO Program as a research program under the Planetary Defense Coordination Office (PDCO), which also coordinates NEO observation efforts conducted at ground-based observatories sponsored 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 developing techniques for deflecting or redirecting, if possible, potentially hazardous objects (PHOs) that are determined to be on an impact course with Earth. In the event that deflection or redirection is not possible, the PDCO is responsible for providing expert input to the Federal Emergency Management Agency for emergency response operations should a PHO be on an impact course or actually impact Earth.

Responsibilities of the PDCO include 1) 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); 2) tracking and characterizing PHOs and issuing warnings about potential impacts; 3) providing timely and accurate communications about PHOs; and 4) performing as a lead coordination node in U.S. Government planning for response to an actual impact threat.

For more information on the search for NEOs, go to http://neo.jpl.nasa.gov.

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 2018.

PLANETARY SCIENCE RESEARCH

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
NEOO	Provider: NASA Lead Center: HQ Performing Center(s): HQ, GSFC, JPL, ARC Cost Share Partner(s): National Science Foundation (NSF), U.S. Air Force, Smithsonian Astrophysical Observatory (SAO)

Acquisition Strategy

The R&A budget will fund competitively selected activities from the ROSES omnibus research announcement.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	Planetary Science Subcommittee	2017	Review to assess progress against strategic objectives of Planetary Science.	Recommendation was to maintain a strong program consistent with the decadal survey.	2018

OTHER MISSIONS AND DATA ANALYSIS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Joint Robotics Program for Exploration	10.0	--	**0.0**	0.0	0.0	0.0	0.0
Planetary Science Directed R&T	0.0	--	**6.1**	11.1	13.6	13.6	19.3
Science Innovation Fund	5.0	--	**0.0**	0.0	0.0	0.0	0.0
Planetary Data System	15.0	--	**15.4**	15.6	16.2	16.3	16.4
Astromaterial Curation	8.5	--	**10.1**	10.4	10.6	10.9	10.9
Science Data & Computing	2.3	--	**2.5**	2.7	2.7	2.8	2.8
Rosetta	12.4	--	**5.4**	0.0	0.0	0.0	0.0
Robotics Alliance	4.3	--	**4.1**	4.1	4.1	4.1	4.1
Total Budget	**57.5**	**--**	**43.6**	**43.9**	**47.2**	**47.7**	**53.5**

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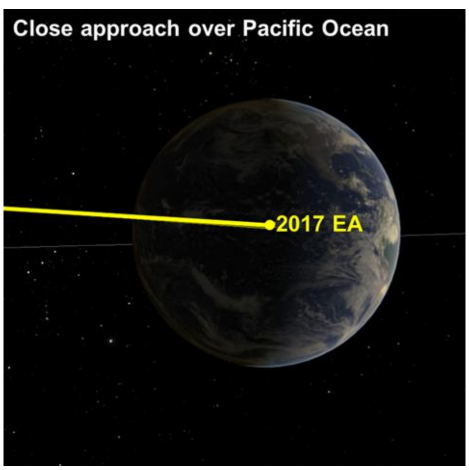


Asteroid 2017 EA Close Approach to Earth on March 2, 2017. A small near-Earth asteroid less than 3 meters across passed by Earth at a distance so close that it passed well inside the ring of geosynchronous satellites. Detected only 6 hours before closest approach by astronomers at the Catalina Sky Survey, near Tucson, Arizona. At its closest point, this asteroid was 20 times closer than the Moon. (D. Farnocchia, NASA/JPL)

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.

EXPLANATION OF MAJOR CHANGES IN FY 2018

The Request reflects termination of the Science Innovation Fund, and transfer of budget and responsibility for the Joint Robotics Program for Exploration to Planetary Science Research and Analysis (see page PS-2).

Mission Planning and Other Projects

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, fostering the growth of a new national economic engine. 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 2016 RAP sponsored 208 FIRST Robotics Competition teams (approximately 5,200 students), 50 VEX robotics teams (approximately 500 students), and sponsored and/or supported 19 FIRST Robotics Competition events (affecting approximately 47,500 students).

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 2018.

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 received data from 16 planetary missions in 2016. PDS also received data sets from ground-based observations, one balloon borne mission, laboratory data, and higher order data sets from NASA data analysis investigations. The Minor Planet Center became a part of the Small Bodies node. The archive grew by 200 TB and more than 4 million data products, to a total holding of approximately 1.3 Petabytes.

ASTROMATERIAL CURATION

The Astromaterials Acquisition and Curation Office at JSC curates all extraterrestrial material and space-exposed flight hardware under NASA control. Curation is an integral part of all sample return missions. Activities conducted by the Curation Office range from research into advanced curation techniques to support future missions, sample-return-mission planning, archiving of engineering and reference materials, recovery and transport of returned materials, initial characterization of new samples, preparation and allocation of samples for research, and providing clean and secure storage for the benefit of current and future generations. Samples currently include Antarctic meteorites, cosmic dust, and returned samples from the Moon (Apollo and Luna), the Sun (solar wind captured by Genesis), a comet (Stardust), an asteroid (Hayabusa), and interplanetary dust (on space-exposed hardware). Planning and research are currently underway for future curation of samples from asteroids (Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx), and Hayabusa2),

OTHER MISSIONS AND DATA ANALYSIS

Mars, and comets. New laboratory space is being constructed and outfitted within the Curation facility to prepare for receipt of the OSIRIS-REx and Hayabusa 2 materials.

Recent Achievements

In the past year, the Curation Office completed the OSIRIS-REx contamination knowledge activity, completed the 100 percent design review for the combined OSIRIS-REx and Hayabusa 2 labs, built the CT scanner lab and installed a new four-source CT scanner for astromaterials (the first facility of its type in the world dedicated to astromaterials). The Curation Office also acquired and is developing techniques for a new, state-of-the-art micromanipulator, applied new high-resolution 3D imaging techniques to two collections, and initiated advanced curation activities for contamination control (including organics and microbiological characterization of existing labs). This is in addition to maintaining 8 collections and 22 clean rooms, and, over the past year, allocating over 1500 samples to the 431 registered PIs from around the world.

SCIENCE DATA AND COMPUTING

This project, through the National Space Science Data Center (NSSDC), preserves NASA's science data collected since the first robotic missions in the 1960s. The NSSDC also serves as the back-up archive for the PDS. In addition to being a depository that makes unique data and metadata available, the NSSDC 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 NSSDC 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.

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 4,600 million 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.

Recent Achievements

Science observation and operations lasted from the comet c orbit insertion in the spring of 2014 until the end of FY 2016, with the lander touching down the comet in November 2014. Data analysis will continue to the end of FY 2018.

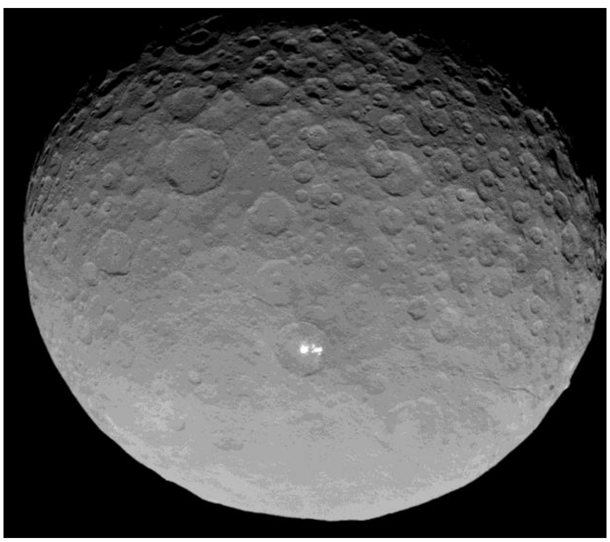
DISCOVERY

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
InSight	92.1	32.3	**109.4**	22.3	11.8	9.0	9.0
Lucy	0.0	--	**101.4**	170.9	205.1	141.1	36.2
Psyche	0.0	--	**25.0**	160.4	210.0	169.2	181.0
Other Missions and Data Analysis	96.9	--	**70.3**	71.8	61.4	57.5	149.0
Total Budget	**189.0**	**--**	**306.1**	**425.4**	**488.3**	**376.8**	**375.2**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



All completed Discovery missions have achieved ground-breaking science, each taking a unique approach to space exploration, doing what's never been done before, and driving new technology innovations. The Dawn spacecraft gently settled into orbit at the dwarf planet Ceres in early March 2015 to begin its 16-month study of this largest object in the main asteroid belt. Early images revealed a heavily cratered surface and enigmatic bright spots. The mission has shown that the surface is dominated by clay-like minerals with little or no obvious ice, which has scientists rethinking the formation and evolution history and the internal structure of this small world.

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 two operational spacecraft: Lunar Reconnaissance Orbiter (LRO) and Dawn; two newly selected mission(s) in formulation: Lucy and Psyche; and one flight mission in development: the Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight). The program has also developed and delivered the Strofio instrument as a part of ESA's BepiColombo mission to Mercury.

EXPLANATION OF MAJOR CHANGES IN FY 2018

None.

DISCOVERY

ACHIEVEMENTS IN FY 2016

The Discovery Program conducted its PIR in August 2016. The Standing Review Board (SRB) found that the program met all criteria and should continue to implement the program as designed.

Dawn arrived at Ceres in March 2015, and successfully ended its prime mission in June 2016. NASA subsequently approved a one year extended mission at Ceres.

InSight continued development of its Seismic Experiment for Interior Structure (SEIS) instrument, including design changes and testing on the evacuated chamber. Working with the French partners, new designs to eliminate loss of vacuum were developed, tested, and constructed.

NASA awarded the LRO a third extended mission, to operate through the end of FY 2018.

The five Step One potential Discovery missions selected in FY 2015 delivered their Concept Study Reports for evaluation, leading to the down selection of two missions in the first quarter of FY 2017.

WORK IN PROGRESS IN FY 2017

The program office will establish contracts for Phase B for the newly down selected missions, Lucy and Psyche.

InSight will continue testing and integration throughout FY 2017, with delivery of the SEIS instrument by July 2017. InSight will re-start the Assembly Test and Launch Operations Phase in July 2017.

Dawn will complete its high altitude extended mission in the third quarter.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

NASA will launch InSight in May 2018. Lucy and Psyche will work towards their Preliminary Design Reviews (PDRs) and prepare to enter implementation upon confirmation.

Program Schedule

Date	Significant Event
May 2018	InSight Launch at Vandenberg
2019	Discovery 14 Announcement of Opportunity (AO)
2021	Lucy Launch
2022	Psyche Launch

Program Management & Commitments

The Planetary Missions Program Office at MSFC provides program management.

Program Element	Provider
InSight	Provider: JPL Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): CNES, DLR
Dawn	Provider: University of California, Los Angeles (UCLA) Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): DLR, Agenzia Spaziale Italiana (ASI)
LRO	Provider: N/A Lead Center: GSFC Performing Center(s): GSFC, JPL Cost Share Partner(s): N/A
Lucy	Provider: SwRI Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): NA
Psyche	Provider: Arizona State University (ASU) Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A
Strofio	Provider: SwRI Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): ESA

Acquisition Strategy

NASA competitively selects new Discovery missions, releasing announcements of opportunity when available funding allows.

DISCOVERY

INDEPENDENT REVIEWS

The Discovery Program’s next Program Implementation Review (PIR) will occur in 2019.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
PIR	SRB	Aug 2016	Review implementation of Program	Passed	2019

INSIGHT

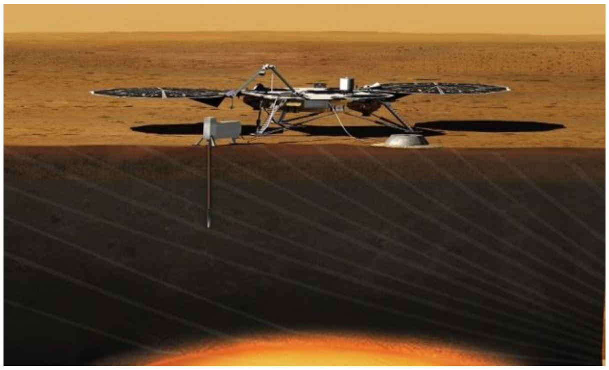
Formulation	Development	Operations

FY 2018 Budget

		Actual	Enacted	Request	Notional					
Budget Authority (in $ millions)	Prior	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	BTC	Total
Formulation	98.9	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	98.9
Development/Implementation	462.2	92.1	32.3	**86.9**	0.0	0.0	0.0	0.0	0.0	673.5
Operations/Close-out	0.0	0.0	0.0	**22.5**	22.3	11.8	0.0	0.0	0.0	56.6
2017 MPAR LCC Estimate	**561.1**	**92.1**	**32.3**	**109.4**	**22.3**	**11.8**	**0.0**	**0.0**	**0.0**	**829.0**
Total Budget	**561.1**	**92.1**	**32.3**	**109.4**	**22.3**	**11.8**	**9.0**	**9.0**	**0.0**	**846.9**
Change from FY 2017				**77.1**						
Percentage change from FY 2017				**238.7%**						

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



Scientists have determined the deep structure of only one planet: Earth. To obtain vital clues to how Mars formed, InSight will deploy a German-built drill nicknamed "The Mole" to pound 16 feet into the Martian crust for thermal measurements, and a sensitive French-built seismometer to detect "Marsquakes." Through these and other instruments, scientists will be able to deduce the deep structure of Mars, which currently is a mystery.)

PROJECT PURPOSE

InSight is a Mars lander mission to investigate fundamental issues of terrestrial planet formation and evolution with a study of the deep interior of Mars. This mission will seek to 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.

EXPLANATION OF MAJOR CHANGES IN FY 2018

The new launch date for InSight is May 2018.

PROJECT PARAMETERS

NASA plans to launch InSight in May 2018, landing on Mars in November 2018. The InSight lander will be equipped with two science instruments that will conduct the first "check-up" of Mars in its more than

Formulation	Development	Operations

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 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 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.

ACHIEVEMENTS IN FY 2016

Due to problems with SEIS, the primary instrument, NASA had to cancel the March 2016 launch. NASA determined the cause of the SEIS instrument failure and developed a plan to repair the instrument by re-designing the hardware. In August 2016, NASA approved a mission replan for launch in May 2018 (next Mars launch opportunity).

WORK IN PROGRESS IN FY 2017

NASA started implementation of the SEIS instrument repairs and has so far demonstrated a validation and qualification of the new design.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2018 PB Request
Launch	Mar 2016	May 2018
KDP-E	Apr 2016	June 2018
Mars Landing	Sep 2016	Nov 2018
End of Prime Mission	Sep 2018	Nov 2020

INSIGHT

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 Milesto ne	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2014	541.8	70	2017	673.5	24.3	LRD	Mar 2016	May 2018	26

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

Development Cost Details

NASA approved a new launch date of May 2018 at the replan review in August 2016. The development cost details in the table below reflect the budget approved at the replan review.

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**541.8**	**673.5**	**131.7**
Aircraft/Spacecraft	196.9	273.1	76.2
Payloads	18.1	72.1	54.0
Systems I&T	0.0	3.0	3.0
Launch Vehicle	159.9	168.5	8.6
Ground Systems	7.4	18.1	10.7
Science/Technology	7.1	15.7	8.6
Other Direct Project Costs	152.4	123.0	-29.4

INSIGHT

Formulation	Development	Operations

Project Management & Commitments

NASA selected the InSight project through the competitive Discovery 2010 AO. The principal investigator for InSight is from JPL. JPL will manage the InSight 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	Similar in design to the Mars lander that the Phoenix mission used successfully in 2007	Provider: Lockheed Martin Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
SEIS	Will take precise measurements of quakes and other internal activity on Mars	Provider: CNES Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	JPL to design and develop the evacuated container for SEIS
HP3	A heat flow probe that will hammer five meters into the Martian subsurface (deeper than all previous arms, scoops, drills and probes) to measure heat emanating from the core	Provider: DLR Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Rotation and Interior Structure Experiment (RISE)	Uses the spacecraft's communication system to provide precise measurements of planetary rotation	Provider: JPL Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Launch Vehicle	Atlas V launch vehicle and related launch services	Provider: United Launch Alliance (ULA) Lead Center: KSC Performing Center(s): KSC Cost Share Partner(s): N/A	N/A

INSIGHT

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: Mars environment, entry conditions, or spacecraft behavior is not as anticipated, Then: Landing may not be successful.	Project will build comprehensive simulations of landing scenarios and test entry descent and landing systems, including independent verification of analysis. The project employs personnel who conducted previous successful Mars landings. The project will certify potential landing ellipses for elevation, slopes, and rock abundance. The project will use validated environmental models informed by atmospheric measurements from the previous three decades of observations at Mars.
If: Deployment of SEIS is not successful, Then: The project will not be able to meet its science objectives.	The project will conduct extensive testing of deployments in test beds, including fault scenarios. Test beds will also be available during mission operations to verify actual deployment moves, with ground verification deployed at each step during operations. The project will certify potential landing ellipses for elevation, slopes, and rock abundance.
If: Development of SEIS is not successful, Then: Spacecraft will miss its launch date	The project will conduct extensive environmental testing of the individual parts and the integrated flight SEIS instrument to make sure it meets all the requirements, and in addition, the project will develop a second flight unit as a spare.

Acquisition Strategy

NASA selected the InSight mission through a competitive Discovery Program 2010 AO and a down selection in September 2012. All major acquisitions are in place.

MAJOR CONTRACTS/AWARDS

A contract with Lockheed Martin is in place for the flight system.

Element	Vendor	Location (of work performance)
Spacecraft	Lockheed Martin	Denver, CO

INSIGHT

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Feb 2015	SIR	InSight successfully met the criteria for SIR and the PMC decision authority approved the project to continue to the next phase at KDP-D.	May 2017
Performance	SRB	May 2017	SIR-2	TBD	Feb 2018
Performance	SRB	Feb 2018	ORR	TBD	Apr 2018
Performance	JPL System Review Team and SRB	Apr 2018	FRR	TBD	N/A

LUCY

Formulation	Development	Operations

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	0.0	--	101.4	170.9	205.1	141.1	36.2

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

Lucy will for the first time investigate Trojans 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.

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 in stable orbits near the Lagrange Point 4 and Lagrange Point 5 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 Trojans asteroids, and NASA plans to launch it by November of 2021.

EXPLANATION OF MAJOR CHANGES IN FY 2018

Lucy is a new Discovery mission selected in December 2016 to enter Phase B.

PROJECT PRELIMINARY 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 six of these fascinating objects (one encounter is of a nearly equal mass binary).

LUCY

Formulation	Development	Operations

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 tour.

WORK IN PROGRESS IN FY 2017

The Lucy mission is conducting preliminary design activities in FY 2017.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

Lucy will continue with project formulation and risk reduction activities throughout FY 2018.

ESTIMATED PROJECT SCHEDULE

All dates are preliminary.

Milestone	Formulation Authorization Document	FY 2018 PB Request
KDP-C	Dec 2018	Dec 2018
KDP-D	Aug 2020	Aug 2020
Launch	Oct 2021	Oct 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
Jan 4, 2017	930 - 990	Launch	Oct 2021

LUCY

Formulation	Development	Operations

Project Management & Commitments

The Principal Investigator and Deputy Principal Investigator are both from the Southwest Research Institute (SwRI) and lead the management of the mission. GSFC serves as the development Center for the Lucy mission, working for the Principal Investigator. GSFC 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
Spacecraft	Spacecraft bus and propulsion system	Provider: Lockheed Martin Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
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): N/A Cost Share Partner(s): N/A	N/A
High resolution visible imager (L'LORRI)	Provides high resolution images to determine shape, geology and albedo of the Trojans asteroids	Provider: Johns Hopkins University (JHU)/Applied Physics Laboratory (APL) Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Thermal Emission Spectrometer (L'TES)	Provides, thermal inertia maps of the Trojans elemental composition.	Provider: ASU Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Radio Science	Utilizes the X-band radio telecommunications system to measure the Trojans mass	Provider: GSFC Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Navigation	Provides mission navigation design and operations.	Provider: KinetX Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

LUCY

Formulation	Development	Operations

Project Risks

Will be finalized by KDP-C.

Risk Statement	Mitigation
N/A	

Acquisition Strategy

NASA competitively selected the mission through an AO. The major elements of the mission and spacecraft are as proposed for the AO.

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

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Life Cycle	SRB	Nov 2018	PDR	TBD	CDR
Life Cycle	SRB	TBD	Critical Design Review (CDR)	TBD	SIR
Life Cycle	SRB	Jul 2020	System Integration Review (SIR)	TBD	ORR
Life Cycle	SRB	TBD	Operations Readiness Review (ORR)	TBD	LRR
Life Cycle	SRB	Sep 2021	Launch Readiness Review (LRR)	TBD	N/A

PSYCHE

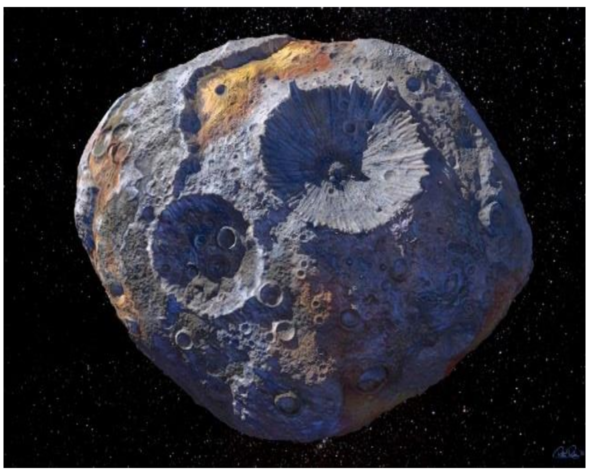
Formulation	Development	Operations

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	**0.0**	**--**	**25.0**	**160.4**	**210.0**	**169.2**	**181.0**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



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 130 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 2018

NASA selected the Psyche mission to proceed into formulation in December 2016 from the Discovery Program’s most recent AO.

PROJECT PRELIMINARY PARAMETERS

NASA plans to launch the mission in the summer of 2022 for arrival at 16 Psyche in the winter of 2025. 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

Formulation	Development	Operations

Psyche will spend 20 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, 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.

WORK IN PROGRESS IN FY 2017

The Psyche mission is the second to launch of the two selected Discovery missions, so it will execute a longer than usual preliminary design phase that slowly ramps up in FY 2017. Psyche is conducting activities in FY 2017 designed to reduce risks associated with mission development, and to identify an optimal development schedule and launch date.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

Psyche will continue with project formulation and risk reduction activities throughout FY 2018.

ESTIMATED PROJECT SCHEDULE

All dates are preliminary.

Milestone	Formulation Authorization Document	FY 2018 PB Request
KDP-C	May 2019	May 2019
KDP-D	Jan 2021	Jan 2021
Launch	Jul 2022	Jul 2022

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	900 - 950	Launch	Jul 2022

PSYCHE

Formulation	Development	Operations

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): N/A Cost Share Partner(s): N/A	N/A
Psyche Multispectral Imager	Provides high-resolution images using filters to discriminate between 16 Psyche's metallic and silicate constituents.	Provider: ASU Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Magnetometer	Detects and measures the remnant magnetic field of 16 Psyche.	Provider: UCLA Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Gamma Ray and Neutron Spectrometer	Detects, measures, and maps 16 Psyche's elemental composition.	Provider: APL Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Gravity Science	Utilizes the X-band radio telecommunications system to measure 16 Psyche's gravity field.	Provider: Massachusetts Institute of Technology (MIT) Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Deep Space Optical Communications (DSOC)	Demonstrates DSOC technology's capabilities.	Provider: JPL Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): NASA Human Exploration and Operations Mission Directorate (HEOMD)/Space Technology Mission Directorate (STMD)	N/A

PSYCHE

Formulation	Development	Operations

Project Risks

The Project will develop its major risks during Phase B.

Risk Statement	Mitigation
N/A	

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.

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. The major contracts are under development.

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

PSYCHE

Formulation	Development	Operations

INDEPENDENT REVIEWS

All dates are preliminary.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Life Cycle	SRB	April 2019	PDR	TBD	CDR
Life Cycle	SRB	April 2020	CDR	TBD	SIR
Life Cycle	SRB	Jan 2021	SIR	TBD	ORR
Life Cycle	SRB	May 2022	ORR	TBD	LRR
Life Cycle	SRB	July 2022	LRR	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

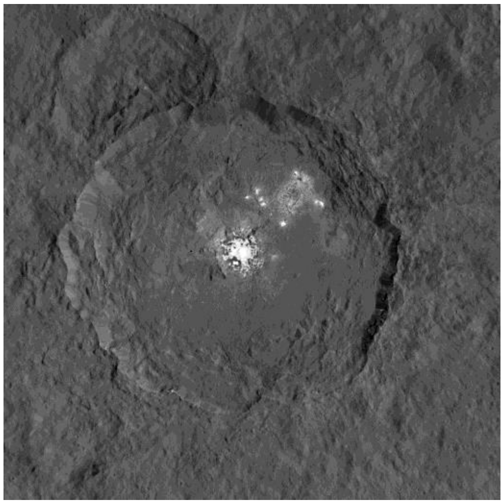
FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Strofio	1.6	--	**1.0**	0.6	0.7	0.6	0.6
International Mission Contributions (IMC	2.9	--	**2.5**	3.5	2.4	2.2	2.0
Planetary Missions Program Office	16.8	--	**16.7**	17.0	17.0	17.0	17.0
Discovery Future	11.6	--	**12.9**	14.2	13.5	9.7	102.8
Discovery Research	15.8	--	**7.2**	8.5	9.8	10.0	8.6
Lunar Reconnaissance Orbiter (LRO)	19.0	--	**20.0**	18.0	18.0	18.0	18.0
Dawn	22.2	--	**10.0**	10.0	0.0	0.0	0.0
MESSENGER	6.8	--	**0.0**	0.0	0.0	0.0	0.0
Gravity Recovery and Interior Laboratory	0.2	--	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**96.9**	**--**	**70.3**	**71.8**	**61.4**	**57.5**	**149.0**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

OTHER MISSIONS AND DATA ANALYSIS



Enigmatic bright spots in Occator crater on the dwarf planet Ceres as seen by the Dawn spacecraft from its high-altitude mapping orbit of 915 miles (1470 kilometers). Based on the absence of other craters within it, Occator is a very recent 56-mile (90-kilometer) wide impact crater. The intense brightness of the persistent spots is due to the presence of a highly reflective material on the surface, possibly a mineral salt or pure water ice. The smooth crater floor indicates possible flowing material – either impact debris or post-impact melting or volcanism.

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 (e.g., the instrument Strofio; operating missions (Dawn, LRO); missions whose operations have ceased but data analysis continues (Gravity Recovery and Interior Laboratory [GRAIL] and MESSENGER); competed research; funding for future mission selections; and program management activities.

Mission Planning and Other Projects

STROFIO

Strofio is a unique mass spectrometer, part of the SERENA suite of instruments that will fly onboard the ESA BepiColombo spacecraft, scheduled for launch in 2018. Strofio will determine the chemical composition of Mercury's surface, providing a powerful tool to study the planet's geologic history.

Recent Achievements

The Strofio instrument is on board the BepiColombo spacecraft ready for launch in 2018.

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 2017 include the Japanese Space Agency's Hayabusa-2 and Akatsuki (Venus Climate Orbiter) missions. The Akatsuki mission is in orbit around Venus and will investigate the planet Venus for two years. Hayabusa-2, which launched in 2014, will arrive at asteroid Ryugu in 2018 and capture and return a sample by 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 Programs as well as 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 work at the LaRC office for Mission Assessments to support the mission selection process including the development of AO 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. Technology development includes NASA'S Evolutionary Xenon Thrusters and Power Processing Units. Future competitive opportunities are under evaluation for both planetary cubesats and planetary balloon missions of opportunity.

Recent Achievements

NASA down selected two missions, Lucy and Psyche, based upon their mission concept study reports to enter Phase B. These will be the Discovery missions 13 and 14 presuming a successful formulation phase.

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.

Recent Achievements

The Laboratory Analysis of Returned Samples (LARS) project successfully commissioned the new CHILI instrument, supported by the LARS program over the last five to six years for work on returned samples. CHILI (the CHicago Instrument for Laser Ionization) at the University of Chicago will measure isotopic and elemental analyses with unprecedented spatial resolution, sensitivity, and control of isobaric interferences. It uses a focused gallium ion beam to sputter atoms or a focused laser to thermally evaporated atoms from a surface, resonantly ionize them with a laser, and mass-analyze them with a time-of-flight mass spectrometer. This instrument enabled the first measurements of all of the isotopes of Fe and Ni simultaneously in pre-solar SiC (Trappitsch et al., 2016). Applications to returned samples from Stardust and Genesis are underway and will continue with Hayabusa2 and OSIRIS-REx in coming years.

Combining images of Mercury's South Pole from NASA's MESSENGER spacecraft with radar images from NSF's Arecibo Observatory shows that nearly all of the areas of high radar reflectivity, suggestive of water ice, lie in the permanently shadowed regions. However, more than half of the permanently shadowed regions are not highly radar reflective. These results are similar to those found previously for Mercury's North Pole, raising the question of whether (and why) ice exists in all, or only some, of Mercury's cold traps.

OTHER MISSIONS AND DATA ANALYSIS

The Moon's South Pole Aitken Basin is the location of a significant concentration of magnetic anomalies — regions of locally high magnetic field compared to their surroundings. Using magnetometer data from NASA's Lunar Prospector and JAXA's SELENE/Kaguya spacecraft, researchers have found that the magnetic field directions in these anomalies are unaligned. This finding argues against formation scenarios in which a global, dynamo-generated magnetic field left its imprint on iron-rich ejecta from the impact that formed the basin. Among the multiple possible alternatives is a dynamo unaligned with the Moon's spin axis.

Operating Missions

LUNAR RECONNAISSANCE ORBITER (LRO)

Over the upcoming year, LRO will characterize areas on the Moon that spend most of the time in shadow but the Sun briefly illuminates them for a few hours to a few days over the 18-year lunar precession cycle. If these measurements show that surface frosts change during and just after illumination, this will provide new constraints on the transport of polar volatiles. Another focus in the coming year will be probing the vertical distribution of volatiles. Each of the instruments onboard LRO contributes to understanding volatiles by probing different depths, from coatings on the surface to volatiles mixed within the first few feet (about one meter) below the surface. Researchers will deploy new operating modes for LRO's instruments. This includes a new mode for the ultraviolet instrument that allows 80 times more light into the instrument during dayside observations. This increased signal may lead to new understanding of the day/night variability of the ultraviolet water signature on the lunar surface. LRO will continue work examining recent and ongoing surface changes and observing how the regolith (the loose material on the surface of the Moon) evolves over time. Its observations improve what we know about the interior of the Moon based on surface observations, by examining the interactions between the Moon and the space environment, the solar wind and galactic cosmic radiation.

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. The mission has uncovered new evidence of surface frost in polar regions where temperatures remain below 110 kelvin (-260 degrees Fahrenheit). Evidence of subsurface hydrogen deposits (water or other hydrogen containing volatiles) has been uncovered in both LRO radar and neutron instrument data. New polar hydrogen maps derived from neutron data show that water exists in permanently shadowed regions (PSRs), with the highest water concentration being found inside Cabeus Crater, a site in the lunar South Pole. LRO has also determined that there is a broader distribution of water outside of the PSRs, but at lower concentration than inside the PSRs.

By re-imaging the Moon to detect changes in the surface over the life of the mission, LRO has provided new constraints on the rate at which meteor impacts disturb and overturn of the surface. LRO data indicates that the rate at which meteors impact the lunar surface appears significantly greater than current models suggest. The reimaging of sites captured by previous LRO camera images under similar lighting and viewing conditions creates temporal pairs and enables the automatic detection of surface changes. The dataset of over 14,000 image pairs (6.6 percent of the lunar surface) resulted in the identification of 33 percent more impact craters larger than 10 meter in diameter than models predict. In addition to the new impact craters, these image pairs show extensive disturbances of the surface surrounding the new impact craters as well as distant secondary cratering. Researchers identified over 47,000 discrete surface changes, not including the new craters. These results are unique to LRO, in that only a mission with an extended baseline of high-resolution observations can generate the necessary coverage over time to discover such changes.

DAWN

Dawn is completing its journey to two of the most massive, intact bodies in the main asteroid belt between Mars and Jupiter. 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. Launched in September 2007, Dawn reached Vesta in July 2011, left in August 2012, and arrived at Ceres in March 2015. Dawn is currently on an extended mission period and will continue studying Ceres until June 2017.

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

Early images of Ceres revealed a heavily cratered surface and enigmatic bright spots. The mission has shown that clay-like minerals with only small areas of ice dominate the surface, which has scientists rethinking the formation and evolution history and the internal structure of this small world. The intense brightness of the persistent spots is due to the presence of highly reflective materials on the surface, which appear to be mineral salts and water ice. In 2016, Dawn completed its primary mission. NASA approved the mission to remain in orbit at Ceres for a 12-month extended mission. During the extended mission, Dawn moved to a high, elliptical orbit to obtain an improved calibration of its gamma ray and neutron detector, which provides information about the elemental composition of Ceres' surface.

NEW FRONTIERS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Other Missions and Data Analysis	194.0	--	**82.1**	121.7	169.4	227.8	307.0
Total Budget	**194.0**	**--**	**82.1**	**121.7**	**169.4**	**227.8**	**307.0**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

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NASA's Juno spacecraft is in orbit at Jupiter where it captured this beautiful image of Jupiter's swirling clouds. Juno's primary science goal is to use science instruments to probe beneath those clouds to understand Jupiter's interior structure. Knowing the details of the interior will tell us how Jupiter formed and by extension, how planets throughout the Universe form.

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.

The program is currently comprised of three missions in operations: New Horizons, Juno, and OSIRIS-REx.

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 is in its way to a fly-by of a small world in the Kuiper Belt.

Juno is a mission to Jupiter that will significantly improve 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 to study and analyze on Earth. This will increase our understanding of 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 NEO. This knowledge will provide significant insight for potential planetary defense strategies.

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 AO, Ocean Worlds targets Enceladus and Titan.

NEW FRONTIERS

EXPLANATION OF MAJOR CHANGES IN FY 2018

NASA expects to select up to three New Frontiers missions for Phase A study from the New Frontiers 4 AO.

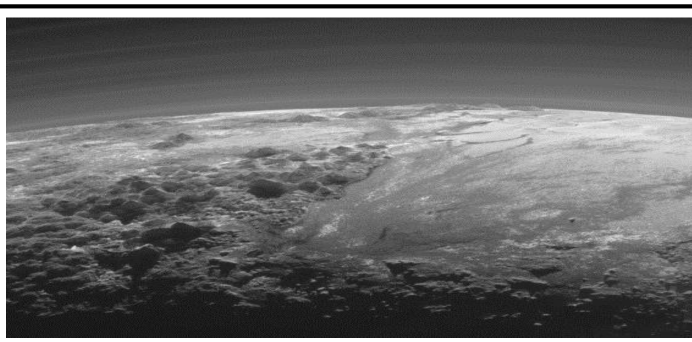
OTHER MISSIONS AND DATA ANALYSIS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
New Frontiers Future Missions	2.0	--	**13.4**	20.0	64.8	183.6	271.1
New Frontiers Research	0.0	--	**5.4**	9.4	12.4	13.1	13.7
Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer (OSIRIS-REx)	124.7	--	**36.8**	55.3	50.7	21.6	22.2
New Horizons	21.5	--	**12.0**	12.0	16.5	9.5	0.0
Juno	45.8	--	**14.5**	25.0	25.0	0.0	0.0
Total Budget	**194.0**	--	**82.1**	**121.7**	**169.4**	**227.8**	**307.0**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



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), 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 AO. NASA released the fourth New Frontiers AO in early December 2016, and expects to select a new mission in 2019.

NEW FRONTIERS RESEARCH

New Frontiers Research funds analysis of archived data from New Frontiers missions. New Frontiers Research gives the research community access to samples and data and allows research to continue for many years after mission completion. This allows the maximum science return from each of the missions.

OTHER MISSIONS AND DATA ANALYSIS

Scientists in the U.S. planetary science community submit research proposals that NASA selects through competitive peer review. NASA will select new research in 2018, using the New Horizons mission data returned from Pluto and the Juno mission data returned from Jupiter.

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 will next venture deeper into the Kuiper Belt, and as part of a NASA-approved extended mission, study one of the icy mini-worlds in this region approximately two billion miles beyond Pluto's orbit. The project has completed the maneuvers required to fly by Kuiper Belt Object 2014MU69 in January 2019.

Recent Achievements

The New Horizons project developed the Kuiper Belt Extended Mission (KEM) Integrated Master Schedule (IMS), in support of establishing the baseline by April 2017. KEM began October 1, 2016. The Student Dust Counter continues to collect unprecedented new data of an area of our Solar System little explore before.

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.
- 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 atmospheric gases that escaped Pluto and then accreted on Charon's surface.
- Pluto's vast 1,000-kilometer-wide heart-shaped nitrogen glacier (informally 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 – something only seen elsewhere on Earth, Mars and Saturn's moon Titan in our solar system.

OTHER MISSIONS AND DATA ANALYSIS

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 successfully launched on August 5, 2011 and is the first solar-panel powered spacecraft to orbit the giant planet, which began in July 2016. During its science operations mission, Juno, with the first-ever polar orbit of Jupiter, will sample 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 successfully entered orbit around Jupiter in July 2016. Juno is currently in a 53-day orbit and has successfully completed four science flybys of Jupiter. Juno has returned numerous striking visual-light, ultra-violet, and infrared images including the huge circumpolar storms at both Jovian poles. Initial results from the observations of Jupiter's interior indicate that its structure is far more complex than previously thought.

Similarly, observations of the energetic particles that create the incandescent aurora suggest a complicated current system involving charged material lofted from volcanoes on Jupiter's moon Io.

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. This sample will yield insight into planet formation and the origin of life, and 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. The small force adds up over time, but it is uneven due to an asteroid's shape, wobble, surface composition, and rotation. For scientists to predict an Earth-approaching asteroid's path, they must understand how the effect will change its orbit. By describing the integrated global properties of a primitive carbonaceous asteroid, this mission will allow for direct comparison with ground- based telescopic data of the entire asteroid population.

OSIRIS-REx launched on September 8, 2016 and will fly by the Earth on September 22, 2017. After almost two years in space, OSIRIS-REx will approach Bennu, arriving close enough to begin observations in August 2018. The mission will study the asteroid for about one year, 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 launched on September 8, 2016. OSIRIS-REx will fly by the Earth on September 22, 2017, receiving a gravity assist to change the plane of its orbit to match the orbit of its target asteroid, Bennu. OSIRIS-REx will take advantage of this flyby to obtain calibration observations of the Earth and Moon.

MARS EXPLORATION

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Mars Rover 2020	321.8	377.5	**374.3**	363.8	322.8	150.0	120.0
Other Missions and Data Analysis	191.2	--	**210.4**	198.7	207.6	206.9	330.7
Total Budget	**513.0**	**--**	**584.7**	**562.5**	**530.4**	**356.9**	**450.7**

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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.

EXPLANATION OF MAJOR CHANGES IN FY 2018

None.

MARS ROVER 2020

Formulation	Development	Operations

FY 2018 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022	BTC	Total
Formulation	274.4	118.8	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	393.1
Development/Implementation	0.4	227.7	0.0	**392.6**	373.4	293.0	0.0	0.0	0.0	1674.6
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	32.1	153.4	121.9	68.6	375.8
2017 MPAR LCC Estimate	**274.8**	**346.4**	**0.0**	**392.6**	**373.4**	**325.0**	**153.4**	**121.9**	**68.6**	**2443.5**
Total Budget	**253.3**	**321.8**	**377.5**	**374.3**	**363.8**	**322.8**	**150.0**	**120.0**	**67.0**	**2350.5**
Change from FY 2017				**-3.2**						
Percentage change from FY 2017				**-0.8%**						
Total NASA Budget	**274.4**	**346.5**	**387.7**	**392.6**	**373.4**	**325**	**153.4**	**121.9**	**68.6**	**2443.5**

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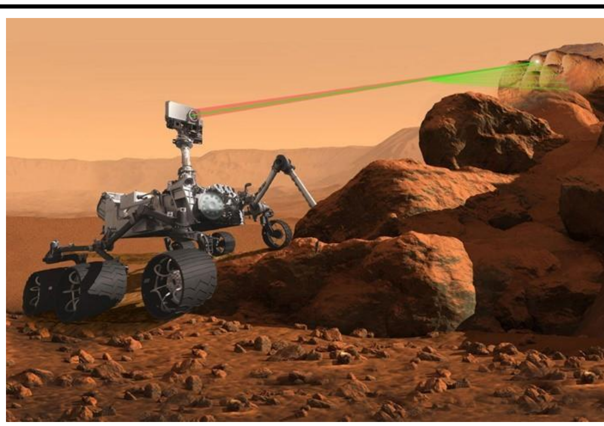

Mars 2020 will re-use the basic engineering of NASA's Mars Science Laboratory to send a different rover to Mars, with new objectives and instruments, launching in 2020. The rover will carry seven instruments to conduct its science and exploration technology investigations including two contributed by international partners and one to demonstrate a critical technology for future human exploration.

PROJECT PURPOSE

The 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 provided by the HEOMD and the STMD that align with their priorities and are compatible with SMD priorities.

NASA’s Mars 2020 mission 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

MARS ROVER 2020

Formulation	Development	Operations

potential return to Earth in the future, and test new technology to benefit future robotic and human exploration of Mars. The mission will also deploy new capabilities developed through investments by NASA's Space Technology Mission Directorate, Human Exploration and Operations Mission Directorate, and contributions from international partners.

EXPLANATION OF MAJOR CHANGES IN FY 2018

None.

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. NASA is exploring a range of options to potentially return these cached samples to Earth, including a future NASA Science or NASA-sponsored mission, or via a commercial or international partnership. We are exploring opportunities to partner with industry to leverage their future missions to advance decadal survey science objectives.

The rover’s baseline power source is a Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) provided by the U.S. Department of Energy. It uses the heat from the natural decay of plutonium-238 to generate electricity. NASA and ESA telecommunications relay assets in Mars orbit will support the mission.

ACHIEVEMENTS IN FY 2016

The Mars 2020 mission passed its KDP-C review and formally entered the final design and fabrication phase of implementation (Phase C) in June 2016.

MARS ROVER 2020

Formulation	Development	Operations

WORK IN PROGRESS IN FY 2017

The Mars 2020 mission completed the CDR and continues design and fabrication.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

The Mars 2020 mission will complete the System Integration Review and begin Assembly, Test, and Launch Operations (ATLO).

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2018 PB Request
KDP-C	Jun 2016	Jun 2016
CDR	Dec 2016	Feb 2017
KDP-D	Jan 2018	Jan 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

This is the first report of development costs for this mission.

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2017	SMD 1620.1 NASA 1676.9	70	2017	SMD 1620.1 NASA 1674.7	0	LRD	Jul 2020	Jul 2020	0

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

MARS ROVER 2020

Formulation	Development	Operations

Development Cost Details

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:	1676.9	1674.7	-2.2
Technology Development	88.4	114.6	26.2
Aircraft/Spacecraft	527.4	585.8	58.4
Payloads	155.4	177.0	21.6
Systems I&T	71.1	71.1	0
Launch Vehicle/Services	342.5	239.5	-103.0
Ground Systems	80.4	98.8	18.4
Science Technology	16.5	16.5	0
Other Direct Project Costs	395.1	371.3	-23.8

MARS ROVER 2020

Formulation	Development	Operations

Project Management & Commitments

The Jet Propulsion Laboratory 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
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 (UV) 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

MARS ROVER 2020

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
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

Project Risks

Risk Statement	Mitigation
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 (MCS), 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.	The Flight System has worked with the Project and the SCS and MCS subsystems to do the following: Finalized end-effector design and actuator selection, allowing closure of performance requirements; finalized vendors and designs for all new actuators required for SCS; finalized rover motor controller design relative to actuators; reduced complexity by removing tube warming station and adding T-0 purge to the SCS caching assembly. MCS actuator development detailed design reviews and SCS critical design review are complete; SCS is moving into fabrication, assembly, and test.
If: PIXL and/or SHERLOC have significant implementation issues (technical, schedule, or cost) due to the large number of new and challenging subassemblies (x-ray, laser, etc.), Then: Direct development cost (instrument side) and project ripple effects (flight system thermal/mechanical/ATLO) and schedule impacts could result.	The project aggressively mitigated subassembly level risks at the component and subassembly level and continually develops further subsystem level schedule mitigations.
If: One or several of the aggregated EDL 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. Engineers have brought identified mitigations forward for approval as part of the flight software scrub.

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. By using contracts existing from the MSL project to procure new versions of the as-flown hardware, JPL plans to maintain the lowest possible costs. 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
SRR & MDR	SRB	Oct 2014 / Mar 2015	Evaluate whether the functional and performance requirements defined for the system are responsive to the program's requirements on the project and represent achievable capabilities. Evaluate the credibility and responsiveness of the proposed mission/system architecture to the program requirements and constraints, including available resources.	Mars 2020 successfully met the criteria and the PMC decision authority approved the project to continue to the next phase.	PDR
PDR	SRB	Feb 2016	Evaluate the completeness/consistency of the planning, technical, cost, and schedule baselines developed during Formulation. To assess compliance of the preliminary design with applicable requirements and to determine if the project is sufficiently mature to begin Phase C.	Complete	CDR

MARS ROVER 2020

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
CDR	SRB	Feb/Mar 2017	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.	Complete	SIR
SIR	SRB	Nov/Dec 2017	Evaluate the readiness of the project and associated supporting infrastructure to begin system AI&T, evaluate whether the remaining project development can be completed within available resources, and determine if the project is sufficiently mature to begin Phase D		ORR
ORR	SRB	May 2020	Evaluate the readiness of the project to operate the flight system and associated ground system(s) in compliance with defined project requirements and constraints during the operations/sustainment phase.		

OTHER MISSIONS AND DATA ANALYSIS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Mars Organic Molecule Analyzer (MOMA)	12.5	--	**15.0**	8.0	5.0	6.0	3.0
Aeroscience Ground Test Capabilities	0.0	--	**15.5**	21.5	22.2	22.2	22.2
ExoMars	1.3	--	**1.4**	1.5	1.5	1.5	1.5
Mars Program Management	13.3	--	**19.7**	19.8	19.8	20.0	20.0
Mars Future Missions	3.5	--	**2.9**	10.5	42.0	50.9	178.9
Mars Mission Operations	1.5	--	**1.9**	1.9	1.9	1.9	1.9
Mars Research and Analysis	10.0	--	**10.0**	10.0	10.0	10.0	10.0
Mars Technology	23.0	--	**7.5**	12.0	4.8	1.9	0.7
2011 Mars Science Lab	50.3	--	**57.0**	54.0	49.9	43.0	43.0
Mars Reconnaissance Orbiter 2005 (MRO)	27.7	--	**28.0**	27.0	27.0	26.0	26.0
Mars Exploration Rover 2003	14.2	--	**12.5**	0.0	0.0	0.0	0.0
Mars Odyssey 2001	9.7	--	**12.5**	6.0	0.0	0.0	0.0
Mars Express	2.9	--	**3.0**	3.0	0.0	0.0	0.0
Mars Atmosphere & Volatile EvolutioN	21.3	--	**23.5**	23.5	23.5	23.5	23.5
Total Budget	**191.2**	**--**	**210.4**	**198.7**	**207.6**	**206.9**	**330.7**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

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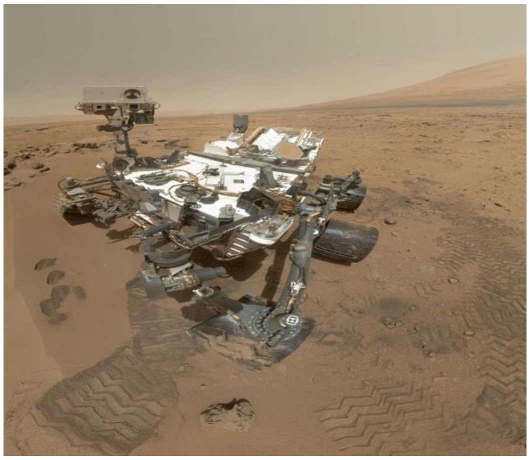

Rigorous scientific questions will drive all of our future missions. The questions will continuously evolve as we make new discoveries. Brand new technologies will enable us to explore Mars in ways we never have before, resulting in higher-resolution images, precision landings, longer-ranging surface mobility, and the ability to cache samples.

Other Missions and Data Analysis includes the NASA contribution to the European Space Agency ExoMars 2020 rover, the operating Mars missions, Mars Research and Analysis, Mars Technology, and Mars Program Management. Also included are the NASA-contributed Electra communications radios that NASA delivered to the European Space Agency 2016 Exobiology on Mars (ExoMars) Trace Gas Orbiter (TGO).

OTHER MISSIONS AND DATA ANALYSIS

Mission Planning and Other Projects

MARS ORGANIC MOLECULE ANALYZER (MOMA)

MOMA is the core astrobiology instrument on the ESA ExoMars 2020 rover, and it addresses the top ExoMars science goal of seeking signs of past or present life on Mars. The MOMA-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 budget consists of SMD's contribution to this agency-wide effort to maintain capabilities, to ensure they are available when needed for specific missions, including Mars.

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 TGO. For this mission, NASA contributed two Electra telecommunication radios, identical to those used successfully on NASA's MRO and MAVEN. Electra acts as a communications relay and navigation aid for Mars spacecraft. Electra's ultra-high frequency (UHF) radios support navigation, command, and data-return needs.

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:

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- 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 allows 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' geology and environment, 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

Sixteen papers recently published in a premier journal in planetary science, Meteoritics and Planetary Sciences, discussed findings related to the nature of volatile materials, including water, in Mars meteorites. These papers have provided significant new information on the water cycle of Mars, and the nature and potential formation mechanisms of organic material indigenous to Mars. Another paper concludes that strong winds behind cold fronts drive Martian dust storms.

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 component technology, 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. Mission concepts that may be studied in FY 2018 include potential public/private 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 9.5 miles and has been exploring the lower reaches of Mt. Sharp – the prime science target of the mission and is now in its second extended mission. It is during the trek to Mt. Sharp that the on-board laboratory measured plumes of methane 10 times above the background level – this presents a challenge in our understanding of the Martian atmosphere because scientists cannot adequately explain the source or the sink for the methane. In addition, Curiosity has measured the fixed nitrogen, permitting a primitive nitrogen cycle and making nitrogen biologically accessible, critical for potential Martian life. At the base of Mt. Sharp, the rover has been able to sample several sediment types as it moves from the plains of Gale Crater to up the initial slope of Mt. Sharp. One derived conclusion is that a combination of lake and river deposits formed the base of Mt. Sharp and indicates that early Mars had an environment with an active hydrologic cycle that could support a substantial body of water for extended periods. 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 the time that the environment could have supported microbial life.

MARS RECONNAISSANCE ORBITER 2005 (MRO)

MRO, currently in its fourth extended operations phase, carries HiRISE, the most powerful camera ever flown on a planetary exploration mission. 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. MRO also carries a radar sounder to find subsurface water, an important consideration in selecting scientifically worthy landing sites for future exploration. A second camera acquires medium-resolution images that provide a broader geological context for more detailed observations from higher-resolution instruments; it has covered much of the planet and searches for new phenomena, such as new impact craters revealing ice. In addition, MRO carries a high resolution imaging spectrometer, Compact Reconnaissance Imaging Spectrometer for Mars (CRISM), which can map minerals at unprecedented spatial resolution. A wide-angle camera provides daily global weather maps and an atmospheric sounder shows how the Martian atmosphere transports dust and water. 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 its fourth extended mission, MRO will reveal 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 flows of liquid water on Mars today. MRO is characterizing landing sites for the 2018 Insight Lander, Mars 2020 Rover and the 2020 ESA ExoMars Rover. It continues a survey of possible landing sites for potential human missions. As it explores, MRO also serves as a major installment of an “interplanetary Internet,” as a relay communications orbiter relaying commands to and data from surface assets to Earth.

Recent Achievements

MRO has been key in identifying mineral and morphological features from orbit that guide the robotic missions – flagging the large clay deposits in Marathon Valley for Opportunity to explore. HiRISE has guided the Curiosity rover by highlighting terrain that could be a hazard to the rover wheels and has connected a major geological unit to the base of Mt. Sharp. MRO helped find ESA's Beagle 2 Mars

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Lander, which has been thought lost since 2003, showing it survived the landing sufficiently to partially deploy the solar arrays. It also supported analysis of causes for the recent crash landing of the ExoMars demonstration lander by imaging the landed craft, its backshell with parachute, and its heat shield. Recent analyses of MRO data combining imaging and radar data have revealed large deposits of subsurface ice beneath the northern plains, placed limits on the last occurrence of mid-latitude glaciation (300,000 years ago), and expanded the inventory of surface changes, including possible brine flow features and new impact craters. MRO has been critical in providing the highest resolution images and mineral maps of candidate robotic and human landing sites. This is an ongoing process in which imaging requests are made to MRO and fulfilled such that the images needed for the Mars 2020 Landing Site Workshop (February 2017), enabled the reduction of candidates to three, and 55 percent of the human landing site requests have been completed in anticipation of the next human landing site workshop.

MARS EXPLORATION ROVER 2003

For over 13 years, the Mars Exploration Rover Opportunity has explored geological settings on the surface of Mars. It has expanded understanding of the history and the geological processes that shaped Mars, particularly those involving water. Opportunity has trekked over 27 miles across the Martian surface, (recently breaking the distance record for traverse on a planetary body beyond Earth), conducting field geology, making atmospheric observations, finding evidence of ancient Martian environments where intermittently wet and habitable conditions existed, and sending back to Earth well over 200,000 spectacular, high-resolution images.

Recent Achievements

In March 2015, the Mars Exploration Rover Opportunity completed its first Red Planet marathon -- 26.219 miles (42.195 kilometers) - with a finish time of roughly 11 years and two months.

Opportunity has begun an extensive campaign exploring the clays identified by MRO's CRISM in orbit. The rover survived its seventh Martian winter on the south facing slopes of the valley, maximizing its solar panel exposure and now continues exploring the most ancient terrain explored to date. This includes plans to investigate the geology of a water-carved gulley, located in Endeavour Crater, for the first time from the surface.

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.

Recent Achievements

The Mars Odyssey spacecraft recently changed to a new orbit with an early morning local time to enable the first systematic observations of how morning fogs, clouds, and surface frost develop in different seasons on the Red Planet. A new analysis by Odyssey's Thermal Emission Imaging System (THEMIS)

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indicates that the streaks known as Recurrent Slope Lineae (RSL) contain little to no liquid water in the shallow subsurface. In another study, researchers used THEMIS data to determine the presence of halite (table salt) in former basins that likely once hosted lakes of liquid water.

MARS EXPRESS

Mars Express, currently in its third 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.

Recent Achievements

Studies of atmospheric escape, securing additional coverage of subsurface water, and characterizing gravity waves and the Convective Boundary Later (CBL) have been significant contributions to the Mars exploration program.

MARS ATMOSPHERE AND VOLATILE EVOLUTION (MAVEN)

MAVEN, successfully launched in 2013, 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 providing the first direct and 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. NASA prepared MAVEN to provide contingency relay support during its primary science mission and it is evolving into a more regular communications role.

After successfully completing its primary mission in Nov 2015, MAVEN completed its first extended mission (EM-1) in Sep 2016, and is now executing its second extended mission (EM-2) with an expanded suite of science objectives and observational techniques.

Recent Achievements

Scientists have quantified the processes controlling the upper atmosphere structure and composition, and how these processes evolved. Using MAVEN data, researchers have identified a large variation with season of the hydrogen escape rate to space, as hydrogen comes from atmospheric water vapor, which will tell us about the loss to space of water through time.

MAVEN also has identified specific mechanisms and routes through which atmospheric ions are lost to space. These include loss down the tail of the solar wind and loss through a "polar plume", with the latter being identified for the first time from MAVEN data. Current estimates suggest that Mars may have lost up to tens of meters of water (as a global equivalent layer) to space through time, and up to an equivalent of more than half a bar of carbon dioxide (with one bar being the atmospheric pressure at the surface of the Earth).

MAVEN measurements of atmospheric argon tell us quantitatively about loss of gas to space through time, and suggest that the loss of gas to space has been a major process, and may have been the dominant process, in the changing Mars atmosphere through time.

OUTER PLANETS AND OCEAN WORLDS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Jupiter Europa	175.0	275.0	**425.0**	303.0	215.7	432.4	253.6
Other Missions and Data Analysis	86.0	--	**32.9**	15.1	13.6	13.8	13.6
Total Budget	**261.0**	**--**	**457.9**	**318.1**	**229.3**	**446.2**	**267.2**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

Other Missions and Data Analysis includes the Jupiter Icy Moons Explorer (JUICE), Outer Planets Research, and the operating mission Cassini.

Mission Planning and Other Projects

JUICE-JUPITER ICY MOONS EXPLORER

NASA is collaborating with 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

UVS, PEP-Hi and RIME all completed their preliminary design reviews and key decision point C reviews, and NASA approved them to proceed into their critical design phases.

OUTER PLANETS RESEARCH

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).

OUTER PLANETS AND OCEAN WORLDS

Recent Achievements

The Cassini Data Analysis portfolio funds a variety of investigations into Saturn, its moons, the rings, and the magnetosphere, including three new results published this year. 1) The moon Rhea's interaction with the Saturnian plasma has a distinctive bend in the magnetic field (called "Alfven wings") that is observed around bodies with ionospheres, which this satellite does not have; it has thus shown that this signature is not necessarily indicative of the presence of an ionosphere, but can also arise around airless bodies that are in a specific regime of plasma conditions. 2) Absorption bands in Titan's atmosphere strongly affect spectral observations of Titan's surface, and recent work has made significant progress on better understanding and constraining that effect by leveraging the specular reflection off surface liquids. This work not only will facilitate researchers' ability to compensate for atmospheric effects but also provides a way to study the structure and behavior of the atmosphere itself. 3) Researchers have observed waves on Titan's standing liquid bodies, and expected that they would be dominated by wind-based generation mechanisms (as in similar situations on Earth). However, a study of Bayta Fretum (a strait within Kraken Mare, a giant sea) indicates that hydrological mechanisms related to Titan's orbital motion play a dominant role. This result, when combined with other results of Titan's seas, suggest that the seas are not isolated, nor governed solely by local conditions.

Operating Missions

CASSINI

Cassini, in its extended operations phase, is a flagship mission in orbit around Saturn that altered our understanding of the planet, its famous rings, magnetosphere, icy satellites, and particularly the moons Titan and Enceladus. Cassini completed its prime mission in July 2008, completed its Equinox extended mission in July 2010, and began the Solstice extended mission in October 2010. It is exploring the Saturn system in detail, including its rings and moons. A major focus is on the ocean worlds in the Saturn system, Titan (Saturn's largest moon), with its dense atmosphere, methane-based meteorology, and geologically active surface; and Enceladus, a tiny icy body with its unexpected global ocean and steady plumes ejecting water from the South Pole. The Solstice mission is observing seasonal and temporal change in the Saturn system, especially at Titan, to understand underlying processes and prepare for future missions. In FY 2017, an encounter with Titan will change its orbit in such a way that, at closest approach to Saturn, it will be only about 1,800 miles above the planet's cloud tops, and below the inner edge of the D ring. This sequence of approximately 22 orbits, named the Grand Finale, will provide an opportunity for an entirely different mission for the Cassini spacecraft, investigating science questions never anticipated at the time Cassini launched. The Cassini mission will end September 15, after the proximal orbits when a final encounter with Titan will send the Cassini probe into Saturn's atmosphere.

Recent Achievements

The Cassini mission completed its final flybys of several icy moons of Saturn, including the tantalizing ocean world Enceladus. It then began a series of close ring-grazing orbits in preparation for the Grand Finale in 2017, a set of orbits at high inclination around Saturn that allowed the spacecraft to observe the rings and poles of the planet from an improved vantage point. The spacecraft completed additional flybys of Titan, monitoring the dramatic seasonal changes in the atmosphere, finding evidence of flooded steep canyons, and gathering more information on the methane seas on the surface.

EUROPA CLIPPER

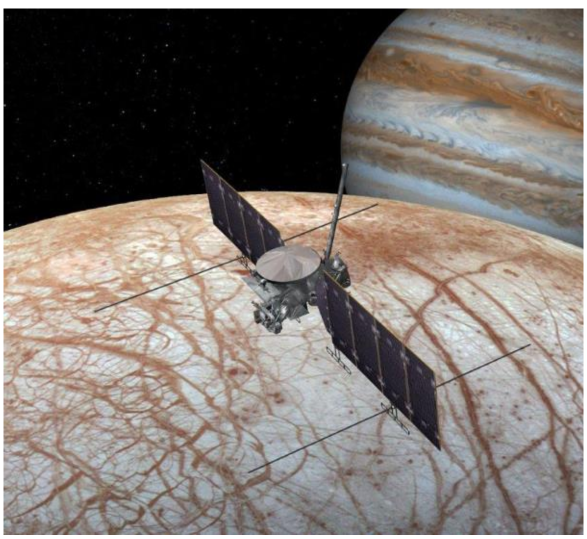
Formulation	Development	Operations

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	**146.3**	**--**	**425.0**	**303.0**	**215.7**	**432.4**	**253.6**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



The Europa Clipper spacecraft is designed 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 15 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 initiated the Phase A study of 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 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.

Costs and schedule for the current Europa Clipper mission design are not baselined, as the mission is still in formulation and NASA does not commit to costs and schedules until KDP-C, however the notional outyear profile in the Budget supports a launch in the mid-to-late-2020s.

EUROPA CLIPPER

Formulation	Development	Operations

The budget provides no funding for a multi-billion-dollar mission to land on Europa that was not in the last Decadal Survey and would send another flagship mission to Europa before analysis of the Europa Clipper data is completed.

EXPLANATION OF MAJOR CHANGES IN FY 2018

None.

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; and understand the formation of surface features, including sites of recent or current activity; identify and characterize high science interest localities.

The Europa Clipper mission will spend four years in orbit around Jupiter, conducting its scientific observations by completing multiple close fly-bys of Europa, minimizing the spacecraft's exposure to the harsh radiation environment near Europa.

ACHIEVEMENTS IN FY 2016

During FY 2016, NASA completed the accommodation of the selected science payload for the Europa Clipper mission. This significant work integrates the spacecraft and science instruments into a single cohesive mission that will lead the exploration of one of the most promising ocean worlds for the possible detection of life beyond Earth. The Europa Clipper mission expects to provide more than 90 percent of the science return of the original Europa Orbiter mission concept endorsed by the Planetary Decadal Survey, but at much lower cost than the earlier mission concept with this scientific payload.

WORK IN PROGRESS IN FY 2017

The Europa Clipper mission passed its KDP-B gate review in February 2017 and is in the preliminary design and technology completion phase (Phase B).

KEY ACHIEVEMENTS PLANNED FOR FY 2018

The Europa Clipper mission will advance from Phase B (preliminary design and technology completion) to Phase C (final design and fabrication) at the beginning of FY 2019. This flagship-class mission will be the first NASA mission explicitly designed to explore an ocean world.

EUROPA CLIPPER

Formulation	Development	Operations

Budget for 2022 Launch

Per Public Law 114-113, Division B, Title III, the following table provides rough estimates for the current mission design, including launch vehicle, assuming launch in 2022. NASA does not recommend acceleration of the launch to 2022, given potential impacts to the rest of the Science portfolio. The Administration supports a balanced science program, as recommended in the Decadal Survey.

	FY18	FY19	FY20	FY21	FY22
Europa 2022 ($M)	425.0	580.0	665.0	485.0	327.0

Note: The Europa profile above assumes an Evolved Expendable Launch Vehicle, as the cost of an SLS flight is not yet known.

ESTIMATED PROJECT SCHEDULE

Milestone	Formulation Authorization Document	FY 2018 PB Request
Formulation Authorization	Apr 2015	
SRR	Jun 2016	Jan 2017
KDP-B	Jul 2016	Feb 2017
PDR	Mar 2019	Aug 2018
KDP-C	May 2019	Sep 2018
CDR		Nov 2019
SIR		Sep 2020
KDP-D	TBD	Dec 2020
Launch (or equivalent)	TBD	TBD

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.

EUROPA CLIPPER

Formulation	Development	Operations

KDP-B Date	Estimated Life Cycle Cost Range ($M)	Key Milestone	Key Milestone Estimated Date Range
Jan 2017	3,100-4,000	LRD	NLT Jul 2023

Project Management & Commitments

Responsibility for Europa Clipper project management resides at JPL, with program management authority assigned to 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	
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	

EUROPA CLIPPER

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
ICEMAG	Magnetometer	Provider: JPL Lead Center: JPL Performing Center(s): JPL, UCLA Cost Share Partner(s): N/A	
PIMS	Plasma Instrument - Faraday Cups	Provider: APL Lead Center: JPL Performing Center(s): APL Cost Share Partner(s): N/A	
MISE	Infrared Spectrometer	Provider: JPL Lead Center: JPL Performing Center(s): JPL, APL Cost Share Partner(s): N/A	
REASON	Sounding Radar	Provider: Univ. of Texas Lead Center: JPL Performing Center(s): JPL, UT, U. Iowa Cost Share Partner(s): N/A	

Project Risks

Risk Statement	Mitigation
Launch Vehicle Availability - uncertainty due to Delta IV-Heavy retirement and Falcon 9 Heavy and SLS developments	Maintaining compatibility with both EELV and SLS. Assessing information on launch vehicles in development as it becomes available. Regular meetings with SLS on performance, interfaces, and environments
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
Planetary Protection and Flight System Bioburden Reduction	Early and regular engagement with the Planetary Protection Officer and planning for bioburden reduction efforts and assessment

EUROPA CLIPPER

Formulation	Development	Operations

Acquisition Strategy

The Europa Clipper spacecraft is a JPL "in-house" build with each subsystem doing its internal make/buy assessment, with competed industry contracts where appropriate. JPL has entered into a partnership with 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 GSFC will be providing the propulsion subsystem. The Europa Clipper payload comprises nine investigations, each competitively selected via a SMD AO.

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
MASPEX instrument	SWRI	San Antonio, TX
UVS instrument	SWRI	San Antonio, TX
E-THEMIS instrument	ASU Ball Aerospace	Tempe, AZ Boulder, CO

EUROPA CLIPPER

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Europa SRR & MDR	SRB	Jan 2017	Ensure that requirements and concept defined for the project will satisfy mission goals and the concept is complete, feasible, and consistent with available resources.	SRB recommend project proceed into phase B	Aug. 2018
Project PDR	SRB	Aug 2018	To evaluate the completeness/consistency of the planning, technical, cost, and schedule baselines developed during Formulation and assess compliance of the preliminary design with applicable requirements.		

EUROPA CLIPPER

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Project CDR	SRB	Nov 2019	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, and to determine if the design is appropriately mature to continue with the final design and fabrication phase.		
Project SIR	SRB	Sep 2020	To evaluate the readiness of the project and associated supporting infrastructure to begin system assembly, integration, and test, and to evaluate whether the remaining project development fits within available resources.		

OTHER MISSIONS AND DATA ANALYSIS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
JUICE - Jupiter Icy Moons Explorer	18.7	--	**18.5**	6.6	5.1	5.3	5.1
Outer Planets Research	8.5	--	**8.5**	8.5	8.5	8.5	8.5
Cassini	58.8	--	**5.9**	0.0	0.0	0.0	0.0
Total Budget	**86.0**	**--**	**32.9**	**15.1**	**13.6**	**13.8**	**13.6**

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Other Missions and Data Analysis includes the Jupiter Icy Moons Explorer (JUICE), Outer Planets Research, and the operating mission Cassini.

Mission Planning and Other Projects

JUICE-JUPITER ICY MOONS EXPLORER

NASA is collaborating with 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

UVS, PEP-Hi and RIME all completed their preliminary design reviews and key decision point C reviews, and NASA approved them to proceed into their critical design phases.

OUTER PLANETS RESEARCH

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).

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

The Cassini Data Analysis portfolio funds a variety of investigations into Saturn, its moons, the rings, and the magnetosphere, including three new results published this year. 1) The moon Rhea's interaction with the Saturnian plasma has a distinctive bend in the magnetic field (called "Alfven wings") that is observed around bodies with ionospheres, which this satellite does not have; it has thus shown that this signature is not necessarily indicative of the presence of an ionosphere, but can also arise around airless bodies that are in a specific regime of plasma conditions. 2) Absorption bands in Titan's atmosphere strongly affect spectral observations of Titan's surface, and recent work has made significant progress on better understanding and constraining that effect by leveraging the specular reflection off surface liquids. This work not only will facilitate researchers' ability to compensate for atmospheric effects but also provides a way to study the structure and behavior of the atmosphere itself. 3) Researchers have observed waves on Titan's standing liquid bodies, and expected that they would be dominated by wind-based generation mechanisms (as in similar situations on Earth). However, a study of Bayta Fretum (a strait within Kraken Mare, a giant sea) indicates that hydrological mechanisms related to Titan's orbital motion play a dominant role. This result, when combined with other results of Titan's seas, suggest that the seas are not isolated, nor governed solely by local conditions.

Operating Missions

CASSINI

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TECHNOLOGY

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	**197.0**	**--**	**207.2**	**198.6**	**200.6**	**204.8**	**206.6**

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Sub-ice Ocean explorer and sampler. The Technology Program is working to miniaturize this technology for Planetary Ocean Worlds exploration.

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 multi-mission capabilities and technology developments in key spacecraft systems, such as power, propulsion, and mission operations. The Planetary Science Technology program includes the Radioisotope Power System (RPS) Program managed by Glenn Research Center, DOE-managed Plutonium production and Production Operations infrastructure, Solar System Robotic Exploration Technology and Advanced Multi-Mission Operations System (AMMOS) projects.

EXPLANATION OF MAJOR CHANGES IN FY 2018

NASA is proposing $43 million for a new solar system robotic exploration technology initiative. This initiative will accelerate technological innovations that will change the paradigm for robotic solar system exploration by funding areas such as planetary science small satellites/Cubesats, technology development to advance small satellite technologies, life-detection instruments, and/or commercial partnerships to support future robotic solar system exploration. NASA is merging the current Advanced Technology project into this new activity.

TECHNOLOGY

ACHIEVEMENTS IN FY 2016

The Technology Program continued to advance the state of technologies for more advanced, higher efficiency power systems to enhance future exploration of deep space. Testing continued on a Stirling converters and controllers, providing engineers with a greater understanding of system reliability and lifetime limiting issues. This work will inform technology investment decisions in the future, and retire risk for the development of a future generation of Stirling power systems. The thermoelectric technology development effort is working in partnership with industry to transfer mature Skutterudite thermoelectric technology into a production facility for the potential enhancement of the MMRTG. The DoE completed the first plutonium-238 production demonstration in FY 2016, and shipped the initial production of new plutonium from the irradiation of neptunium-237 to Los Alamos National Laboratory for quality analysis.

WORK IN PROGRESS IN FY 2017

The RPS Program will conduct a procurement to assess the state of Stirling technologies across industry and define goals and requirements for future Stirling development projects. RPS will continue to advance towards a gate review of the Skutterudite thermoelectric technology transfer effort and develop the plan for the next phase. Additionally, the RPS Program will be supporting the New Frontiers AO, allowing for a potential mission requirement for MMRTGs or Radioisotope Heater Units. As part of preparing to support future flight missions that require nuclear power, such as New Frontiers, NASA is working with DOE to develop a constant fuel clad production process, which will reduce schedule risk and mission support cost.

NASA's Advanced Technology project competitively selected mission concept studies to identify high-priority planetary science objectives that CubeSats and SmallSats can address, and to guide NASA’s development of small spacecraft technologies relevant to deep space science investigations. These selections span a broad range of science objectives and spacecraft configurations, and will inform the design of future planetary smallsat missions. This activity is the Planetary Science component of the broader SmallSat/CubeSat initiative discussed in the Science overview section of this document.

NASA's Advanced Technology project competitively awarded research grants for development of high temperature (greater than 500 degrees Celsius) electronic components to survive on the surface of Venus, the hottest planetary destination in the solar system. This research will enable the future development of long-lived landers for Venus.

NASA's Icy Satellites Technology project competitively awarded research grants for development of technology required to land explore, and investigate the icy moons of Jupiter or Saturn. These awards included concepts specific to life detection technology, helping to develop the technology for future landed missions to the icy satellites.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

The RPS Program supports Mars 2020 by providing an MMRTG flight unit in FY 2018 for preparation for fueling, assembly, test and launch operations. DOE will be performing its second plutonium production demonstration as part of its efforts to restart plutonium production. LANL will be installing the new plutonium hot press that will reduce the schedule risk for producing plutonium fuel clad assemblies to future NASA missions.

TECHNOLOGY

Planetary Science is proposing a new solar system robotic exploration technology initiative. This initiative will accelerate technological innovations that will change the paradigm for robotic solar system exploration by funding areas such as planetary science small satellites/Cubesats, technology development to advance small satellite technologies, life-detection instruments, and/or commercial partnerships to support future robotic solar system exploration. This project will develop new technology based upon advanced technology work begun in 2017.

Program Elements

PLUTONIUM

NASA and DoE are restarting domestic production of Plutonium-238 for the first time since the 1980's. NASA funds the effort, which takes place at the DoE's Oak Ridge National Laboratory. An initial production of 100 grams was achieved in FY 2016, 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.

DOE OPERATIONS AND ANALYSIS

NASA funds the DoE personnel and infrastructure required to maintain the capability to develop and fuel radioisotope power systems for deep space spacecraft missions. DoE performs the work required for NASA missions at Oak Ridge, Los Alamos, Sandia, and Idaho National Laboratories.

ADVANCED TECHNOLOGY

NASA continues to study emerging planetary mission requirements to identify needs for new technology investment. NASA also engages with stakeholders to ensure the relevance and priorities for existing investments, consistent with the NASA Strategic Space Technology Investment Plan. NASA will continue investments in advanced energy production and conversion technologies and spacecraft technologies that can uniquely enable future planetary missions, including partnerships with STMD. Starting in FY 2018, NASA will focus this work on developing new approaches to planetary exploration, to reduce costs and enhance opportunities for scientific investigation through smallsat technologies and commercial partnership opportunities.

RADIOISOTOPE POWER SYSTEM

The radioisotope power system (RPS) Program is continuing technology development and certification of advanced power conversion in preparation for the development of future RPS systems, supporting production and certification of the MMRTG for Mars 2020.

Operating Missions

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, and mission planning. 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.

Program Management & Commitments

Program Element	Provider
RPS Program	Provider: GRC Lead Center: GRC Performing Center(s): GRC, JPL, GSFC, KSC, DOE Cost Share Partner(s): N/A
Plutonium	Provider: DOE Lead Center: GRC Performing Center(s): GRC, 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
Solar System Robotic Exploration Technology	Provider: N/A Lead Center: Headquarters Performing Center(s): ARC, GRC, GSFC, LaRC, JPL, JSC, MSFC Cost Share Partner(s): N/A
AMMOS	Provider: JPL Lead Center: JPL Performing Center(s): JPL, GSFC, JSC, ARC, MSFC, APL Cost Share Partner(s): N/A

Acquisition Strategy

DOE provides radioisotope power systems, production operations, and the Plutonium production projects on a reimbursable basis. The Solar System Robotic Exploration Technology project will fund competitively selected activities from the ROSES omnibus research announcement.

ASTROPHYSICS

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Astrophysics Research	192.8	--	**204.4**	220.5	225.4	261.9	288.1
Cosmic Origins	195.6	--	**191.6**	190.0	142.0	157.8	156.4
Physics of the Cosmos	125.3	--	**99.9**	109.4	111.1	93.6	93.7
Exoplanet Exploration	141.2	--	**176.0**	350.8	473.3	475.8	440.2
Astrophysics Explorer	107.6	--	**144.7**	175.1	201.3	211.5	222.1
Total Budget	**762.4**	**--**	**816.7**	**1045.8**	**1153.2**	**1200.6**	**1200.4**

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Astrophysics

ASTROPHYSICS RESEARCH

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Astrophysics Research and Analysis	69.7	--	**74.1**	81.4	82.6	84.2	84.2
Balloon Project	36.2	--	**37.3**	40.4	39.9	40.4	37.4
STEM Science Activation	37.0	--	**44.0**	44.6	45.9	47.0	48.7
Other Missions and Data Analysis	49.9	--	**49.1**	54.1	57.1	90.3	117.8
Total Budget	**192.8**	**--**	**204.4**	**220.5**	**225.4**	**261.9**	**288.1**

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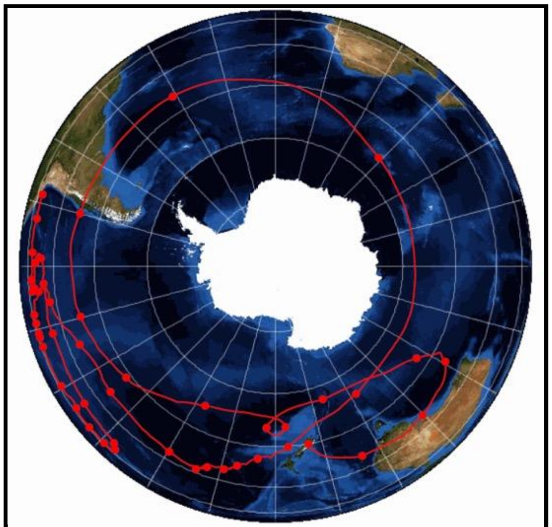


Map of the 46-day and night flight path of a super-pressure balloon, launched from Wanaka, NZ on May 16, 2016. The Compton Spectrometer and Imager (COSI) payload observed the gamma-ray emission from our Milky Way galaxy and detected a gamma-ray burst on May 30.

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 2018

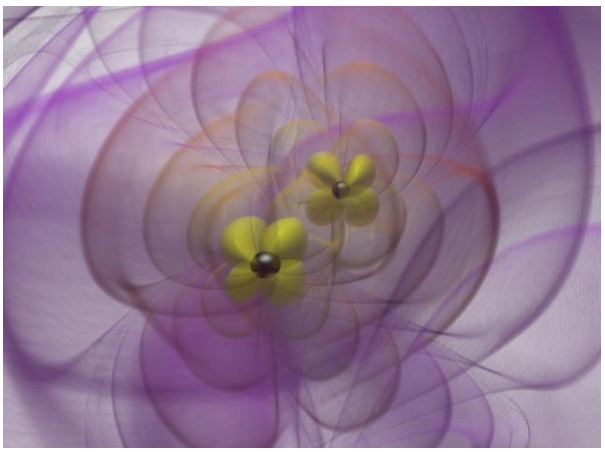
Compared to the FY 2016 enacted level, this budget reflects an increase to Science, Technology, Engineering, and Mathematics (STEM) Science Activation. The budget supports all planned activities unchanged by the proposed termination of the Office of Education.

ASTROPHYSICS RESEARCH

ACHIEVEMENTS IN FY 2016

NASA launched four Astrophysics experiments on sounding rockets in FY 2016. One experiment imaged the debris disk around the nearby star Epsilon Eridani, using a coronagraph to block out the star's glare so the investigators could see the debris disk. Another studied the low-energy X-ray emission produced by solar wind charge exchange by measuring the spatial signature of its emission. The third investigation used ultraviolet light to measure the flows of gas around young stars in a nearby galaxy and around its central black hole. The fourth experiment used ultraviolet light to study the atoms present in the gas around hot nearby stars.

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.



Computational simulation showing the release of gravitational waves during the merger of two black holes.

The Gamma-Ray Imager/Polarimeter for Solar flares payload, launched from Antarctica, provided near-optimal combination of high-resolution imaging, spectroscopy, and polarimetry of solar-flare gamma-ray/hard X-ray emissions. These measurements improve the understanding of solar flares by tracing the emission of charged particles accelerated in the flare. This payload flew for 11 days. The second payload is the Stratospheric Terahertz Observatory (STO2). It uses far-infrared light to trace molecules in the interstellar gas through the life cycle from molecular clouds to star formation. Unprecedentedly poor ground-level weather condition prevented a launch of STO2 during the FY 2016 season. The instrument remained in Antarctica and flew successfully as part of the FY 2017 campaign.

NASA completed reconfiguration of the successful balloon-borne Cosmic Ray Energetics and Mass (CREAM) payload to fly on the International Space Station (ISS) and shipped the ISS-CREAM payload to the Kennedy Space Center (KSC) in August 2015 to await its planned launch. ISS-CREAM remained in storage at KSC until September 2016, when ISS-CREAM came out of storage to complete three verification tests at KSC to validate payload functionality, end-to-end data systems compatibility with the ISS command/telemetry systems, and cleanliness levels of the payload thermal control system active cooling fluid. NASA successfully completed all three tests. The project returned ISS-CREAM to storage to await its planned launch in FY 2017.

Research on exoplanets confirmed the nature of exoplanet candidates identified by the Kepler project, 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.

ASTROPHYSICS RESEARCH

WORK IN PROGRESS IN FY 2017

Four research groups will launch Astrophysics experiments on sounding rockets in 2017. One of the experiments will measure the light of the infrared cosmic background that lurks between galaxies. The second will fly an advanced X-ray microcalorimeter detector to obtain high-resolution spectral data from the Puppis A supernova remnant. The third experiment will use a novel detector of ultraviolet light to study the atoms present in the gas around hot nearby stars. The fourth experiment will provide a uniform brightness calibration for stars from infrared to ultraviolet wavelengths, which is required to link data accurately from different space telescopes.

The Balloon program plans to support the annual Antarctic long-duration balloon flights, a super-pressure balloon campaign to New Zealand, as well as conventional balloon campaigns from Palestine, TX and Fort Sumner, NM. NASA launched three payloads in Antarctica in December 2016 (Antarctic Impulsive Transient Antenna (ANITA), Stratospheric Terahertz Observatory II (STO-2), and Boron And Carbon Cosmic rays in the Upper Stratosphere (BACCUS)). ANITA searched for energetic neutrinos that create distinct radio pulses when interacting in the Antarctic ice sheet. STO-2 performed a large-scale, high-resolution spectroscopic survey of far-infrared light from star-forming regions in the Galactic plane. BACCUS will investigate the density and chemicals in the environment between stars by studying cosmic ray particles. This study complements another investigation known as the Cosmic Ray Energetics and Mass (CREAM) experiment, which has flown previously on NASA balloons. NASA plans to launch the Extreme Universe Space Observatory (EUSO) payload on the 18.8 million-cubic-foot super-pressure balloon from New Zealand in April 2017.

ISS-CREAM successfully completed verification testing at KSC in October 2016 and placed back in storage at KSC until launch to the ISS on SpaceX-12, currently planned for August 2017.

On Monday, August 21, 2017, a total solar eclipse will occur for anyone within a 50 to 60 mile-wide path from Oregon to South Carolina. For the first time since June 8, 1918, anyone in a path that stretches from coast-to-coast will experience a total eclipse, during which the Moon completely covers the Sun for up to two minutes 40 seconds, weather permitting. The entire Nation will observe at least 60 percent or greater coverage of the Sun by the Moon. The Science Mission Directorate (SMD) leads the agency in promoting safety, showcasing the science, enabling educational concepts, public engagement, and citizen science. More than 10 spacecraft, including the ISS, may observe the event. On the ground, NASA is supporting hundreds of activities with the goal of improving the public’s understanding of the Sun/Moon/Earth system and other natural processes.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

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.

At least two research groups plan to launch Astrophysics experiments on sounding rockets in 2018. One investigation will focus on the extreme-ultraviolet spectrophotometry of nearby hot stars to provide powerful constraints on stellar atmosphere models and provide key insights towards understanding the reionization of the early universe. Another will examine low-energy X-rays produced by both the solar wind and hot gas within the Milky Way. The Balloon project plans to support two campaigns outside the continental U.S., including the annual Antarctic long-duration balloon flights and a super-pressure balloon launch from New Zealand, plus two domestic campaigns with conventional balloon flights from Palestine, TX, and Fort Sumner, NM.

The Antarctic campaign plans to launch three payloads for science investigations. The Palestine, TX, campaign plans to launch at least two payloads for science investigations. One of the planned balloon flights from Palestine, TX, will map the cosmic microwave background, and the other will test a new technology for direct imaging of exoplanets.

ISS-CREAM science operations will continue in FY 2018 following its planned launch in August 2017.

As part of the SMD-wide initiative discussed on page SCI-2, during FY 2018 NASA will enhance its investment in CubeSats/SmallSats that can achieve specific Astrophysics objectives at low cost.

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. To better support strategic research investment for the community, this budget supports a rebalance of fellowship awards and research grants.

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 novel 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 to be 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 to 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.

The NASA ISS-CREAM experiment is a former balloon payload that will operate on the ISS for up to three years. The science goal is to extend the reach of direct measurements of cosmic rays to the highest energy possible, to probe their origin, acceleration, and propagation. The long exposure provided by the ISS above the atmosphere offers more than an order of magnitude improvement in data, yielding much greater statistical accuracy and lower background noise. The University of Maryland in College Park leads the ISS-CREAM mission with international collaboration teams from the United States, South Korea, Mexico, and France.

SMD STEM SCIENCE ACTIVATION

The FY 2018 budget continues support for multi-year STEM science activation awards made in 2016. The peer-evaluated competition produced 27 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. They also work with local and national partners to achieve a multiplier effect utilizing NASA and SMD investments. The plan is to make independent evaluations of the STEM Science Activation project to assess the merits of this new approach to enabling science into the learning environment, wherever it occurs.

By 2020, measures of success are to support STEM engagement in all 50 states, improve U.S. scientific literacy, support Federal STEM Education Five-Year Strategic Plan goals; and increase the number of strategic partners, as appropriate, to enhance the overall effort.

The budget supports all planned activities within SMD's STEM Science Activation project, unchanged by the proposed termination of the Office of Education.

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 even 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.

ASTROPHYSICS RESEARCH

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
Mar 2016	Senior Review Operating Missions
Feb 2017	NASA Research Announcement (NRA) Solicitation
Feb 2018	NRA Solicitation
Mar 2019	Senior Review Operating Missions
Feb 2019	NRA Solicitation
Apr 2020	Senior Review Data Archives
Feb 2020	NRA Solicitation
Feb 2021	NRA Solicitation
Mar 2022	Senior Review Operating Missions

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): N/A
Balloon Project	Provider: Wallops Flight Facility (WFF) Lead Center: WFF Performing Center(s): WFF Cost Share Partner(s): N/A

Acquisition Strategy

NASA issues solicitations for competed research awards each February through ROSES. Panels of scientists conduct peer reviews on all proposals. 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	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
Quality	Mission Senior Review Panel	2019	A comparative evaluation of Astrophysics operating missions	Ranking of missions, citing strengths and weaknesses	2019, 2022, 2025
Quality	Independent Evaluation of STEM Science Activation	2017	Validation of approach and Logic Model	Baseline towards meeting overall Desired Outcome by 2020	Annual

OTHER MISSIONS AND DATA ANALYSIS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Astrophysics Directed R&T	1.5	--	**0.0**	4.5	7.0	9.5	13.2
Contract Administration, Audit & QA Svcs	12.1	--	**12.7**	12.7	12.8	12.8	13.1
Astrophysics Senior Review	0.0	--	**0.0**	0.0	0.0	30.6	54.1
Astrophysics Data Program	17.6	--	**17.6**	18.1	18.4	18.6	18.6
Astrophysics Data Curation and Archival	18.7	--	**18.8**	18.9	18.9	18.9	18.9
Total Budget	**49.9**	**--**	**49.1**	**54.1**	**57.1**	**90.3**	**117.8**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

The COSI payload shortly before launch from Wanaka, NZ on May 16, 2016. During the 46-day flight of the super-pressure balloon, COSI observed the gamma-ray emission from our Milky Way galaxy and detected a gamma-ray burst on May 30, 2016.

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.

CONTRACT ADMINISTRATION, AUDIT, AND QUALITY ASSURANCE SERVICES

This project provides critical safety and mission product inspections and contract audit services from the Defense Contract Management Agency and Defense Contract Audit Agency, respectively. It also provides for contract assurance audits, assessments, and surveillance by the NASA Contract Assurance Services Program.

OTHER MISSIONS AND DATA ANALYSIS

ASTROPHYSICS SENIOR REVIEW

The Astrophysics Senior Review project enables extension of the life of current operating missions. Every three years, the Astrophysics division conducts a senior review to do comparative evaluations of all operating 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.

ASTROPHYSICS DATA ANALYSIS PROGRAM (ADAP)

The Astrophysics Data Analysis Program (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. With the ongoing successful operation of a portfolio of missions ranging from modest Explorer-class missions like Swift and Nuclear Spectroscopic Telescope Array (NuSTAR) to the great observatories Hubble and Chandra, the size and scope of NASA's archival astronomical data holdings continue to grow. Investigations funded under the ADAP ensure that NASA's astrophysics data holdings continue to be the subject of vigorous scientific analysis, thereby maximizing the scientific return on NASA mission investments.

Recent Achievements

The scope of the investigations conducted under the ADAP include focused investigations involving the data from a single mission, such as the identification of new exoplanet candidates in data from the Kepler/K2 mission, to broad, multi-wavelength studies of the large-scale structure of the cosmos using data from several missions. Such multi-mission, multi-wavelength studies are almost exclusively the province of the ADAP and are a particularly exciting aspect of the program since combinations of data collected by different missions operating in different regions of the spectrum often yield new scientific insight beyond that derived from the original observations individually.

ASTROPHYSICS DATA CURATION AND ARCHIVAL RESEARCH (ADCAR)

The Astrophysics Data Centers constitute an ensemble of archives that receives 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. Astrophysics Data Curation and Archival Research covers the activities of the Astrophysics Data Centers and the NASA Astronomical Virtual Observatories (NAVO).

Recent Achievements

The Astrophysics Data Centers are tackling challenges and opportunities presented by a tremendous growth of content, and are collaborating effectively on integrated infrastructure leading to the NAVO. In FY 2016, the Astrophysics Data System project rolled out a new application programming interface as well as a user interface, which features network visualizations, citation analysis, and Open Researchers and Contributor iD (ORCiD) integration of its 11 million bibliographic records. ORCiD has a goal of providing a system to uniquely identify scholars across all disciplines. The Mikulski Archive for Space Telescopes (MAST) handled 40 million database searches and delivered over 517 terabytes of data to users; more than 1,300 scientific publications referenced use of the data. A new advanced search interface allows users to sift quickly through more than 2 million observations stored in MAST to find the data

OTHER MISSIONS AND DATA ANALYSIS

they want. New products include Version 2.0 of the Hubble Source Catalog and the final data products from the Kepler mission, as well as complete sets of light curves from the follow-on K2 mission. The High Energy Astrophysics Science Archive Center (HEASARC) released new versions of mission-independent data analysis software, HEASoft. HEASARC responded to 7.4 million queries, mainly through Virtual Observatory protocols, and scientific journals published almost 2,000 refereed papers based on HEASARC data. The Infrared Science Archive (IRSA) responded to over 34 million queries. IRSA data releases included the second year of data from the Near Earth Object Wide-field Infrared Survey Explorer (NEOWISE) reactivation and an update to the second Planck all-sky data sets. All IRSA catalogs are now accessible via the Virtual Observatory's table access protocol. By agreement with the ESA team, IRSA made the European Space Agency's (ESA) Gaia DR1 catalogue of over a billion stars available through IRSA's search services in support of archival research with NASA data. The NASA Extragalactic Database (NED) added over 42 million new objects and data on galaxies gleaned from over 3200 journal articles. A major update to the NED ingest pipeline included greater modularity and parallelization. In FY 2016, more than 700 refereed journal articles acknowledged using NED.

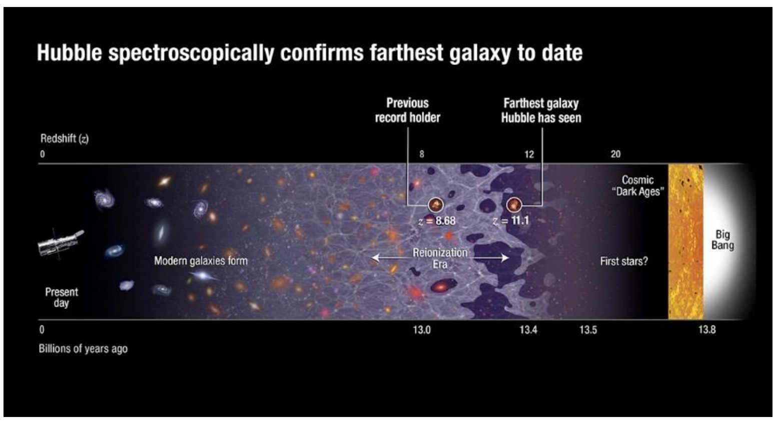
COSMIC ORIGINS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Hubble Space Telescope (HST)	98.3	--	**83.3**	83.3	83.3	98.3	98.3
Stratospheric Observatory for Infrared Astronomy (SOFIA)	83.6	--	**79.9**	79.8	39.8	16.6	0.0
Other Missions and Data Analysis	13.7	--	**28.4**	26.9	18.9	42.9	58.1
Total Budget	**195.6**	--	**191.6**	**190.0**	**142.0**	**157.8**	**156.4**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



By looking back through space, astronomers actually look back through time, converting the Hubble Space Telescope to a time machine. An international team of astronomers has shattered the cosmic distance record by viewing the farthest galaxy ever seen. Named GN-z11, scientists see this surprisingly bright, infant galaxy as it was 13.4 billion years in the past or just 400 million years after the big bang, when the universe was only three percent of its current age. At a spectroscopically confirmed redshift of 11.1, the galaxy is even farther away than originally thought. It existed only 200 million to 300 million years after the time the very first stars started to form. The combination of Hubble and Spitzer space telescopes imaging reveals that GN-z11 is 25 times smaller than the Milky Way and has just one percent of our galaxy's mass in stars.

"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 2018

The budget reflects more efficient operations of the Hubble Space telescope through the rephasing of grant funds, without impact to science.

HUBBLE SPACE TELESCOPE OPERATIONS

Formulation	Development	Operations

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	98.3	--	83.3	83.3	83.3	98.3	98.3

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

At the center of the Crab Nebula, located in the constellation Taurus, lies a celestial "beating heart" that is an example of extreme physics in space. The tiny object blasts out blistering pulses of radiation 30 times per second with unbelievable clock-like precision. Astronomers soon figured out that it was the crushed core of an exploded star, called a neutron star, which wildly spins like a blender on puree. This Hubble image captures the region around the neutron star.

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, 2016, marked the start of Hubble's 26th year in orbit. The observatory is currently in its most scientifically productive period.

EXPLANATION OF MAJOR CHANGES IN FY 2018

Compared to 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.

ACHIEVEMENTS IN FY 2016

New images from NASA's Hubble Space Telescope show suspected water plumes erupting from Jupiter's icy moon Europa. These observations bolster earlier Hubble work suggesting that Europa is

HUBBLE SPACE TELESCOPE OPERATIONS

Formulation	Development	Operations

venting water vapor. The plumes rise an estimated 125 miles before raining material back down onto Europa‘s surface. This is exciting because Europa is a plausible place for life to have developed beyond the Earth. If the venting plumes originate in a subsurface ocean, they could act as an elevator to bring deep-sea life above Europa’s surface, where a visiting spacecraft could sample them. The 2016 Senior Review of Operating Missions recommended continuing Hubble operations through FY 2019. This budget supports that recommendation.

WORK IN PROGRESS IN FY 2017

In FY 2017 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.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

The Space Telescope Science Institute (STScI), which manages Hubble’s science program, will select Cycle 25 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.

Project Schedule

Date	Significant Event
Jul 2017	Deadline of Phase II Cycle 25 Proposal Investigations
Dec 2017	Release of Cycle 26 Call for Proposals

HUBBLE SPACE TELESCOPE OPERATIONS

Formulation	Development	Operations

Project Management & Commitments

Element	Description	Provider Details	Change from Formulation Agreement
Observatory Operation	Provides safe and efficient control and utilization of Hubble, maintenance and operation of its facilities and equipment, as well as creation, maintenance, and utilization of Hubble operations processes and procedures	Provider: Lockheed Martin Lead Center: Goddard Space Flight Center (GSFC) Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Science Management	Evaluates proposals for telescope time and manages the science program	Provider: STScI/Association of Universities for Research in Astronomy (AURA) Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): European Space Agency (ESA)	N/A

Acquisition Strategy

NASA competes all new Hubble research opportunities.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Observatory Operation	Lockheed Martin	Littleton, CO
Science Management	STScI/AURA	Baltimore, MD

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board (SRB)	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)

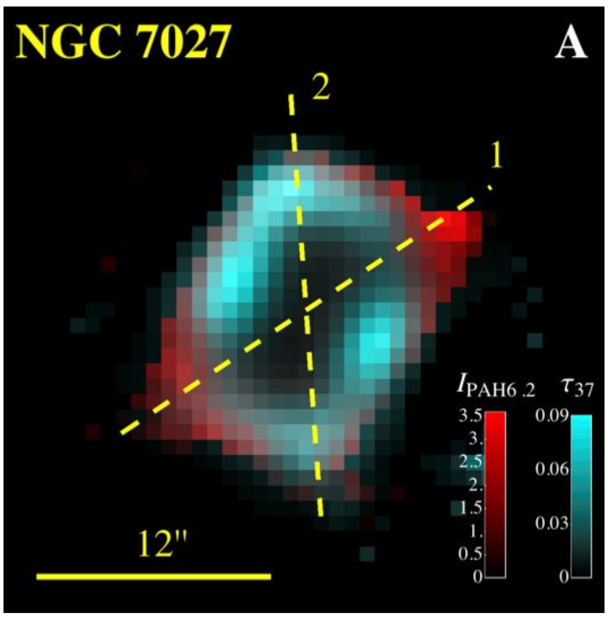
Formulation	Development	Operations

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	83.6	--	79.9	79.8	39.8	16.6	0.0

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



Spatially resolved mid-infrared images of planetary nebula NGC 7027, located around 3,000 light years away in the constellation Cygnus, using the Faint Object Infrared Camera for the SOFIA Telescope (FORCAST). They play a crucial role in the chemical evolution of our galaxy by expelling elements to the interstellar medium (ISM) from stars where those elements were created.

SOFIA is an airborne astronomical observatory that provides the international research community with access to infrared data unattainable from either ground-based or space telescopes. The images, spectra, and polarimetry have significant scientific value due to their coverage of mid- to far-infrared wavelengths. 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 in May 2014.

STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY (SOFIA)

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2018

This budget reflects efficiencies realized by the project in the past few years. SOFIA will participate in the next Astrophysics Senior Review. NASA will budget for the period of the mission extension if NASA grants SOFIA a mission extension as a result of the senior review process held in 2019.

ACHIEVEMENTS IN FY 2016

The SOFIA Program Office successfully transitioned from the Armstrong Flight Research Center (AFRC) to the Ames Research Center (ARC) on October 1, 2015.

NASA selected Cycle 4 proposals in October 2015. In FY 2016, with a suite of seven instruments, researchers used SOFIA to solve questions on the formation and evolution of gas in clouds, local galaxies, and massive protostar nurseries, and investigated the role of density waves on star formation in grand design spirals. SOFIA also measured the deuterium to hydrogen ratio on Mars, a diagnostic of past water history on the red planet.

NASA commissioned a second new observing mode of Updated German REceiver for Astronomy at Terahertz Frequencies, a 2nd-generation science instrument, in December 2015 and mapped 100 separate views of the Horsehead nebula in the constellation Orion 50 times faster than previously. All data were made publicly available, to demonstrate this new exciting capability for SOFIA.

In early February 2016, the project changed its plans for a SOFIA flight to allow a target of opportunity and captured data on a supernova in Centaurus A, a galaxy 15 million light years away. SOFIA also captured the first far-infrared observations of a

In June through July 2016, NASA conducted a seven-week deployment to the Southern Hemisphere to observe astronomical objects that are not visible in the skies from SOFIA's home base in California, followed by a scheduled period of aircraft maintenance. The High-resolution Airborne Wideband Camera (HAWC+), second-generation instrument, began its commissioning and characterization. Its first science observations of the massive star-forming region W3 demonstrate how this unique state-of-the-art diagnostic tool will contribute to our understanding of the role of magnetic fields during the star formation process.

A SOFIA science conference, held in Monterey, California, October 17-20, 2016, brought together 91 scientists and engineers to discuss and advance the field of star formation and feedback, with SOFIA and other observatories.

WORK IN PROGRESS IN FY 2017

SOFIA is nearing the completion of Cycle 4 observations, with the start of Cycle 5 observations commencing in February 2017. Cycle 5 has 762 planned research hours, with 535 research hours

Formulation	Development	Operations

allocated to Guest Investigators for programs covering a wide range of astronomical science areas. The science areas include solar system studies (including a follow-up of Hubble's recent sighting of water plumes on Jupiter's moon Europa), interstellar, circumstellar to extra-galactic (out to objects over 12 billion light years away), including several large observation time proposals. The project scheduled a Southern Hemisphere deployment from June through August of 2017 with three SOFIA instruments to meet the science demand.

HAWC+ completed its commissioning and demonstrated early science in December 2016. HAWC+ also provides a new capability for SOFIA, a far-infrared polarimeter, which enables investigations into the roles magnetic fields play our galaxy. The development phase for the third-generation science instrument, the High Resolution Mid-InfrarEd Spectrometer (HIRMES) began in FY 2017. SOFIA awarded a new primary contract for its Science Mission Operations to the Universities Space Research Association (USRA) in FY 2017.

In June 2017, SOFIA will solicit observing proposals for Cycle 6 (January 2018-February 2019). In addition, the next-generation instrument call for proposals will occur 2017, with a schedule to infuse new capabilities on SOFIA no later than 2021.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

SOFIA will observe an occultation of Neptune's moon Triton, over the Atlantic Ocean, in early October 2017 and will visit the American Astronomical Society (AAS) 2018 winter meeting in Washington, DC, in January 2018. The third-generation SOFIA instrument HIRMES will complete its build and test phase with delivery to SOFIA in the first quarter of FY 2019. NASA will complete the selection of the next-generation science instrument in the first quarter of FY 2018. Whether or not NASA moves forward with development of the instrument is contingent on the result of the 2019 Senior Review.

Project Schedule

Date	Significant Event
Apr 2017	Release of Cycle 6 Call for Proposals
Oct 2017	Announcement of Selected Cycle 6 Investigations

STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY (SOFIA)

Formulation	Development	Operations

Project Management & Commitments

The Ames Research Center (ARC) manages SOFIA.

Element	Description	Provider Details	Change from Formulation Agreement
Science Operations Center	Science Operations Center will solicit and select new investigations, schedule observations, and manage data acquisition and processing	Provider: ARC/ USRA Lead Center: ARC Performing Center(s): ARC Cost Share Partner(s): German Aerospace Center (DLR)/Deutsches SOFIA Institute (DSI)	N/A
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	N/A
Upgraded HAWC+	HAWC+ far-infrared camera to be upgraded with the addition of polarimetry capability and new state of the art detectors	Provider: Jet Propulsion Laboratory (JPL), GSFC Lead Center: ARC Performing Center(s): JPL, GSFC Cost Share Partner(s): N/A	N/A
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): N/A	N/A

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	Mission Senior Review	N/A	Evaluate operations efficiency, merit of science case, and scientific productivity	Ranking of SOFIA science return and reliability within available resources	2019

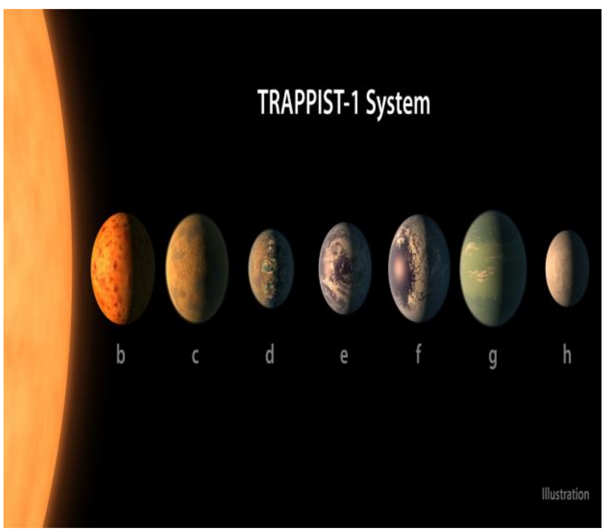
OTHER MISSIONS AND DATA ANALYSIS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Cosmic Origins Program Management	3.0	--	**2.9**	2.9	2.9	2.9	2.9
Cosmic Origins SR&T	3.6	--	**14.3**	13.0	11.1	12.1	12.1
Cosmic Origins Future Missions	0.8	--	**0.2**	1.5	1.5	28.0	43.1
SIRTF/Spitzer	3.9	--	**11.0**	9.5	3.5	0.0	0.0
Herschel	2.4	--	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**13.7**	**--**	**28.4**	**26.9**	**18.9**	**42.9**	**58.1**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



On February 22, 2017, NASA's Spitzer Space Telescope revealed the first known system of seven Earth-size planets around a single star and a new record for greatest number of habitable-zone planets found around a single star outside our solar system. All of these seven planets could have liquid water under the right atmospheric conditions, but the chances are highest with the three in the habitable zone.

Other Missions and Data Analysis supports the Spitzer Space Telescope, the scientific applications of which continue to expand, as well as NASA's partnership with ESA on the Herschel mission. Spitzer determined the mass and age of the youngest known galaxies, seen as they were when the universe was one-tenth or less of its current size and age. Herschel has shown that our galaxy contains abundant filamentary structures on length scales from a few light years to many hundreds. The science team expects many more discoveries over the next several years as they analyze data from both observatories.

Mission Planning and Other Projects

COSMIC ORIGINS PROGRAM MANAGEMENT

Cosmic Origins (COR) program management provides programmatic, technical, and business management, as well as program science leadership.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

The COR program office conducted an updated analysis of Hubble disposal timing and requirements. The program office verified a drift rate analysis of the telescope at lower altitudes and monitored relevant technologies. Under the current solar cycle conditions, the study concluded that the worst-case scenario for Hubble re-entry into the atmosphere is no earlier than FY 2030, and is most likely to occur around FY 2036.

COSMIC ORIGINS STRATEGIC RESEARCH AND TECHNOLOGY (SR&T)

COR Strategic Research and Technology (SR&T) supports program-specific research and advanced technology development efforts, such as the Strategic Astrophysics Technology (SAT) solicitation issued in FY 2015. In addition, funding supports the study of future NASA space observatories.

Recent Achievements

The COR program released its updated Program Annual Technology Report. This report summarizes the status of technology development funded by the program in prior years and in FY 2016. This report describes the prioritization of future technology needs.

A copy of the report is available at https://cor.gsfc.nasa.gov/technology/documents/COR2016PATR.pdf

The scientific community is actively engaged to lay the groundwork to mature mission concept studies and technology development that will eventually provide inputs to the 2020 Astronomy and Astrophysics Decadal Survey. The four mission concept studies are Large Ultraviolet/Visible/Infrared Surveyor, Origins Space Telescope, Habitable Exoplanet Imaging Mission, and Lynx X-ray Surveyor. The four mission concept studies and the science case and notional telescope design and instrument studies began in FY 2016.

COSMIC ORIGINS FUTURE MISSIONS

COR Future Missions funding supports studies of future mission concepts. COR Future Missions also supports the extension of COR missions following the Senior Review.

Recent Achievements

The scientific community is actively engaged to lay the groundwork to mature mission concept studies and technology development that will eventually provide inputs to 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, is now 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 Missions recommended continuing Spitzer operations until 2019. This budget supports that recommendation.

Recent Achievements

Spitzer has continued contributing to the study of unique stellar objects and of several exoplanet systems such as the detection of unusual pulsations in the outer shell of a star called HAT-P-2. These pulsations are the first example of the effect of a planet causing a heartbeat-like behavior in its host star. Researchers have observed this heartbeat effect in several Kepler observations of a handful of close binary stars with high eccentricity.

Scientists announced the science observation with the largest impact made by Spitzer on February 22, 2017, which was the discovery of seven Earth-size planets around a single and nearby star. This is a new record for greatest number of habitable-zone planets found around a single star outside our solar system. All of these seven planets could have liquid water under the right atmospheric conditions, but the chances are highest with the three in the habitable zone. This planetary system, called TRAPPIST-1, named for The Transiting Planets and Planetesimals Small Telescope (TRAPPIST) in Chile, is in the constellation Aquarius, about 40 light years (235 trillion miles) from Earth. In May 2016, researchers using TRAPPIST announced they had discovered three planets in the system. Spitzer, assisted by several ground-based telescopes, confirmed the existence of two of these planets and discovered five additional ones. Using Spitzer data, the team precisely measured the sizes of the seven planets and developed first estimates of the masses of six of them. This allowed scientists to estimate their density. Based on their densities, the TRAPPIST-1 planets are likely to be rocky. In contrast to our sun, the TRAPPIST-1 star – classified as an ultra-cool dwarf – is so cool that liquid water could survive on planets orbiting very close to it. All seven of the TRAPPIST-1 planetary orbits are closer to their host star than Mercury is to our sun. The planets also are very close to each other. The planets may be tidally locked to their star, which means the same side of the planet is always facing the star.

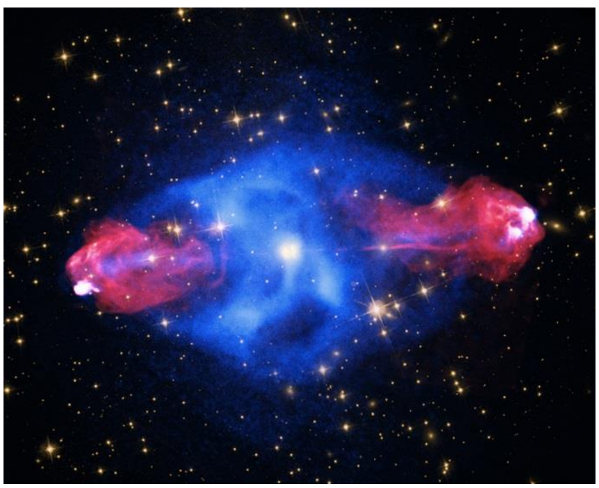
PHYSICS OF THE COSMOS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Other Missions and Data Analysis	125.3	--	**99.9**	109.4	111.1	93.6	93.7
Total Budget	**125.3**	**--**	**99.9**	**109.4**	**111.1**	**93.6**	**93.7**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



Images of the galaxy Cygnus A shows the dramatic impact of a supermassive black hole on its surroundings. Relativistic jets of particles accelerate from the vicinity of black hole, and punch giant holes in hot gas, detected with NASA's Chandra X-ray Observatory (blue). Radio data from the Very Large Array (red) reveal "hot spots" of light hundreds of thousands light years away from the center of the galaxy. Visible light data (yellow) from Hubble and Sloan Digital Sky Survey (SDSS) complete this view. Credit: X-ray: NASA/CXC/SAO; Optical: NASA/STScI; Radio: NSF/NRAO/AUI/VLA.

The universe can be viewed as a laboratory that enables scientists to study some of 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 data from the Fermi mission are trying to determine what comprises dark matter and how black holes accelerate immense jets of material to nearly the speed of light. The Planck mission observed the earliest moments of the universe and provided a high-resolution map of the cosmic microwave background. The X-ray Multi-Mirror Mission (XMM-Newton) is helping scientists solve cosmic mysteries, including enigmatic massive black holes. The Chandra X-Ray Observatory mission continues to reveal new details of celestial X-ray phenomena, such as the collisions of clusters of galaxies that directly detect the presence of dark matter. It unveiled a population of faint, obscured, massive black holes that may provide the early seeds for galaxy formation and growth since the birth of the universe nearly 14 billion years ago.

PHYSICS OF THE COSMOS

PCOS includes a vigorous program to develop the technologies necessary for the next generation of space missions to address the science questions of this program.

For more information, see: https://science.nasa.gov/about-us/smd-programs/physics-of-the-cosmos

EXPLANATION OF MAJOR CHANGES IN FY 2018

The FY 2018 Request is significantly lower than the FY 2016 Actual appropriation because of the expected completion of most of NASA's hardware development activities for ESA's Euclid mission.

OTHER MISSIONS AND DATA ANALYSIS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Physics of the Cosmos SR&T	17.7	--	**16.9**	22.0	20.8	20.1	20.1
Euclid	22.3	--	**6.9**	7.2	8.8	9.4	9.5
Physics of the Cosmos Program Management	3.4	--	**3.2**	3.2	3.2	3.2	3.2
Physics of the Cosmos Future Missions	1.1	--	**0.0**	2.1	2.5	2.5	2.5
Fermi Gamma-ray Space Telescope	15.9	--	**14.0**	14.0	14.0	0.0	0.0
Chandra X-Ray Observatory	59.8	--	**55.4**	57.4	58.4	58.4	58.4
XMM	2.9	--	**3.5**	3.5	3.5	0.0	0.0
Planck	2.2	--	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**125.3**	--	**99.9**	**109.4**	**111.1**	**93.6**	**93.7**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

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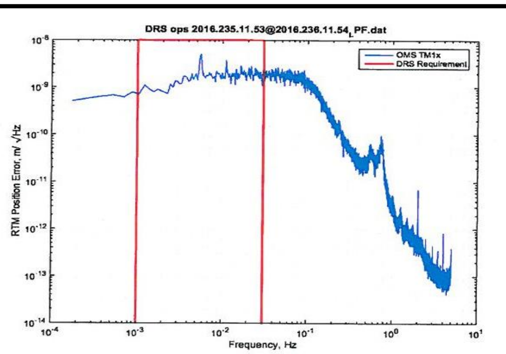


Figure 2: Amplitude Spectral Density of Position Error for Test Mass 1. The red box shows DRS requirements, which are easily met.

Space Technology (ST)-7 contains an experimental technology demonstration of a Disturbance Reduction System. The amplitude spectral density of position error for the test mass 1.

Other Missions and Data Analysis supports PCOS SR&T, PCOS Program Management, PCOS Future Missions, Euclid, Fermi, Chandra, and XMM.

Mission Planning and Other Projects

PCOS SUPPORTING RESEARCH AND TECHNOLOGY

PCOS Supporting Research and Technology includes Einstein Fellowships and strategic technology development efforts, to prepare for the next generation of PCOS space missions and continue discussions with ESA on a partnership on their Large 2 (Athena) and Large 3 (Gravitational Waves) missions with a goal to define the partnerships. The ST-7 project launched on the ESA Laser Interferometer Space Antenna (LISA) Pathfinder (LFP) mission in December 2015. NASA contributed enhanced thrusters that will apply thrust equivalent to the weight of a single grain of sand and have been a key component of the LPF gravitational technology demonstration experiment. ESA has now concluded the LPF prime mission and is conducting the short, extended mission, which will end in June 2017. ST-7 will operate for approximately six weeks during this extended mission.

Recent Achievements

The PCOS program released its updated Program Annual Technology Report. This report summarizes the status of technology development funded by the program in FY 2016 and describes the prioritization of future technology needs.

For more information, go to: https://pcos.gsfc.nasa.gov/technology/documents/PCOS2016PATR.pdf.

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 2020. 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

Teledyne has delivered all 25 flight candidate detectors to JPL. JPL has completed acceptance vibration testing of 23 of the detectors. GSFC has completed performance testing of 20 of the detectors, sufficient to meet the delivery requirements of 16 flight units and 4 spares to ESA. All detectors meet requirements with substantial margins. Integration and testing of the first four flight detector subsystems for ESA (detectors, cables, and readouts) began at GSFC in early February 2017. NASA delivered the first flight detector subsystems to ESA in March 2017.

PCOS PROGRAM MANAGEMENT

PCOS program management provides programmatic, technical, and business management, as well as program science leadership.

Recent Achievements

NASA entered into a letter of agreement with ESA to contribute to their Large 2 mission, Athena, an X-ray observatory dedicated to high-resolution spectroscopy. The details of the contribution are still under discussion. PCOS is leading the management of this contribution.

NASA is also pursuing a partnership with ESA on their Large 3 mission concept, a Gravitational Wave observatory, by assembling a Community Science Team to define options for NASA contributions. The details of the contribution are still under discussion. PCOS is leading the management of this contribution.

OTHER MISSIONS AND DATA ANALYSIS

PCOS FUTURE MISSIONS

PCOS Future Missions funding supports concept studies of future missions.

Recent Achievements

The PCOS program is engaging 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.

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 data 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, and has strong international and Department of Energy involvement. Fermi entered extended mission operations in August 2013. The 2016 Senior Review of Operating Missions recommended continuing Fermi operations through FY 2019. This budget supports that recommendation.

Recent Achievements

Recent notable accomplishments by Fermi include a misfit "skeleton" of a star that may link two different kinds of stellar remains. Researchers caught the mysterious object, called pulsar (PSR) J1119-6127, behaving as two distinct objects—a radio pulsar and a magnetar—and could be important to understanding their evolution. Since the 1970s, scientists have treated pulsars and magnetars as two distinct populations of objects. However, in the last decade, evidence has emerged that these could be stages in the evolution of a single object. These recent Fermi results, combined with other observations of the object, suggest that J1119 could be in a never-before-seen transition state between radio pulsar and magnetar. Using data from NASA's Fermi Gamma-ray Space Telescope and other facilities, an international team of scientists has also found the first gamma-ray binary in another galaxy, the most luminous one ever seen. The dual-star system, dubbed Large Magellanic Cloud (LMC) P3, contains a massive star and a crushed stellar core that interact to produce a cyclic flood of gamma rays, the highest-energy form of light. These rare systems contain either a neutron star or a black hole and radiate most of their energy in the form of gamma-rays. Remarkably, LMC P3 is the most luminous such system known in gamma rays, X-rays, radio waves, and visible light, and it is only the second one discovered with Fermi.

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 through FY 2019. This budget supports that recommendation.

Recent Achievements

With its unique vision of some of the hottest and most energetic phenomena in the cosmos, Chandra delivered several outstanding results over the past year. Astronomers have discovered a cosmic one-two punch unlike any ever seen before. Two of the most powerful phenomena in the universe, a supermassive black hole and the collision of giant galaxy clusters, have combined to create a stupendous cosmic particle accelerator. By combining data from Chandra, the Giant Metrewave Radio Telescope (GMRT) in India, the National Science Foundation's (NSF's) Karl G. Jansky Very Large Array, and other telescopes, researchers have found out what happens when the merger of two enormous galaxy clusters sweeps up matter ejected by a giant black hole. Another unparalleled image from Chandra gives astronomers the best look yet at the growth of black holes over billions of years beginning soon after the Big Bang. This is the deepest X-ray image ever obtained, collected with about 7 million seconds, or 11.5 weeks, of Chandra observing time. The image comes from what scientists call the Chandra Deep Field-South. The central region of the image contains the highest concentration of supermassive black holes ever seen, equivalent to about 5,000 objects that would fit into the area of the full Moon and about a billion over the entire sky. Astronomers have also used the Chandra observatory and other telescopes to show that a recently discovered galaxy is undergoing an extraordinary boom of stellar construction. The galaxy is 12.7 billion light years from Earth, seen at a critical stage in the evolution of galaxies about a billion years after the Big Bang. Astronomers have also found a pair of extraordinary cosmic objects that dramatically burst in X-rays. This discovery, obtained with NASA's Chandra X-ray Observatory and ESA's XMM-Newton observatory, may represent a new class of explosive events found in space. The mysterious X-ray sources flare up and become about a hundred times brighter in less than a minute, before returning to original X-ray levels after about an hour. At their peak, these objects qualify as ultraluminous X-ray sources that give off hundreds to thousands of times more X-rays than typical binary systems where a star is orbiting a black hole or neutron star.

X-RAY MULTI-MIRROR MISSION (XMM-NEWTON)

XMM-Newton is an ESA-led mission with substantial NASA contributions. The telescope launched in December 1999. XMM-Newton provides unique data for studies of the fundamental processes of black holes and neutron stars. It 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 XMM-Newton operations through FY 2019. This budget supports that recommendation.

Recent Achievements

During the past year, XMM-Newton observations yielded a number of important new science results. The XMM-Newton X-ray observatory has proved the existence of a 'gravitational vortex' around a black hole. The discovery, aided by NASA's NuSTAR mission, solves a mystery that has eluded astronomers for more than 30 years and will allow them to map the behavior of matter very close to black holes. It could

OTHER MISSIONS AND DATA ANALYSIS

also open the door to future investigations of Albert Einstein's theory of general relativity. An XMM-Newton observation of a giant bubble surrounding the center of the Milky Way also shows that six million years ago our Galaxy's supermassive black hole was ablaze with furious energy. It also shines a light on the hiding place of the Galaxy's so-called 'missing' matter. The observations have shown that there is a vast quantity of ordinary, so called baryonic matter scattered through the Galaxy. XMM-Newton found it in the form of gas at a temperature of one million degrees that permeates both the disc of the Galaxy, where the majority of the stars are found, and a spherical volume that surrounds the whole Galaxy. XMM-Newton observations of the Milky Way's nearby 'twin' galaxy Andromeda have led to the discovery of an elusive breed of stellar corpse, a neutron star, one particular class of object never detected before in the Andromeda galaxy: spinning neutron stars. Neutron stars are the small and extraordinarily dense remains of a once-massive star that exploded as a powerful supernova at the end of its natural life. They often spin very rapidly and can sweep regular pulses of radiation towards Earth, like a lighthouse beacon appearing to flash on and off as it rotates. Now, astronomers systematically searching through the archives of data from XMM-Newton X-ray telescope have uncovered the signal of an unusual source fitting the bill of a fast-spinning neutron star. It spins every 1.2 seconds and appears to be feeding on a neighboring star that orbits it every 1.3 days.

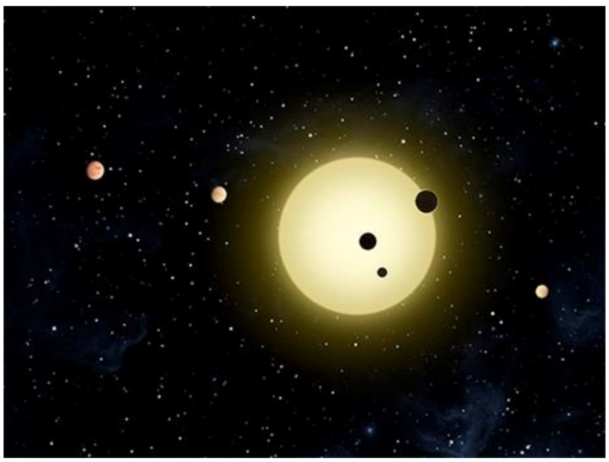
EXOPLANET EXPLORATION

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Other Missions and Data Analysis	141.2	--	**176.0**	350.8	473.3	475.8	440.2
Total Budget	**141.2**	**--**	**176.0**	**350.8**	**473.3**	**475.8**	**440.2**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



Two new exoplanets, Kepler 20e and 20f, are part of a five-planet system orbiting a sun-like star, similar to the artist's rendering above.

Humankind stands on the threshold of a voyage of unprecedented scope and ambition, promising 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 over 3,470 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 http://exep.jpl.nasa.gov/.

EXPLANATION OF MAJOR CHANGES IN FY 2018

None.

OTHER MISSIONS AND DATA ANALYSIS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
WFIRST	90.0	--	**126.6**	302.1	432.6	435.5	400.1
Exoplanet Exploration SR&T	20.9	--	**23.5**	25.8	24.0	24.7	24.5
Exoplanet Exploration Program Management	5.6	--	**6.5**	6.7	7.2	7.3	7.4
Exoplanet Exploration Future Missions	1.3	--	**0.3**	8.2	8.2	8.2	8.3
Keck Operations	5.8	--	**6.2**	0.0	0.0	0.0	0.0
Large Binocular Telescope Interferometer	1.5	--	**1.8**	0.0	0.0	0.0	0.0
Kepler	16.0	--	**11.1**	8.0	1.3	0.0	0.0
Total Budget	**141.2**	**--**	**176.0**	**350.8**	**473.3**	**475.8**	**440.2**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

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Relative sizes of habitable-zone planets discovered by the Kepler spacecraft, shown alongside Earth. NASA-Ames / JPL-Caltech.

Mission Planning and Other Projects

EXOPLANET EXPLORATION STRATEGIC RESEARCH AND TECHNOLOGY

Exoplanet Exploration Strategic Research and Technology supports program-specific scientific research, in addition to technology development activities that support and enable future Exoplanet Exploration missions.

In FY 2017, NASA supported eight competitively selected technology development projects involving 32 different investigators. The selected technology development projects all focus on advancing technologies for separating the feeble reflected light of an exoplanet from the overwhelming glare of its parent star, revealing clues to the planet’s nature. Those technologies will one day enable the ultimate goal of NASA’s Exoplanet Exploration Program: a future mission capable of imaging and measuring the spectra of habitable, Earth-like exoplanets in the solar neighborhood. Precision radial velocity technologies will enable better measurements of exoplanet masses. These precision radial velocity measurements, in conjunction with the transit photometric information that can provide the exoplanet radii, will result in the determination of exoplanet densities and structures before possible follow-ups in the search of chemical biomarkers of life.

Recent Achievements

New coronagraph techniques have demonstrated suppression of starlight glare to a few parts per billion and only a few image diameters away from the bright parent star. Coronagraphs and starshades are enabling technologies for the direct detection 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 this technology in possible future missions, enabling direct imagining of exoplanets and the search for spectral bio signatures. The Wide-Field Infrared Survey Telescope (WFIRST) coronagraph has completed its three-year technology demonstration program and remains on schedule to fly on the WFIRST observatory. NASA has consolidated starshade technology development efforts under a new management structure in which NASA will organize and fund an interdependent array of activities by industry, academia, and government.

The NASA and NSF partnership to develop a new precision radial velocity instrument for the WIYN telescope is progressing well, with completion of a detailed design review. The plan is to commission this new instrument in 2019.

EXOPLANET EXPLORATION PROGRAM MANAGEMENT

Exoplanet Exploration program management provides programmatic, technical, and business management, as well as program science leadership. Program management coordinates, supports, tracks the progress of the program’s numerous technology development tasks, and oversees the program’s portfolio of projects.

Recent Achievements

Scientists have confirmed approximately 3,500 exoplanets among the approximately 4,500 candidates currently catalogued. Current estimates indicate that perhaps 1 in 10 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 and providing oversight of the WFIRST project. 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.

WIDE-FIELD INFRARED SURVEY TELESCOPE (WFIRST)

WFIRST will execute a diverse and compelling set of surveys to explore the nature of dark energy, in addition to completing the exoplanet census through a gravitational microlensing survey. It also will directly detect and characterize exoplanets through a coronagraph technology demonstration, thereby paving the way for future missions to look for signs of life on earthlike planets beyond our solar system. The WFIRST mission utilizes existing large telescope assets. A 2014 report by National Academies (Harrison et. al.) found that NASA’s use of these assets “will significantly enhance the scientific power of the mission, primarily for cosmology and general survey science, and will also positively impact the exoplanet microlensing survey.”

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

WFIRST is currently in its concept and technology development phase, having entered formulation in February 2016. NASA held the WFIRST Acquisition Strategy Meeting (ASM) successfully in August 2016. Two aerospace companies are currently engaged in formulation studies for the Wide Field Instrument Opto-Mechanical Assembly, a critical element of the mission payload system. Engineers continue to achieve technology milestones in accordance with development plans established in March 2014. Engineers demonstrated thee Wide Field Instrument sensor chip assembly subsystem in a space-like environment, as well as components of the coronagraph instrument. NASA is currently studying the cost and benefits of system features that would make WFIRST compatible with a potential future starshade mission for exoplanet characterization. The WFIRST system requirements review and mission definition review will occur during 2017.

In April 2017, NASA initiated an independent, external review on the scope of the WFIRST project to help ensure it would provide compelling scientific capability with an appropriate, affordable cost and a reliable schedule. NASA expects the review panel to complete its work and submit a report outlining its findings and recommendations by approximately late June. NASA intends to incorporate these recommendations into its design and plans for WFIRST before proceeding with development of the mission.

EXOPLANET EXPLORATION FUTURE MISSIONS

Exoplanet Exploration Future Missions funding supports the execution of the exoplanet mission science and technology definition teams, and ultimately the formulation, development, and implementation of a future Exoplanet Exploration flight mission.

Recent Achievements

Community-based science and technology teams continue to be engaged to develop mission concepts and technology development plans. The Starshade Rendezvous Working Group recently developed an approach to ground-based demonstrations in a flight-like environment to support potential future flight missions.

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 Exoplanet Exploration, COR, and PCOS 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.

Recent Achievements

NASA is partner for one-sixth of the observing nights with the W.M. Keck Observatory for both 10-meter telescopes. Similarly, the Keck Observatory Archive (KOA), managed by the NASA Exoplanet Science

Institute, ingests and curates existing and new data from the Keck Observatory. In the past year, the KOA continued to add to the archive of data available to the community from the 10 Keck active and decommissioned instruments. This archive occupies more than 45 terabytes of astronomical data. In September 2016, Keck held the Keck/James Webb Space Telescope (Webb) Webb Workshop, which explored the ways in which Keck observations are likely to complement Webb capabilities.

Research using archival data from KOA continues to rise rapidly; to date, a total of 120 refereed publications have cited KOA data, with more than 19 of these in 2016. In May 2016, KOA made publicly available high-level science products from the Keck Observatory Database of Ionized Absorption toward Quasars (KODIAQ) project. The data, which are accessible from a dedicated interface for KODIAQ, include 170 spectra of fully reduced quasi-stellar objects, continuum normalized, and derived from public High Resolution Spectrograph raw data served through KOA.

For the first observing semester in 2017A (February to July 2017), proposals requested 126 nights to use either of the two Keck telescopes in Single Aperture Mode. This represents an oversubscription of 4.8 to one for both Keck telescopes. The project continued support for three multi-semester programs representing the sub disciplines of exoplanets, dark energy characterization, and planetary sciences (Europa) as part of the ongoing key strategic mission support solicitation. The proposal pressure, demonstrated by the high over subscription rates, continues to confirm the community interest in accessing Keck via the NASA observing time offered to all the U.S. astronomical community.

NASA’s current cooperative agreement with the W.M. Keck Observatory expires in 2018. NASA is working to put into place a new cooperative agreement and thereby to ensure continued NASA access to this key science facility.

LARGE BINOCULAR TELESCOPE INTERFEROMETER

The Large Binocular Telescope Interferometer (LBTI) is the NASA portion of the Large Binocular Telescope partnership. Engineers designed the LBTI to allow high contrast, high spatial resolution infrared imaging of dust clouds around 50 nearby stars. The system surveys nearby stars for dust and debris disks that may hamper the detection of 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 is currently executing the Hunt for Observable Signatures of Terrestrial Systems (HOSTS) survey. As of January 2017, the survey was 16 percent complete, with observations completed on 8 stars. Engineers collaborated with personnel from the Large Binocular Telescope Observatory to increase the reliability of the LBTI system and to ensure the completion of the HOSTS survey within budget and schedule commitments. The HOSTS results will provide important inputs to the design of the next generation of planet-hunting telescopes.

OTHER MISSIONS AND DATA ANALYSIS

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 in which the spacecraft observes along the ecliptic plane, opening up new possibilities for discovery. The 2014 Senior Review of Operating Missions favorably evaluated this new operating mode, which compensates for the loss of an attitude control actuator. The 2016 Senior Review of Operating Missions reaffirmed the scientific merit of continued Kepler operations using this modified operating mode.

Kepler's ultimate mission lifetime depends on its remaining fuel. NASA continually updates the estimates of the remaining fuel reserve. The 2016 Senior Review of Operating Missions recommended continuing Kepler/K2 operations through 2019. This budget supports that recommendation.

Recent Achievements

In May 2016, the Kepler/K2 mission announced 1,284 newly verified planets orbiting other stars in the Milky Way galaxy. The announcement more than doubled the number of confirmed planets from the spacecraft and represents the single largest finding of exoplanets to date. The new discoveries brought the tally of potentially habitable, earth-size planets identified by Kepler up to 21. The spacecraft continues to find new transiting planet candidates. K2 points to different astronomical fields every 70 to 80 days, which are called observing campaigns. Scientists identified over 800 candidates in the first eight campaigns of the extended mission (K2). K2 is also helping to prepare exoplanet targets that Webb will observe by identifying particularly nearby planets like K2-3b, announced in October 2015.

Similarly, on March 12, 2017, K2 released the data of the recently completed campaign 12, which included observations of the nearby multiple planetary system TRAPPIST-1. This is a system with previously observed three exoplanets, but subsequent Spitzer observations detected four additional Earth-size planets in this system. The K2 data taken over 79 days of observations of TRAPPIST-1 confirmed all seven planets, determined a more accurate orbital period for the seventh planet of 18.7 days, a radius of 0.715 of the Earth radius, and a rotation period of 3.3 days for the star. Owing to the proximity and size of this system, Webb should be able to discern the properties of the atmospheres of this intriguing multiple planetary system.

K2 dedicated its ninth campaign to a search for microlensing events. K2 successfully observed over 100 microlensing events in an experiment that serves as a pathfinder for the WFIRST mission. Astronomers also used Kepler/K2 to observe hundreds of galaxies beyond the Milky Way and detected, for the first time, the brilliant flash that occurs in the earliest moments of a supernova explosion, when the shockwave reaches the surface of the collapsing star, called a shock breakout, the detection reveals details about the physics of these explosive events. Kepler/K2 discovered nearly 75 percent of the more than 3,470 exoplanets currently known to humanity. Moreover, the spacecraft continues to make breakthrough discoveries in other key areas of astrophysics and solar system science.

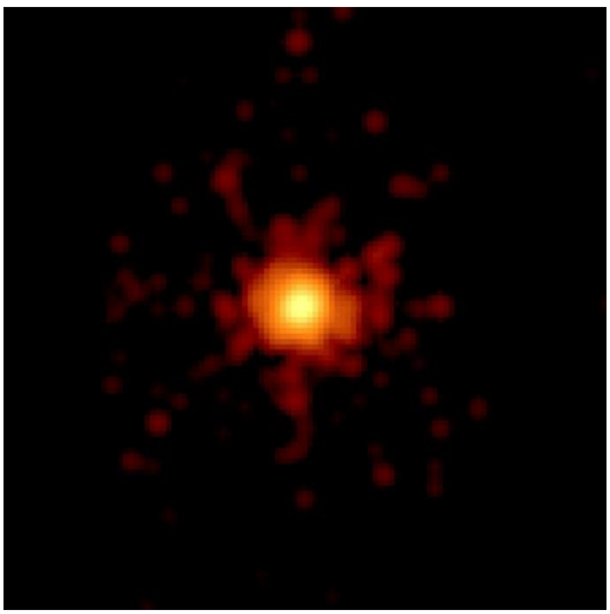
ASTROPHYSICS EXPLORER

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Transiting Exoplanet Survey Satellite (TESS)	62.5	89.0	**36.9**	9.1	2.5	0.0	0.0
Other Missions and Data Analysis	45.1	--	**107.8**	166.0	198.8	211.5	222.1
Total Budget	**107.6**	**--**	**144.7**	**175.1**	**201.3**	**211.5**	**222.1**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



A titanic burst of energy from a dying star 13 billion light years away has been spotted (center) from Earth.

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 that can be 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.

Medium-Class Explorers (MIDEX) missions cost up to $400 million in total, including launch services. Small Explorers (SMEX) may cost about half that total. Explorer missions of opportunity (MO) have a total NASA cost of under $75 million and may be of several types. The most common type of 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 associated with each AO issued for MIDEX and SMEX investigations.

For more information on Explorer missions, see: http://explorers.gsfc.nasa.gov/missions.html.

ASTROPHYSICS EXPLORER

EXPLANATION OF MAJOR CHANGES IN FY 2018

None.

ACHIEVEMENTS IN FY 2016

Japan launched the Japanese Aerospace Exploration Agency (JAXA) ASTRO-H (Hitomi) mission on February 17, 2016. The mission failed on orbit, however, the NASA team collected science data from the Soft X-Ray Spectrometer (SXS) instrument prior to failure and performed analysis of that data. The Neutron-star Interior Composition Explorer (NICER) completed the fabrication and integration of the instrument and shipped the payload to KSC, awaiting launch. The Transiting Exoplanet Survey Satellite (TESS) mission started critical design review. The three selected SMEX proposals and two MO proposals for Phase A continued their concept studies.

WORK IN PROGRESS IN FY 2017

The NICER payload is currently in storage at KSC awaiting launch no earlier than May 2017. The launch vehicle is a SpaceX Falcon 9 to the International Space Station. The TESS mission will continue its development of the instrument and spacecraft bus elements leading to its System Integration Review (SIR) in May 2017. NASA selected the Imaging X-ray Polarimetry Explorer (IXPE), SMEX mission, to begin preliminary design and technology completion activities. NASA also selected the Galactic/Extragalactic ULDB Spectroscopic Terahertz Observatory (GUSTO) MO mission, to begin preliminary design and technology completion activities. In summer 2017, NASA will select MIDEX and MO Phase A mission concept studies from proposals submitted in response to the 2016 NASA AO. NASA is considering fabrication of the critical components for the SXS instrument for a JAXA X-ray Astronomy Recovery Mission. TESS will begin Phase D, the system assembly, integration and test, launch and checkout phase of implementation in June 2017.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

NICER, having launched in FY 2017, will have completed in-orbit checkout and will be in the operational phase of data collection. TESS will launch in FY 2018. Selected MIDEX and MO investigation teams will continue preparing their Phase A mission concept studies. IXPE will pass its Key Decision Point (KDP)-C review to enter into Phase C, the final design and fabrication activities phase of development.

ASTROPHYSICS EXPLORER

Program Schedule

Date	Significant Event
Sep 2016	Announcement of Opportunity (AO) announcement for MIDEX and MO opportunity to propose
Jan 2017	Down select one SMEX mission for implementation
Mar 2017	Down select one MO mission for implementation
Aug 2017	MIDEX and Explorer MO KDP-A
Feb 2019	Down select one MIDEX and one MO mission for implementation
Sep 2019	AO announcement of SMEX and MO opportunity to propose
Aug 2020	SMEX and Explorer MO KDP-A
Sep 2021	AO announcement for MIDEX and MO opportunity to propose
Feb 2022	Down select one SMEX and one MO mission for implementation
Aug 2022	MIDEX and Explorer MO KDP-A

Acquisition Strategy

NASA selects all Explorer missions through a competitive AO.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Program Independent Review	SRB	Oct 2014	Assess performance of program	Successful	Sep 2019

TRANSITING EXOPLANET SURVEY SATELLITE (TESS)

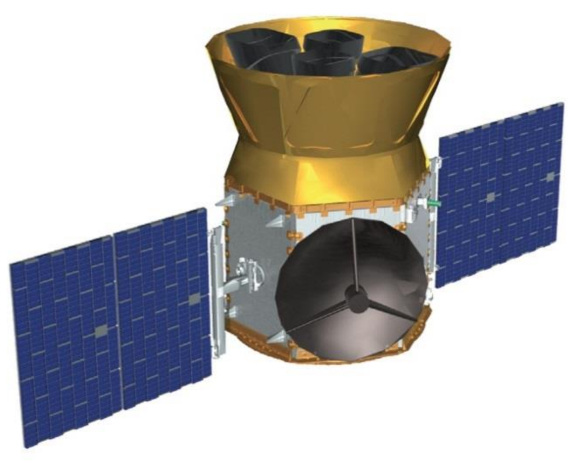
Formulation	Development	Operations

FY 2018 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022	BTC	Total
Formulation	27.1	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	27.1
Development/Implementation	124.6	62.5	85.2	**24.1**	0.0	0.0	0.0	0.0	0.0	296.4
Operations/Close-out	0.0	0.0	3.8	**12.8**	9.1	2.5	0.0	0.0	0.0	28.2
2017 MPAR LCC Estimate	**151.7**	**62.5**	**89.0**	**36.9**	**9.1**	**2.5**	**0.0**	**0.0**	**0.0**	**351.7**
Total Budget	**151.7**	**62.5**	**89.0**	**36.9**	**9.1**	**2.5**	**0.0**	**0.0**	**0.0**	**351.7**
Change from FY 2017				**-52.1**						
Percentage change from FY 2017				**-58.5%**						

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



The TESS mission will detect small planets with bright host stars in the solar neighborhood, so that other telescopes can perform detailed characterizations of the planets and their atmospheres.

PROJECT PURPOSE

The TESS mission objective is to survey bright nearby stars for transiting exoplanets over a three-year period, including two years of TESS observations and an additional third year of follow-up ground-based observations. The TESS mission will use an array of wide-field cameras to perform an all-sky survey.

TESS will carry out the first space-borne all-sky exoplanet transit survey, covering 400 times as much sky as any previous mission, including Kepler. It may discover approximately 30 Earth sized planets, 200 Super-Earth sized planets, and 400 sub-Neptune sized planets around other stars in the solar neighborhood.

With TESS, it will be possible to study the masses, sizes, densities, and orbits of small exoplanets, including a sample of rocky worlds in the habitable zones of their host stars. TESS will provide prime targets for further characterization by the James Webb Space Telescope (Webb), as well as other future large ground-based and space-based telescopes.

TRANSITING EXOPLANET SURVEY SATELLITE (TESS)

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2018

None.

PROJECT PARAMETERS

NASA will launch TESS into a high Earth elliptical orbit. TESS will make observations in the visible and infrared spectrum, utilizing four telescopic charge-coupled device (CCD) cameras. TESS will obtain imagery from both northern and southern hemispheres of the sky. TESS will orbit the Earth every 13.7 days, and will downlink, via Ka-band, the data it has collected over a period of approximately five hours each orbit. TESS will be a three axis-stabilized spacecraft using both momentum wheels and hydrazine thrusters.

ACHIEVEMENTS IN FY 2016

TESS successfully completed the Critical Design Review (CDR)/delta CDR process in December 2015.

WORK IN PROGRESS IN FY 2017

TESS will continue its development of the instrument and spacecraft bus elements leading to its System Integration Review (SIR) in May 2017. TESS will begin observatory integration in May 2017, with the KDP-D review planned in June 2017. The project will then begin Phase D, the system assembly, integration and test, launch and checkout phase of implementation.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

NASA plans to deliver TESS to KSC and launch in June 2018.

SCHEDULE COMMITMENTS/KEY MILESTONES

NASA plans to launch TESS in June 2018 to begin a three-year prime mission.

Milestone	Confirmation Baseline Date	FY 2018 PB Request
CDR	Apr 2015	Dec 2015
SIR	Oct 2016	May 2017
Start Phase D	Nov 2016	June 2017
Operations Readiness Review (ORR)/Flight Readiness Review (FRR)	Dec 2017	Feb 2018

TRANSITING EXOPLANET SURVEY SATELLITE (TESS)

Formulation	Development	Operations

Milestone	Confirmation Baseline Date	FY 2018 PB Request
Launch Readiness Date (LRD)/Initial Operating Capability (IOC)/IC	Jun 2018	Jun 2018
Start Phase E/FC/IC	Aug 2018	Aug 2018
End Prime Mission	Aug 2021	Aug 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	323.2	>70	2017	296.4	-8	LRD	Jun 2018	Jun 2018	0

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

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**323.2**	296.4	-26.8
Aircraft/Spacecraft	43.0	59.7	16.7
Payloads	23.2	52.4	29.2
Systems I&T	3.7	3.7	0.0
Launch Vehicle	114.1	87.4	-26.7
Ground Systems	16.7	-12.9	-3.8
Science/Technology	7.5	5.8	-1.7

TRANSITING EXOPLANET SURVEY SATELLITE (TESS)

Formulation	Development	Operations

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
Other Direct Project Costs	115.0	74.5	-40.5

Project Management & Commitments

GSFC is responsible for Project Management.

Element	Description	Provider Details	Change from Baseline
Instrument	Visible-IR telescopic CCDs detectors	Provider: Massachusetts Institute of Technology (MIT) Lead Center: Lincoln Laboratories Performing Center(s): N/A Cost Share Partner(s): N/A	None
Spacecraft Bus	LEO Star three-axis stabilized spacecraft bus	Provider: Orbital ATK Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A	None
Launch Vehicle	Launch Vehicle	Provider: Space Exploration Technologies Corporation (SpaceX) Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	None

Project Risks

Risk Statement	Mitigation
If: the SpaceX launch vehicle and launch pad are not certified in time, Then: the TESS LRD will need to slip.	The TESS Project is working closely with the KSC Launch Services Program to monitor SpaceX certification progress.

TRANSITING EXOPLANET SURVEY SATELLITE (TESS)

Formulation	Development	Operations

Acquisition Strategy

NASA selected the mission through a competitive AO.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Spacecraft Bus	Orbital ATK	Dulles, VA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Feb 2014	SRR	Successful	Preliminary Design Review (PDR)
Performance	SRB	Sep 2014	PDR	Successful	CDR
Performance	SRB	Start Aug 2015/ completed Dec 2015	CDR/delta CDR	Successful	SIR
Performance	SRB	May 2017	SIR	TBD	Launch Readiness Review (LRR)
Performance	SRB	2018	LRR	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Galactic/Extragalactic ULDB Spectroscopi	0.3	--	**4.7**	12.2	11.1	8.2	2.9
Imaging X-Ray Polarimetry Explorer	0.0	--	**42.2**	42.6	47.3	30.9	22.9
ASTRO-H (SXS)	7.2	--	**0.0**	0.0	0.0	0.0	0.0
Astrophysics Explorer Future Missions	2.7	--	**36.7**	89.8	117.1	163.3	188.5
Astrophysics Explorer Program Management	12.2	--	**10.2**	8.6	10.8	9.0	7.8
Neutron Star Interior Composition Explor	10.1	--	**1.7**	0.5	0.0	0.0	0.0
Swift	5.1	--	**5.4**	5.4	5.5	0.0	0.0
Suzaku (ASTRO-E II)	0.6	--	**0.0**	0.0	0.0	0.0	0.0
Nuclear Spectroscopic Telescope Array	6.9	--	**7.0**	7.0	7.0	0.0	0.0
Total Budget	**45.1**	--	**107.8**	**166.0**	**198.8**	**211.5**	**222.1**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

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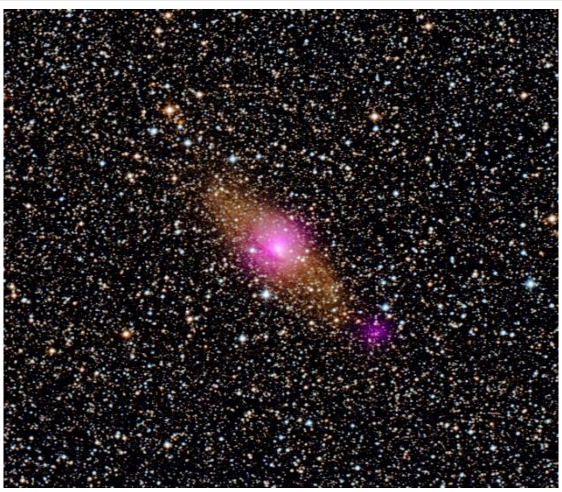

NuSTAR took this X-ray image of two black holes in the Circinus Galaxy, which is 13 million light-years away. The two black holes, shown as magenta-colored objects superimposed on the optical galaxy image, consist of a supermassive black hole at the galaxy center and a smaller black hole on the galaxy edge.

Astrophysics Explorer Other Missions and Data Analysis includes funding for small missions in formulation and development (NICER) operating missions (NuSTAR, Swift), and funding for future mission selections and program management functions.

Mission Planning and Other Projects

ASTRO-H (SXS)

NASA provided a High-Resolution SXS instrument to Japan for launch onboard the JAXA ASTRO-H mission. The SXS instrument is a cryogenically cooled high-resolution X-ray spectrometer to allow the most detailed studies of a wide range of astronomical systems from nearby stars to distant active galaxies.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

Japan launched the JAXA-led ASTRO-H mission on February 17, 2016 from Tanegashima Japan, and subsequently renamed it Hitomi. As part of the commissioning program, the project cooled the SXS instrument to its cryogenic operating temperature and conducted science observations of the Perseus Cluster of galaxies. The SXS observations revealed for the first time the fine details, on both small and large scales, of motions in the X-ray-bright gas in a giant galaxy cluster. During commissioning Hitomi experienced an on-orbit failure (not attributed to the SXS instrument) on March 26, 2016, and the mission was declared ended on April 28, 2016. NASA activities will close out in FY 2017.

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 2021 for approximately 100 days. GUSTO’s 0.85-m 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 reinitiation 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.

THE IMAGING X-RAY POLARIMETRY EXPLORER (IXPE)

NASA selected the Imaging X-ray Polarimetry Explorer (IXPE) a small Explorer-class mission to continue into Phase B formulation in January 2017. 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 mission will be launched into a low inclination, low Earth orbit for a 2-year mission beginning in November 2020.

ASTROPHYSICS EXPLORER FUTURE MISSIONS

Astrophysics Explorer program management provides programmatic, technical and business management of ongoing missions in formulation and development. The FY 2018 Request supports NASA’s participation with JAXA on a recovery mission to achieve ASTRO-H science. Consistent with Japan’s schedule, NASA intends to hold a KDP-A/B review in 2017, formally establishing the Project and its budget.

ASTROPHYSICS EXPLORER PROGRAM MANAGEMENT

Astrophysics Explorer program management provides programmatic, technical and business management of ongoing missions in formulation and development.

OTHER MISSIONS AND DATA ANALYSIS

NEUTRON STAR INTERIOR COMPOSITION EXPLORER (NICER)

The NICER instrument, to be located on the external logistics carrier of the ISS, will perform high time resolution and spectroscopic observations of neutron stars to uncover the nature and probe the physics of ultra-dense matter in the core of neutron stars. NICER will explore the exotic states of matter inside these stars where density and pressure are higher than in atomic nuclei. NICER will enable rotation-resolved spectroscopy of the thermal and non-thermal emissions of neutron stars in the soft X-ray band with unprecedented sensitivity, probing interior structure, the origins of dynamic phenomena, and the mechanisms that underlie the most powerful known cosmic particle accelerators.

Recent Achievements

The project completed the fabrication and integration of the instrument, shipped the payload to Kennedy Space Center for storage awaiting launch no earlier than May 2017.

Operating Missions

SWIFT

Swift 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. The 2016 Senior Review of Operating Missions recommended continuing Swift operations through FY 2019. This budget supports that recommendation.

Recent Achievements

Swift has detected and characterized 1,250 gamma ray bursts to date. Swift continues to observe gamma-ray bursts at a rate of around 90 per year, as well as many other astrophysical targets. Recent high-profile examples of Swift's utility include the discovery of magnetic cycles on our closest stellar neighbor that hosts a potentially habitable planet, the discovery of rapidly spinning stars spun up as the result of two stars merging, and distant black holes shredding and consuming wandering stars.

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 survey 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. NuSTAR research teams collaborate with those using Fermi to make simultaneous observations. The NuSTAR mission implemented a Guest Observer Facility for U.S. observers in 2015. Scientists implement the observations selected under Cycle 2 of the Guest Observer program and NASA received proposals for Cycle 3 on January 27, 2017. The 2016 Senior Review of Operating Missions recommended continuing NuSTAR operations through FY 2019. This budget supports that recommendation.

Recent Achievements

NuSTAR continued its highly successful science program, providing invaluable new insights into the high-energy phenomena in the universe. Supermassive black holes often lurk behind gas and dust, but give themselves away when material they feed on emits high-energy X-rays. NuSTAR, the first telescope capable of focusing high-energy X-rays into sharp pictures, has begun to pinpoint large numbers of hidden black holes. NuSTAR recently identified two gas-enshrouded supermassive black holes, located at the centers of nearby galaxies. These massive black holes are relatively close to the Milky Way, but they have remained hidden from us until now. Supernova SN 2014C, a star exploding at the end of its life in a spiral galaxy about 40 million light years away, is challenging astronomers' models of how exploding stars distribute the chemical elements that are made inside the star. NuSTAR has allowed scientists to watch how the temperature of electrons accelerated by the supernova shock changed over time. They used this measurement to estimate how fast the supernova expanded and how much material is in the external shell. Together with other observations, the NuSTAR measurements showed that, surprisingly, the supernova brightened in X-rays after the initial explosion; this is probably because the outgoing shock wave hit a shell of gas previously ejected by the dying star.

JAMES WEBB SPACE TELESCOPE

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	**620.0**	**569.4**	**533.7**	**304.6**	**197.2**	**149.8**	**150.0**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

James Webb Space Telescope

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

FY 2018 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022	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	4190.6	620.0	569.4	**533.7**	227.6	0.0	0.0	0.0	0.0	6141.3
Operations/Close-out	0.0	0.0	0.0	**0.0**	77.0	197.2	149.8	150.0	310.0	884.0
2017 MPAR LCC Estimate	**5990.7**	**620.0**	**569.4**	**533.7**	**304.6**	**197.2**	**149.8**	**150.0**	**310.0**	**8825.4**
Total Budget	**5918.6**	**620.0**	**569.4**	**533.7**	**304.6**	**197.2**	**149.8**	**150.0**	**310.0**	**8753.3**
Change from FY 2017				**-35.7**						
Percentage change from FY 2017				**-6.3%**						

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

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
- 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 2018

None.

PROJECT PARAMETERS

Webb is an infrared-optimized observatory that will conduct imaging and spectrographic observations in the 0.6- to 28-micrometer wavelength range. Webb will be roughly 100 times more capable than Hubble, because its mirror is seven times larger, it will spend about twice as much time observing targets since the Earth will not be in the way, its detectors cover larger regions of the sky and are always on (i.e., can

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

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 2018 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 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 2016

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:

- Completed the third and final cryogenic test of the Integrated Science Instrument Module, with all flight instruments and new detectors;

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

- Delivered the Integrated Science Instrument Module to Goddard Space Flight Center (GSFC) for Optical Telescope Element/Integrated Science Instrument Module integration;
- Completed the integration of flight primary mirror subassemblies onto the flight primary mirror backplane;
- Completed the integration of the Science Instrument Module to the Optical Telescope Element;
- Completed the spacecraft bus structure;
- Completed the acceptance testing of the cryocooler compressor assembly, and integration of the assembly into the spacecraft bus;
- Completed the integration of the spacecraft bus electronic equipment panels; and
- Completed the manufacture of sunshield flight layers.

WORK IN PROGRESS IN FY 2017

In FY 2017, the project plans to complete the following development and test efforts:

- Conduct ambient environmental testing of the Optical Telescope/Integrated Science module (OTIS);
- Deliver OTIS to the NASA Johnson Space Center (JSC) for cryovacuum testing;
- Conduct OTIS cryovacuum testing;
- Complete the sunshield structure manufacture and test.
- Deliver the flight solar array to the observatory for integration; and
- Issue General Observers Call for Proposals for the first year of Webb observing time.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

The President's FY 2018 Budget request provides the full level of funding required to keep Webb on schedule for a 2018 launch. In FY 2018, the project plans to:

- Complete integration and testing of Webb;
- Conduct testing of the Webb flight operations system and science processing system;
- Install ground support equipment at the launch site in Kourou, French Guiana; and
- Transport Webb to the launch site in Kourou, French Guiana.

SCHEDULE COMMITMENTS/KEY MILESTONES

NASA plans to launch Webb in October 2018 to begin a five-year prime mission. The following timeline shows the development agreement schedule per the rebaseline plan from September 2011.

Milestone	Confirmation Baseline Date	FY 2017 PB Request
Key Decision Point (KDP)-C	Jul 2008	Jul 2008

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

Milestone	Confirmation Baseline Date	FY 2017 PB Request
Mission Critical Design Review (CDR)	Mar 2010	Mar 2010
Rebaseline/KDP-C Amendment	Sep 2011	Sep 2011
System Integration Review (SIR)	Jul 2017	Oct 2017
Launch	Oct 2018	Oct 2018
Begin Phase E	Apr 2019	Apr 2019
End of Prime Mission	Apr 2024	Apr 2024

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	2017	6,188.8	-0.2	LRD	Oct 2018	Oct 2018	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost. NASA originally baselined Webb in 2009, it was re-baselined in 2012. 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**	**6,188.8**	**-9.1**
Aircraft/Spacecraft	2,955.0	3,409.3	454.3
Payloads	695.1	765.4	70.3
Systems Integration & Test (I&T)	288.4	406.5	118.1
Launch Vehicle	0.9	0.6	-0.3
Ground Systems	652.3	569.1	-83.2
Science/Technology	42.7	25.1	-17.6
Other Direct Project Costs	1,563.5	1012.8	-550.7

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. The observatory is 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 issues arise during environmental testing of OTIS, spacecraft, sunshield, or observatory, Then: This may delay completion of testing of the affected element, adding risk to achieving the October 2018 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	April 2016	OTE/Integrated Science SIR	Completed	N/A
Performance	SRB	August 2016	OTE/Integrated Science Pre-Environmental Review	Completed	N/A
Performance	SRB	N/A	Spacecraft Element Readiness Review		Mar 2017
Performance	SRB	N/A	SIR		Oct 2017
Performance	SRB	N/A	LRR		Sep 2018

HELIOPHYSICS

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Heliophysics Research	160.0	--	**200.2**	217.2	214.8	219.0	219.5
Living with a Star	337.1	--	**381.0**	255.9	123.3	118.9	122.1
Solar Terrestrial Probes	49.5	--	**37.8**	97.9	171.5	185.1	191.1
Heliophysics Explorer Program	100.6	--	**58.9**	116.8	183.1	174.9	165.1
Total Budget	**647.2**	**--**	**677.8**	**687.8**	**692.8**	**697.8**	**697.8**

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Heliophysics

HELIOPHYSICS RESEARCH

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Heliophysics Research and Analysis	36.3	--	**49.9**	58.2	58.6	58.6	58.6
Sounding Rockets	49.8	--	**59.0**	61.1	63.1	63.1	63.1
Research Range	21.6	--	**24.1**	25.5	25.5	25.6	25.6
Other Missions and Data Analysis	52.2	--	**67.1**	72.4	67.6	71.7	72.2
Total Budget	**160.0**	--	**200.2**	**217.2**	**214.8**	**219.0**	**219.5**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.
FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

Three NASA rockets launched within a two-hour period March 2, 2017. They carried instruments into active auroras over Alaska to aid scientists studying the northern lights and the interactions of the solar wind with Earth's upper atmosphere and ionosphere.

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 humanactivities?

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's interior to Earth's upper atmosphere and beyond, through interplanetary space to the end of the region of the Sun's influence, far beyond the outer planets.

For more information, go to https://science.nasa.gov/heliophysics/programs/research

HELIOPHYSICS RESEARCH

EXPLANATION OF MAJOR CHANGES IN FY 2018

The FY 2018 Request would enable NASA to implement the Diversify, Realize, Integrate, Venture and Educate (DRIVE) Initiative as recommended in the Heliophysics Decadal Survey, and includes an increase for the Cubesats small satellite project.

ACHIEVEMENTS IN FY 2016

The Sun continuously emits an energetic stream of electrified and magnetized gas called the solar wind. Understanding the solar wind is essential to ultimately being able to predict space weather as the different parameters of solar wind, such as temperature, velocity, and direction, can affect the impact of space weather events on Earth. The mechanisms that propel and heat the solar wind from the surface of the Sun out into the heliosphere remain a mystery. New statistical analyses enabled by long-term datasets from the Wind and Advanced Composition Explorer (ACE) missions, which observe the solar wind near Earth, examined the various processes through which solar wind is heated and accelerated. Results from Wind data have revealed that during periods when the solar wind is relatively slow, particle collisions, while infrequent, play a critical role in regulating the electron temperature. Using ACE data, scientists examined times when the solar wind was not dominated by collisions, and found that the heavy ions appear to be much hotter than solar wind protons and helium, suggesting heating via a process earlier in the solar wind lifetime. Heliophysics Research is enabling new and important insights into these evolving scientific mysteries around solar wind heating and acceleration.

Dynamic processes in the troposphere and stratosphere drive the Earth’s mesosphere, our outermost atmospheric boundary with interplanetary space. A recent study using data from the Aeronomy of Ice in the Mesosphere (AIM) revealed that the coupling between the lower and upper regions of our atmosphere extends to the spatial properties of the mesosphere. The study analyzed polar mesospheric cloud (PMC) edges and holes to find that they have fractal properties, or never-ending patterns, which are essentially the same between the northern and southern hemispheres. This is a surprising result, since many other characteristics of PMCs, such as altitude and brightness, as well as environmental conditions, such as temperature and water vapor content, are different in the north and south. Small-scale atmospheric gravity waves that propagate energy to the upper atmosphere from local lower atmospheric sources, such as winds over mountains, thunderstorms, and tornados, largely determine the intricate patterns seen in PMCs. These results suggest that the gravity waves important to the PMC region must also be similar in the two hemispheres. Because of their relatively small scale, gravity waves are difficult to observe directly on a global scale and only poorly characterized in atmospheric models; therefore, insights into their properties represent steps toward improving our ability to simulate and predict weather and climate.

The successful development of a new type of space-based magnetometer holds great promise for further discoveries. Funded by NASA, engineers developed a miniature atomic scalar magnetometer based on an isotope of the element rubidium for operation in space. The instrument design utilizes microelectromechanical system technology with a vapor cell and a metal-oxide-semiconductor integrated circuit. The vapor cell is so small that it efficiently warms to its operating temperature and takes advantage of stimulation of magnetically sensitive atomic resonance sensors. The prototype instrument has very small mass and power requirements, while maintaining state-of-the-art sensitivity. Future advances in heliophysics research critically depend on infusion of new technology such as this magnetometer to enable more cost-effective future heliophysics missions.

HELIOPHYSICS RESEARCH

The Sounding Rockets Program began FY 2016 with a successful test flight of the new Black Brant Mk4 rocket motor. The program has subsequently approved the Mk4 for volume production. Overall, FY 2016 featured 13 total missions from three different launch sites: Wallops Flight Facility (WFF) in Virginia, White Sands Missile Range in New Mexico, and Andoya Space Center in Norway. These missions investigated the Sun, the physical characteristics of the Aurora Borealis, and various astrophysics phenomena. Three of these missions performed demonstrations of new technologies, and two missions provided spaceflight opportunities for undergraduate college students. Additionally, two instrumented disposal/test burns of Peregrine rocket motors at WFF supported the ongoing NASA Engineering and Safety Center-funded re-design effort.

WORK IN PROGRESS IN FY 2017

In FY 2017, NASA will continue its restructured and improved portfolio of competed research programs by fully implementing the Diversify, Realize, Integrate, Venture, Educate (DRIVE) initiative, as outlined in the National Academies' 2013 Decadal Survey for Solar and Space Physics. The Heliophysics Division continues implementation of CubeSats on behalf of the Science Mission Directorate (SMD). The Tandem Beacon-Explorer (TBEx), a Heliophysics CubeSat mission in development to study tropical weather relationship to ionospheric bubbles, will launch in FY 2017.

NASA will continue 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.

The current sounding rocket mission manifest features 18 missions in FY 2017. Five rockets successfully launched from the Poker Flat Research Range in Alaska between January and March 2017. Two technology demonstration missions from the WFF will enable 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. In addition to the normal complement of solar and astrophysics investigations from White Sands Missile Range, two geospace science missions will launch from the Kwajalein Atoll in the Marshall Islands. 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. The NASA Engineering and Safety Center redesign effort continues with the Critical Design Review (CDR) planned for the end of the year. On the horizon, the Program is in the planning stages for a potential FY 2019 campaign in Australia, which will likely feature several missions investigating celestial targets of interest in the Southern sky.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

In FY 2018, the Heliophysics Research program anticipates significant science results from the analysis of data from the Ionospheric Connections Explorer (ICON) mission and from the Global-scale Observations of the Limb and Disk (GOLD) mission of opportunity, as well as results from 18 active space missions (28 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) (two spacecraft), Van Allen Probes (two spacecraft), Voyager (two spacecraft), and Wind. The Space Environment Testbeds (SET) project, a collection of technology experiments, should fly along with several other spacecraft in early FY 2018. 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 2018 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).
SMD will continue to collaborate with the Human Exploration and Operations Mission Directorate (HEOMD) 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 2018.

In addition, Heliophysics plans three CubeSats in FY 2018 to address targeted Heliophysics science questions. 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. In addition, the Electron Losses and Fields Investigation (ELFIN) will study dominant wave-loss mechanism of relativistic electrons.

Program Elements

RESEARCH RANGE

The Research Range Services (RRS) 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. RRS 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 (theory) (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.

HELIOPHYSICS RESEARCH

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 2018 funds to ROSES-2017, ROSES-2016, and ROSES-2015 selections.

Date	Significant Event
Q1, Q2 FY 2017	ROSES-2016 selections: Oct 2016–May 2017
Q2 FY 2017	ROSES-2017 solicitation: Feb 2017
Q3/Q4 FY 2017	Review of proposals submitted to Heliophysics ROSES-2017 elements
Q1 FY 2018	ROSES-2017 selection within six to nine months of receipt of proposals
Q2 FY 2018	ROSES-2018 solicitation
Q1 FY 2019	ROSES-2018 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

HELIOPHYSICS RESEARCH

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	Mission Senior Review Panel	Apr 2015	A comparative evaluation of Heliophysics operating missions	The report, released in June 2015, assessed missions individually, and as part of a system observatory	Jul 2017
Quality	Mission Senior Review Panel	Jul 2017	A comparative evaluation of Heliophysics operating missions	The report, planned for released in June 2017, will assess missions individually, and as part of a system observatory	Apr 2020
Relevance	NASA Advisory Council Heliophysics Subcommittee	2016	To review progress towards Heliophysics objectives in the NASA Strategic Plan	All areas were rated green as documented in the FY 2016 Agency Financial Report	Future reviews will be conducted by newly chartered Heliophysic s Advisory Committee
Relevance	Heliophysics Advisory Committee	2017	To review progress towards Heliophysics objectives in the NASA Strategic Plan		Reviews will be conducted annually

OTHER MISSIONS AND DATA ANALYSIS

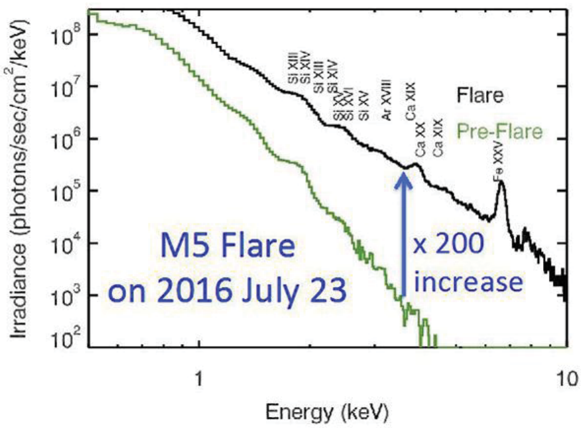
FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Science Planning and Research Support	6.6	--	**6.7**	6.7	6.7	6.7	6.8
Directed Research & Technology	0.0	--	**0.0**	0.0	0.0	3.9	4.2
CubeSat	5.0	--	**15.0**	15.0	10.0	10.0	10.0
Solar Data Center	1.0	--	**1.2**	1.3	1.1	1.2	1.2
Data & Modeling Services	2.6	--	**2.7**	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	10.5	--	**15.2**	20.0	20.0	20.0	20.0
Community Coordinated Modeling Center	2.2	--	**2.3**	2.3	2.4	2.4	2.4
Space Science Mission Ops Services	11.5	--	**11.5**	11.6	11.9	11.9	11.9
Voyager	5.7	--	**5.6**	5.6	5.5	5.5	5.5
SOHO	2.2	--	**2.2**	2.3	2.3	2.3	2.4
Wind	2.2	--	**2.2**	2.2	2.2	2.2	2.2
Geotail	0.4	--	**0.2**	0.2	0.2	0.2	0.2
Total Budget	**52.2**	**--**	**67.1**	**72.4**	**67.6**	**71.7**	**72.2**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

OTHER MISSIONS AND DATA ANALYSIS



MinXSS CubeSat data fill an important spectral gap in solar irradiance measurements, collecting solar soft X-ray (SXR) data at unprecedented spectral resolutions. This is a MinXSS measurement of the M5.0 flare taken on July 23, 2016 and indicates a factor of 200 increase in the brightness of soft X-ray (SXR) emissions. The pre-flare spectrum is the green line, and the flare spectrum is the black line. Also labeled are some of the brighter coronal emissions lines.

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 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 across the various themes and disciplines within SMD.

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 $3 million and $6 million per investigation and with rapid development cycles, CubeSats can provide frequent science and technology flight opportunities.

OTHER MISSIONS AND DATA ANALYSIS

All SMD science disciplines allow proposals to build and fly instruments on CubeSats. 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 is initiating an exciting re-evaluation in many aspects of the NASA space research enterprise and thus provides conceptual level benefits well beyond the individual missions themselves. SMD is also working closely with STMD to maximize the benefit from STMD's CubeSat efforts.

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 Facility (SPDF) 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 (CCMC)

The Community Coordinated Modeling Center (CCMC) 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.

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 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

Voyager 1 continues to measure the properties of the interstellar matter expelled from other stars. At the same time, IBEX remotely images the region where Voyager is from Earth orbit. This combination of observations allows scientists to unravel mysteries of the interaction of solar and stellar wind. In 2009, IBEX revealed a narrow, bright emission feature of neutral hydrogen atoms surrounding the entire sky, the so-called "ribbon", which lead to a number of theories trying to explain it. According to a leading model, the ribbon comes from repeated neutralization and ionization of hydrogen, in which magnetic mirroring plays a key role: The ribbon particles travel toward Earth from directions nearly perpendicular to the interstellar magnetic field, providing a unique way to pin down the field's properties. Analysis of recent Voyager 1 magnetic field observations has now explained why the magnetic field information returned by the spacecraft immediately after entering interstellar space was not as expected. The magnetic field orientation in interstellar space was extremely similar to the magnetic field orientation inside the heliosphere. Researchers assumed that there should have been an abrupt transition in the magnetic field orientation separating the region inside the heliopause (dominated by solar wind) from the region outside the heliopause (dominated by the interstellar medium). Researchers discovered that Voyager 1 measured a magnetic field orientation that slowly but steadily changed over time to rotate toward the same direction as the center of the IBEX ribbon. The study shows that the presence of the heliosphere deflected the magnetic field in the interstellar flow from its initial direction. Therefore, scientists concluded that the spacecraft is moving through a region of space where, albeit outside the solar wind, the presence of the heliosphere still affects the interstellar magnetic field.

OTHER MISSIONS AND DATA ANALYSIS

SOLAR AND HELIOSPHERIC OBSERVATORY (SOHO)

SOHO reached a milestone on December 2, 2016, when the spacecraft turned 21 years old. SOHO, a joint mission of the European Space Agency (ESA) and NASA, 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

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WIND

The Wind spacecraft 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 upcoming Solar Probe Plus (SPP) and Solar Orbiter Collaboration (SOC) missions will improve our understanding of these events as they move out from the Sun. These multi-spacecraft measurements constrain models of space weather events and improve their predictive capabilities.

Recent Achievements

Wind continues to provide unique, robust, high-resolution solar wind observations. The dataset now spans 22 years (a full solar cycle), providing a comprehensive and continuous look at the nature and evolution of solar activity. More than 4,000 refereed scientific publications have used (directly or indirectly) Wind data.

GEOTAIL

Geotail enables scientists to assess data on the interaction of the solar wind and magnetosphere. July 24, 2015 marked the 23rd 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 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Solar Probe Plus	255.6	210.3	**265.8**	107.2	30.6	22.1	22.2
Solar Orbiter Collaboration	32.8	97.7	**51.4**	66.3	2.3	2.4	2.3
Other Missions and Data Analysis	48.7	--	**63.8**	82.4	90.5	94.4	97.6
Total Budget	**337.1**	**--**	**381.0**	**255.9**	**123.3**	**118.9**	**122.1**

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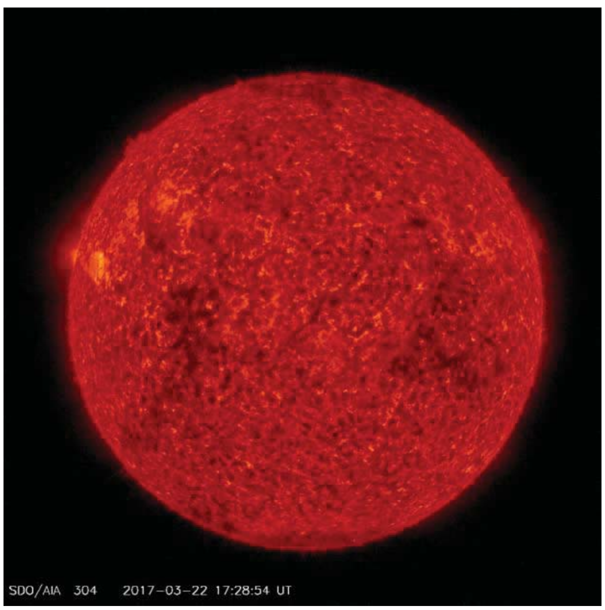

This image at a wavelength at 304 Angstroms is especially good at showing areas where cooler dense plumes of plasma (filaments and prominences) are located above the visible surface of the Sun. Many of these features either cannot be seen or appear as dark lines in the other wavelengths. The bright areas here show places where the plasma has a high density.

The 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 2018

An increase to LWS Science focuses on space weather research, enhancing the ability to forecast and characterize space weather events in collaboration with NASA's inter-agency partners.

SOLAR PROBE PLUS

Formulation	Development	Operations

FY 2018 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022	BTC	Total
Formulation	247.1	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	247.1
Development/Implementation	289.5	255.6	210.4	**265.8**	0.0	0.0	0.0	0.0	0.0	1021.3
Operations/Close-out	0.0	0.0	0.0	**0.0**	107.2	30.6	22.1	22.2	102.9	285.0
2017 MPAR LCC Estimate	**536.6**	**255.6**	**210.4**	**265.8**	**107.2**	**30.6**	**22.1**	**22.2**	**102.9**	**1553.4**
Total Budget	**561.6**	**255.6**	**210.3**	**265.8**	**107.2**	**30.6**	**22.1**	**22.2**	**102.9**	**1578.4**
Change from FY 2017				**55.5**						
Percentage change from FY 2017				**26.4%**						

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

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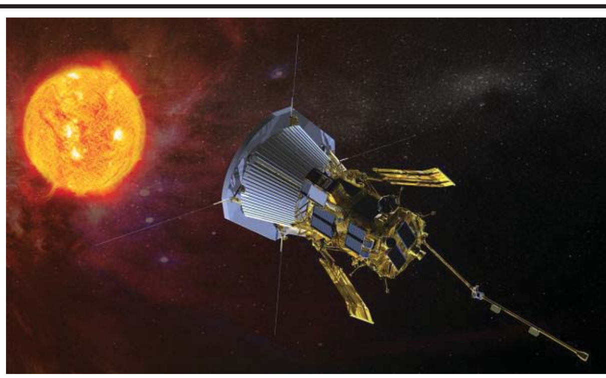


Artist's concept of the SPP spacecraft as it approaches the Sun.

PROJECT PURPOSE

Solar Probe Plus (SPP) will explore the Sun's outer atmosphere, or corona, as it extends out into space. SPP will orbit at a distance from the Sun of less than five times the Sun's diameter, closer than any other spacecraft. SPP will repeatedly obtain direct in-situ coronal magnetic field, plasma, and white-light remote sensing observations in the region that heats the solar atmosphere and accelerates the solar wind. SPP's findings could revolutionize our knowledge and understanding of coronal heating and of the origin and evolution of the solar wind, answering critical questions posed in the 2003 and 2013 Heliophysics Decadal Surveys.

Its seven-year prime mission lifetime will permit observations over a significant portion of a solar cycle. SPP will enable direct sampling of plasma, enabling observations that otherwise are impossible. These observations will allow heliophysicists to verify and discriminate between a broad range of theory and models that describe the Sun's coronal magnetic field and the heating and acceleration of the solar wind. SPP will enable NASA to gain a better understanding of the radiation environment in which future space explorers will work and live.

SOLAR PROBE PLUS

Formulation	Development	Operations

For more information, go to https://science.nasa.gov/missions/solar-probe.

EXPLANATION OF MAJOR CHANGES IN FY 2018

None.

PROJECT PARAMETERS

After launch in August 2018, SPP will orbit the Sun 24 times, gradually "walking in" toward the Sun with each pass. SPP's first close approach to the Sun occurs just three months after launch. Over a period of several years, seven Venus flybys will gradually shrink the spacecraft's orbit around the Sun. The closest points of each orbit come well within the path of Mercury, the closest planet to the Sun. On the final three orbits, SPP will fly within 3.8 million miles of the Sun's surface. That is about seven times closer than the Helios spacecraft, the current record holder for the closest solar pass. SPP will sample changes in the solar wind with increasing solar activity.

ACHIEVEMENTS IN FY 2016

In FY 2016, the project successfully held the Systems Integration Review to evaluate the readiness of the project and associated supporting infrastructure to begin system Assembly Integration and Test (AI&T). The review team also, evaluated whether the project would complete the remaining project development milestones within available resources and determined the project was sufficiently mature to begin Phase D. Subsequently, the Agency conducted the Key Decision Point D, authorizing the project to begin AI&T, which began in the summer of 2016 at JHU/APL.

WORK IN PROGRESS IN FY 2017

In FY 2017, the project will complete all subsystems and instruments, conduct pre-environmental reviews, and put each subsystems or instrument through the requisite environmental test. The project will deliver the subsystems and instruments to JHU/APL for system AI&T following the successful completion of these tests.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

In early FY 2018, the project will hold a pre-environmental review to determine the readiness of the project to initiate environmental testing of the completed spacecraft. Environmental testing will require a duration of up to five months. The project plans to have the system pre-ship review late in the winter of 2018 with shipment of the spacecraft to the launch site immediately following. NASA has scheduled launch processing at the Kennedy Space Center (KSC) for spring/summer 2018, with the primary launch window of 20 days opening on July 31, 2018.

SOLAR PROBE PLUS

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2018 PB Request
KDP-C	Mar 2014	Mar 2014
CDR	Mar 2015	Mar 2015
System Integration Review (SIR)	Jun 2016	May 2016
Launch	Aug 2018	Aug 2018
Start of Phase E	Oct 2018	Oct 2018
End of Prime Mission	Sep 2025	Sep 2025

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	1,055.7	70	2017	1,050.3	-0.5	LRD	Aug 2018	Aug 2018	0

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

Development Cost Details

NASA confirmed Solar Probe Plus to proceed into implementation phase in March 2014.

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**1,055.7**	**1,050.3**	**-5.4**
Aircraft/Spacecraft	170.8	231.9	61.1
Payloads	143.4	157.4	14.0

SOLAR PROBE PLUS

Formulation	Development	Operations

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
Systems I&T	31.2	31.0	-0.2
Launch Vehicle	430.5	425.0	-5.5
Ground Systems	17.8	19.3	1.5
Science/Technology	4.5	4.5	0
Other Direct Project Costs	257.5	181.2	-76.3

Project Management & Commitments

GSFC provides program management. JHU-APL manages the project.

Element	Description	Provider Details	Change from Baseline
Expendable Launch Vehicle	Deliver the spacecraft to operational orbit.	Provider: United Launch Alliance (ULA) Lead Center: KSC Participating Centers: KSC Cost Share Partners: N/A	N/A
Ground Systems	Receive science and telemetry data from spacecraft, command spacecraft, and distribute science data to investigator teams.	Provider: JHU-APL Lead Center: GSFC Participating Centers: N/A Cost Share Partners: N/A	N/A
Spacecraft	Transport instruments to science destination, operate instruments, and modify orbit, including several Venus gravity assists.	Provider: JHU-APL Lead Center: GSFC Participating Centers: N/A Cost Share Partners: N/A	N/A
Instruments	Provide in-situ measurements and remote observations of the Sun.	Provider: NASA funded investigators Lead Center: GSFC Participating Centers: N/A Cost Share Partners: N/A	N/A

SOLAR PROBE PLUS

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: The spacecraft is unable to resolve faults with sufficient speed, Then: Over-exposure of critical components to the solar environment may occur, leading to a mission-ending failure.	The project will develop a system response for every manageable fault and perform extensive ground testing and simulation of system fault responses. Management will consider the risk mitigated after these activities are complete.
If: The optical properties of the solar array result in a solar array that is colder than expected, Then: The cooling system margin above freezing may fall below acceptable levels, threatening the arrays.	The project will measure the optical properties of the solar array cover glass and perform the power-thermal analysis to assess margin during thermal vacuum testing in FY 2016. Management will consider the risk mitigated after these activities are complete.

Acquisition Strategy

PIs selected through the competitive AO are building the science instruments. JHU-APL builds the spacecraft, and competitively procures the spacecraft subassemblies, components, and parts. The project is refining the ground system components and requirements. GSFC manages the operations contracts.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Prime Contract and Mission Management	JHU-APL	Laurel, MD
FIELDS Experiment (FIELDS) magnetometers and plasma wave instrument	University of California, Berkeley	Berkeley, CA
Integrated Science Investigation of the Sun (ISIS) energetic particle instruments	Southwest Research Institute (SwRI)	San Antonio, TX
Solar Wind Electrons Alphas and Protons (SWEAP) plasma instruments	Smithsonian Astrophysical Observatory	Cambridge, MA
Wide-Field Imager for Solar Probe Plus (WISPR) heliospheric imager	Naval Research Laboratory	Washington, DC
Heliophysics Origins Investigation	JPL	Pasadena, CA

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board (SRB)	Jan 2014	Preliminary Design Review (PDR) to assess readiness for KDP-C	Successful, project ready to proceed to development	Mar 2015
Performance	SRB	Mar 2015	CDR to assess readiness for KDP-D	Successful, project's mission design is appropriately mature to continue with the final design and fabrication phase.	May 2016
Performance	SRB	May 2016	SIR to assess readiness for project to begin system I&T	Successful, project ready to proceed to integration and test	Mar 2018
Performance	SRB	Mar 2018	Operations Readiness Review (ORR) to assess readiness for project to operate the flight system	TBD	N/A

SOLAR ORBITER COLLABORATION

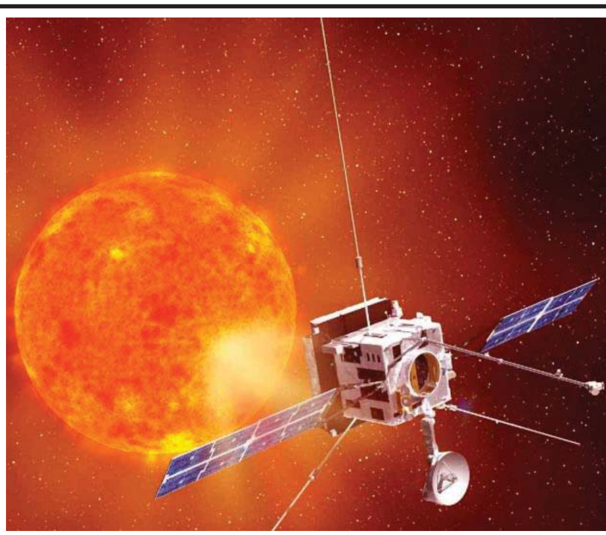
Formulation	Development	Operations

FY 2018 Budget

		Actual	Enacted	Request	Notional					
Budget Authority (in $ millions)	Prior	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	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	78.0	32.8	97.7	**51.4**	60.1	0.0	0.0	0.0	0.0	320.0
Operations/Close-out	0.0	0.0	0.0	**0.0**	6.2	2.2	2.3	2.3	4.4	17.4
2017 MPAR LCC Estimate	**119.5**	**32.8**	**97.7**	**51.4**	**66.3**	**2.2**	**2.3**	**2.3**	**4.4**	**378.9**
Total Budget	**119.5**	**32.8**	**97.7**	**51.4**	**66.3**	**2.3**	**2.4**	**2.3**	**4.4**	**378.9**
Change from FY 2017				**-46.3**						
Percentage change from FY 2017				**-47.4%**						

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



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 ESA 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 longer than is currently possible.

SOLAR ORBITER COLLABORATION

Formulation	Development	Operations

ESA provides the spacecraft and operations, the ESA member states provide the majority of the instruments, and NASA provides the launch vehicle and two science investigations/instruments: the Solar Orbiter Heliospheric Imager (SoloHI) and the Heavy Ion Sensor (HIS). In return for its contributions, NASA will have access to the entire science mission data set.

For more information, go to https://science.nasa.gov/missions/solar-orbiter.

EXPLANATION OF MAJOR CHANGES IN FY 2018

None.

PROJECT PARAMETERS

A NASA-provided launch vehicle will place the ESA-provided 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 2016

The Naval Research Laboratory completed all environmental testing on a completely integrated SoloHI flight instrument and SwRI completed all environmental testing on a completely integrated HIS flight instrument.

WORK IN PROGRESS IN FY 2017

NASA will deliver flight models of both the SoloHI and HIS instruments to ESA. The project completed the pre-ship review in March 2017. NASA and the HIS instrument team will support the integration and testing of the Solar Wind Analyzer suite at the Mullard Space Science Laboratory in the United Kingdom.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

NASA and the instrument teams will support the integration of the HIS and SoloHI instruments onto the spacecraft, as well as the observatory-level environmental testing at Airbus facilities in the United Kingdom.

SOLAR ORBITER COLLABORATION

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2018 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	Oct 2018
Begin Phase E	Oct 2018	Jan 2019
End of Prime Mission	Nov 2026	Nov 2026

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2014	376.9	N/A	2017	320.0	-15.1	LRD	Oct 2018	Oct 2018	0

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

Development Cost Details

NASA confirmed 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**	**320.0**	**-56.9**
Aircraft/Spacecraft	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)
Payloads	23.7	54.9	31.2
Systems I&T	0.0	0.0	0.0
Launch Vehicle	250.0	172.7	-77.3
Ground Systems	N/A	N/A	N/A
Science/Technology	1.3	1.6	0.3
Other Direct Project Costs	101.9	90.7	-11.2

Project Management & Commitments

GSFC has program management responsibility for the LWS 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

SOLAR ORBITER COLLABORATION

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Mar 2013	PDR to assess readiness for KDP-C	Successful, project ready to proceed to development	Jul 2015
Performance	SRB	Oct 2013	SoloHI Instrument to assess readiness for CDR	Successful	Jul 2016
Performance	SRB	Mar 2014	HIS Instrument to assess readiness for CDR	Successful	Jul 2016
Performance	SRB	Mar 2017	Pre-ship Review to assess readiness for shipment to ESA	Successful	
Performance	SRB	Oct 2018	Operations Readiness Review/Mission Readiness Review to assess readiness for KDP-E		

OTHER MISSIONS AND DATA ANALYSIS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
LWS Space Environment Testbeds	0.4	--	**0.2**	0.0	0.0	0.0	0.0
LWS Science	18.4	--	**29.0**	35.5	35.3	35.3	35.3
LWS Program Management and Future Missions	5.8	--	**9.6**	21.8	34.9	47.1	50.3
Van Allen Probes (RBSP)	11.9	--	**13.0**	13.0	8.3	0.0	0.0
Solar Dynamics Observatory (SDO)	12.0	--	**12.0**	12.0	12.0	12.0	12.0
Total Budget	**48.7**	--	**63.8**	**82.4**	**90.5**	**94.4**	**97.6**

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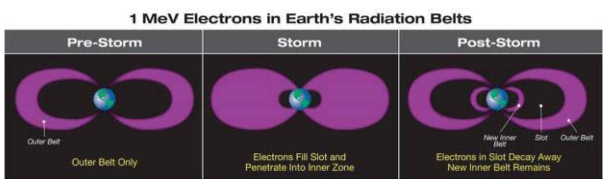

Past space missions have not been able to distinguish electrons from high-energy protons in the inner radiation belt. However, by using a special instrument, the Magnetic Electron and Ion Spectrometer (MagEIS) on the Van Allen Probes, scientists could look at the particles separately for the first time and discovered virtually no relativistic electrons in the inner radiation belt, contrary to what scientists expected.

The LWS Other Missions and Data Analysis budget includes operating LWS missions, a science research program, program management, and funding for missions to launch in the next decade.

For more information, go to http://science.nasa.gov/about-us/smd-programs/living-with-a-star/.

Mission Planning and Other Projects

LWS SPACE ENVIRONMENT TESTBEDS

The 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's) Demonstration and Space Experiments (DSX) spacecraft, with the launch expected no earlier than September 2017.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

Working launch date is January 2018, with a firm window that extends to March 30, 2018. AFRL successfully completed a payload readiness review at Space Exploration Technologies Corporation (SpaceX). Remaining activities leading to launch are work with the separation system, interface testing, mission readiness review, and four rehearsals. GSFC upgraded the program operations control center with the installation of a new back-up integrated test and operations system. GSFC also continued research on evaluating the space radiation environment for spacecraft design purposes, which the LWS SET data will supplement. The project also completed an Orbital Debris Assessment Report (ODAR).

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.
- 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 strategic capabilities studies have produced significant progress in heliophysics modeling capabilities. This five-year program element has sponsored a group of nine teams who are developing space weather modeling capability. The goal is to predict the production of solar events, their movement through the inner solar system, and estimate their impact on space weather at Earth. Research topics include: the emergence and transport of magnetic flux in the Sun; the production of solar flares, CME, and the 3D global solar corona; the production of SEPs in the solar corona and solar wind; and the impact on the Earth through interaction with the Earth's extended upper atmosphere (magnetosphere, ionosphere, thermosphere, mesosphere). Recent progress includes the development of improved data assimilation of NASA data into models, comparison of model and observed results, and the continued testing and transfer of model components to NASA's Community Coordinated Modeling Center (CCMC). Based on the recent review, NASA anticipates the completion of the proposed goals during the final two years of this program element.

Ongoing studies in the origins and initiation of solar eruptions will play a prominent role in future space weather predictive capability. A current study explores the physical relationship between changes in the solar magnetic field, sunspot motions, and sunquakes during solar eruptions. Recent results include the comprehensive study of magnetic structural evolution of numerous large X-class flares observed between 2011 and 2014 with several of these causing sunquakes. Several NASA/NOAA space missions (IRIS, Hard X-ray Spectrometer (HXR), Geostationary Operational Environmental Satellite (GOES)) observed these events, as well as ground-based observations by the Big Bear Solar Observatory (BBSO)/New Solar Telescope (NST). This study reveals that magnetic structures near the surface, called filaments, can reside within an overlying dome-shaped magnetic field. The eruption of filaments is one source of CMEs that can have significant space weather impacts at Earth. These filaments can become unstable and rise upward, interacting with the overlying magnetic dome, which can lead to a partial opening of the dome and a circular-ribbon flare. Researchers have found the starting point of the sunquake associated with these flares to be located at the middle section where the erupting flux rope collides with the overlying dome rather than at the endpoints of the filaments. These observations help clarify questions on the relationship between the flux rope eruption, solar flare, and sunquake generation and will help in the prediction of the magnitude and timing of solar flares and filament eruptions (CME).

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.

Operating Missions

Van Allen Probes (Formerly Radiation Belt Storm Probes)

The Van Allen Probes mission 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

Empirical models based on in situ magnetic field measurements from past and present spacecraft missions provide a robust framework for the magnetic field specifications during geomagnetic storms. The Van

OTHER MISSIONS AND DATA ANALYSIS

Allen Probes addition to the Heliophysics System Observatory (HSO) dramatically increased the sampling of the inner magnetosphere, which led to a breakthrough in modeling capabilities. Magnetic field measurements collected by the Probes provided the first data-derived reconstruction of the global current system deep within radiation belts, which could not be resolved with the data from previous missions.

SOLAR DYNAMICS OBSERVATORY (SDO)

Launched on February 11, 2010, the SDO seeks to understand the Sun's influence on Earth and near-Earth space by simultaneously studying the solar atmosphere on small scales of space and time and in many wavelengths. The observatory enables scientists to determine how the Sun's magnetic field is generated and structured and how stored magnetic energy is converted and released in the form of solar wind, energetic particles, and variations in the solar irradiance. SDO collects data to help explain the creation of solar activity, which drives space weather. Measurements of the interior of the Sun, the Sun's magnetic field, the hot plasma of the solar corona, and the irradiance that creates Earth's ionosphere are the primary data products.

Recent Achievements

Scientists analyzed sequences of images from SDO instruments, AIA, HMI, and other missions to determine the wave properties around sunspots as a function of altitude. They found we could follow these waves from the photosphere through the chromosphere and into the corona. The paths of these waves are not vertical but tilt away from the sunspot at the center of the images. Scientists could determine the strength and direction of the magnetic field by the changes in the wave field as it moved upward. This novel application of an analysis technique traditionally used for seismology of the solar interior shows a possible energy transport mechanism (from the photosphere to the corona) and addresses a long-standing question in heliophysics.

Two of the main causes of space weather events are solar flares and CMEs. While flares are associated with some hazardous space weather (radio blackouts), CMEs can cause geomagnetic storms that can threaten the power distribution grid. A prediction of a CME is critical for estimating the impact at Earth, and scientists can use solar magnetic field data for this purpose. By using results from SDO's Helioseismic and Magnetic Imager (HMI), solar physicists are learning how to make better predictions of solar activity. By using machine-learning techniques, scientists can identify patterns in the data that indicate a solar flare or coronal mass ejection is about to occur. One critical requirement is the frequent measurements of all three components of the surface magnetic field, the vector magnetic field.

SOLAR TERRESTRIAL PROBES

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Other Missions and Data Analysis	49.5	--	**37.8**	97.9	171.5	185.1	191.1
Total Budget	**49.5**	**--**	**37.8**	**97.9**	**171.5**	**185.1**	**191.1**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

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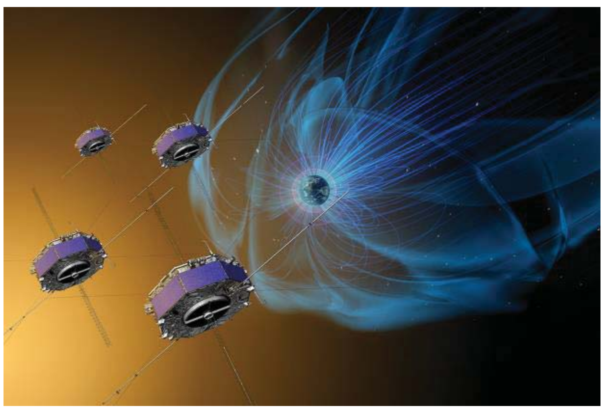

MMS consists of four identical spacecraft that orbit around Earth through the dynamic magnetic system surrounding our planet to study a little-understood phenomenon called magnetic reconnection. Magnetic reconnection is a fundamental process that happens in space, which powers a wide variety of events, from giant explosions on the Sun to green-blue auroras shimmering in the night sky.

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 2018

None.

SOLAR TERRESTRIAL PROBES

ACHIEVEMENTS IN FY 2016

The MMS mission has made the first definitive observations of the electron physics that initiate and control magnetic reconnection. Magnetic reconnection is pervasive in the universe, but the Earth's magnetosphere is the closest and most important place where we can observe this phenomenon in detail. When magnetic reconnection happens in the Earth's magnetosphere, it can lead to auroras (northern/southern lights) and disruption of the ionosphere, which in turn disrupts numerous types of communication and GPS positioning.

WORK IN PROGRESS IN FY 2017

Operations of the MMS, STEREO, Hinode, and TIMED missions continue. NASA plans to release an AO for the STP-5 mission, called the Interstellar Mapping and Acceleration Probe (IMAP) mission in the 2013 Heliophysics decadal survey, and an MO. IMAP will provide observations that will help us understand the global processes that act in 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.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

NASA plans to select and begin the STP-5 mission and select a MoO.

Program Schedule

Date	Significant Event
FY 2017	AO for IMAP Mission and MO
FY 2018	STP-5 and MO selection
FY 2018	STP-5 KDP-A

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.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Program Independent Review	SRB	Nov 2014	Assess performance of program	Successful	Oct 2019
Program Independent Review	SRB	Oct 2019	Assess performance of program		

OTHER MISSIONS AND DATA ANALYSIS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
STP Program Management and Future Missions	1.2	--	**8.0**	69.1	142.7	163.3	169.2
Magnetospheric Multiscale (MMS)	30.1	--	**12.1**	11.0	11.0	4.0	4.0
Solar Terrestrial Relations Observatory (STEREO)	8.3	--	**8.3**	8.3	8.3	8.3	8.3
Hinode (Solar B)	7.3	--	**6.8**	7.0	7.0	7.0	7.0
TIMED	2.7	--	**2.6**	2.6	2.6	2.5	2.7
Total Budget	**49.5**	**--**	**37.8**	**97.9**	**171.5**	**185.1**	**191.1**

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TIMED's 15 years of data has given scientists an unprecedented perspective on changes in the upper atmosphere. The long lifespan has allowed scientists to track the upper atmosphere's response to both quick-changing conditions, such as solar storms, and longer trends, such as unexpectedly fast increases in carbon dioxide in Earth's upper atmosphere.

The 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

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.

OTHER MISSIONS AND DATA ANALYSIS

Operating Missions

MAGNETOSPHERIC MULTISCALE (MMS)

The MMS mission 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, but 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 6 to 250 miles during science operations in the area of interest.

For more information, go to http://science.nasa.gov/missions/mms/.

Recent Achievements

The four MMS spacecraft recently flew through an invisible maelstrom in space- magnetic reconnection. Scientists had never directly observed magnetic reconnection in action until October 16, 2015. Thanks to its break-through technological advancements and complex orbits, MMS is the only mission capable of observing particle interaction at the resolutions needed to see the fast processes involved in magnetic reconnection. Science published a paper providing the first direct observations of a magnetic reconnection event in Earth's magnetosphere on May 12, 2016 . Because of MMS, scientists were able to track the electric fields present, the way the magnetic fields changed, and the speeds and directions of the different charged particles involved in the event. Since MMS began its prime mission phase in September 2015, the spacecraft have observed at least nine reconnection events in Earth's magnetosphere. In addition to the May 2016 paper published in Science, a special collection of 58 papers in Geophysical Research Letters showcased the new and groundbreaking data from the first phase of the MMS mission.

SOLAR TERRESTRIAL RELATIONS OBSERVATORY (STEREO)

STEREO enables studies of the origin of the Sun's CMEs and their consequences for Earth, other planets, and interplanetary space. The mission consists of two spacecraft, one (STEREO-A) Ahead and the other (STEREO-B) Behind Earth 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.

OTHER MISSIONS AND DATA ANALYSIS

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 made several attempts to establish control of the spacecraft with limited success. STEREO-B has now moved into a less-desirable attitude for communication until the summer of 2017. The project team will make monthly attempts to re-establish contact with the spacecraft. STEREO-A continues to operate nominally and is still providing significant science data.

Recent Achievements

Recent observations by the STEREO-A Plasma and Suprathermal Ion Composition (PLASTIC) instrument helped prove a concept of determining the interstellar helium inflow direction into the solar system. Scientists still investigate the concept for any systematic effects, but it will likely yield a more accurate determination of the longitude of interstellar wind inflow than is possible with the IBEX mission, making both missions highly complementary. Scientists made the STEREO measurement by analyzing helium ions that flowed in from interstellar space as neutral helium. Near 1 AU they were ionized by solar radiation and subsequently picked up by the magnetic field in the solar wind, where they can be measured by STEREO/PLASTIC. IBEX observes neutral helium atoms directly, but leaves a large uncertainty in solar longitude. The recent STEREO study proved that the combination of IBEX and STEREO observations can increase the accuracy of interstellar inflow determination by more than an order of magnitude. This knowledge would help improve understanding of the global interaction of the heliosphere with the wind from other stars.

HINODE

Hinode 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

Hinode made unique observations of the transit of Mercury. On May 9, 2016, Mercury passed directly between the Earth and Sun. The Hinode observatory captured images with its three unique instruments as Mercury transited the solar disk. The Hinode Solar Optical Telescope (SOT) captured images of magnetically driven structures on the solar surface with its high-resolution Spectro-Polarimeter (SP), which uses a slit to disperse light. The instrument held the slit in a fixed position while Mercury and the Sun drifted by over a period of 3.4 minutes. The image consists of 828 vertical strips stitched together, each one approximately 110 kilometers wide. The background shows how the solar granules in the previous image change with time as convection causes material to flow up and down during the heating and cooling process. The Hinode Extreme ultra-violet Imaging Spectrometer (EIS) also created images by scanning with a slit optimized to observe the hotter temperature solar material in the Sun's atmosphere. Hinode is also equipped with an X-Ray Telescope (XRT), which is capable of taking full-disk Sun images of the hottest layers of the solar atmosphere in soft X-rays. Using one of its Aluminum filters, XRT tracked Mercury from edge to edge against a background of coronal material at millions of degrees.

THERMOSPHERE, IONOSPHERE, MESOSPHERE ENERGETICS AND DYNAMICS (TIMED)

The TIMED mission 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 (MLTI). 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

A basic question in climate science is to what extent changes in the output of energy of the Sun drive changes in the atmosphere. The balance between the solar energy input and the infrared energy output determines the climate of the upper atmosphere. Infrared radiation from carbon dioxide and nitric oxide are the key components of the outgoing energy to space from Earth's upper atmosphere. The TIMED mission Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) instrument has already observed rapid increases in upper atmosphere carbon dioxide. To understand changes in the upper atmosphere, long-term records are required. SABER has been monitoring the infrared output of the upper atmosphere for nearly 15 years. New analyses using SABER data have enabled accurate reconstruction of the infrared energy budget of the upper atmosphere stretching back 70 years, to 1947. Researchers can use this new 70-year record to test existing climate models as never before possible. Specifically, researchers can now retest models against a long-term, accurate data set. Retests will identify model improvements enabling much higher confidence in predictions of future atmospheric change as carbon dioxide continues to increase. The project expects improved predictions in ozone, temperature, and density. The latter two will help in future predictions of orbital lifetimes of the ISS, orbiting satellites, and space debris.

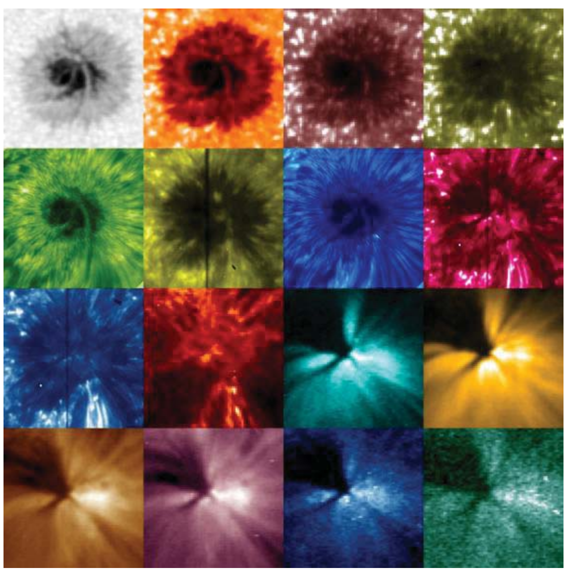
HELIOPHYSICS EXPLORER PROGRAM

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Ionospheric Connection Explorer (ICON)	48.4	49.4	**9.0**	4.5	1.3	0.0	0.0
Other Missions and Data Analysis	52.3	--	**50.0**	112.2	181.8	174.9	165.1
Total Budget	**100.6**	**--**	**58.9**	**116.8**	**183.1**	**174.9**	**165.1**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



Scientists used data from NASA's SDO, NASA's Interface Region Imaging Spectrograph, and the BBSO to track a solar wave as it channeled upwards from the Sun's surface into the atmosphere.

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 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 Program.

Explorer 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.

HELIOPHYSICS EXPLORER PROGRAM

For more information on Explorer missions, go to https://science.nasa.gov/about-us/smd-programs/explorers/.

EXPLANATION OF MAJOR CHANGES IN FY 2018

None.

ACHIEVEMENTS IN FY 2016

In July 2016, NASA released a SMEX AO and a solicitation for Heliophysics Explorer MO through the Second Stand Alone Missions of Opportunity Notice (SALMON-2). NASA also released a solicitation for Explorer program U.S. Participating Investigator through the ROSES 2016 NRA to accomplish Heliophysics Explorer program science objectives.

WORK IN PROGRESS IN FY 2017

NASA will evaluate proposals received in response to the NASA FY 2016 AO and solicitations. NASA will make new mission selections for competitive concept studies (Phase A) for the SMEX and MO AO.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

Missions selected for SMEX and MO Phase A concept studies will deliver their reports to NASA for evaluation. NASA will launch the ICON and GOLD missions.

Program Schedule

Date	Significant Event
Spring/early Summer 2016	AO announcement of SMEX and MO opportunity to propose
Spring 2017	SMEX and Explorer MO KDP-A
Late Summer/Fall 2018	Down select one SMEX and one MO mission for implementation
FY 2019	AO announcement for MIDEX and MO opportunity to propose
FY 2020	MIDEX and Explorer MO KDP-A
FY 2021	Down select one MIDEX and one MO mission for implementation

HELIOPHYSICS EXPLORER PROGRAM

Program Management

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.

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	Oct 2019

IONOSPHERIC CONNECTION EXPLORER (ICON)

Formulation	Development	Operations

FY 2018 Budget

		Actual	Enacted	Request	Notional					
Budget Authority (in $ millions)	**Prior**	**FY 2016**	**FY 2017**	**FY 2018**	**FY 2019**	**FY 2020**	**FY 2021**	**FY 2022**	**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	101.3	48.4	46.3	**0.0**	0.0	0.0	0.0	0.0	0.0	196.0
Operations/Close-out	0.0	0.0	3.1	**9.0**	4.5	1.3	0.0	0.0	0.0	17.9
2017 MPAR LCC Estimate	**140.1**	**48.4**	**49.4**	**9.0**	**4.5**	**1.3**	**0.0**	**0.0**	**0.0**	**252.7**
Total Budget	**140.1**	**48.4**	**49.4**	**9.0**	**4.5**	**1.3**	**0.0**	**0.0**	**0.0**	**252.6**
Change from FY 2017				**-40.4**						
Percentage change from FY 2017				**-81.8%**						

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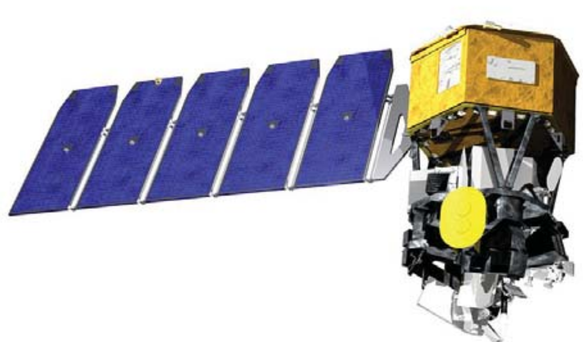


ICON will explore the boundary between Earth and space to understand the physical connection between our world and our space environment.

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 2018

None.

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,

IONOSPHERIC CONNECTION EXPLORER (ICON)

Formulation	Development	Operations

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 2016

The ICON project conducted a successful SIR on Aug 10, 2016. NASA confirmed ICON to proceed into integration phase (Phase D) on August 26, 2016.

WORK IN PROGRESS IN FY 2017

The Project will continue observatory integration and test and conduct the Observatory pre-ship review by the end of FY 2017.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

NASA plans to launch ICON in October 2017 to begin a two-year prime mission.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2018 PB Request
KDP-C	Oct 2014	Oct 2014
CDR	Apr 2015	Apr 2015
SIR	Jun 2016	Aug 2016
Launch	Oct 2017	Oct 2017
Start of Phase E	Nov 2017	Nov 2017
End of Prime Mission	Dec 2019	Dec 2019

IONOSPHERIC CONNECTION EXPLORER (ICON)

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	196.0	70	2017	196.0	0.0	LRD	Oct 2017	Oct 2017	0

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

Development Cost Details

NASA confirmed 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**	**196.0**	**0.0**
Aircraft/Spacecraft	29.8	46.5	16.7
Payloads	35.8	43.3	7.5
Systems I&T	9.4	3.1	-6.3
Launch Vehicle	54.3	56.3	2.0
Ground Systems	2.9	4.0	1.1
Science/Technology	3.0	2.7	-0.3
Other Direct Project Costs	60.8	40.0	-20.8

IONOSPHERIC CONNECTION EXPLORER (ICON)

Formulation	Development	Operations

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Expendable Launch Vehicle	Deliver the spacecraft to operational orbit	Provider: Orbital-ATK Lead Center: KSC Performing Center(s): KSC Cost Share Partner(s): n/a	N/A
Spacecraft	Transport instruments to science destination	Provider: Orbital ATK 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 (MIGHTI)	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 (ICON)

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: Multiple programs are vying for the environmental test facilities at Orbital ATK, Dulles, VA Then: The facilities may not be available at the time needed for ICON's environmental test.	NASA will coordinate with Orbital ATK commercial programs on facility usage. If necessary, the project will seek other test facilities that do not have usage conflict.
If: Inspections of the Pegasus launch vehicle motors, which experienced a shock event during transport, reveal problems that require inspection, repair or replacement, and the launch range is impacted Then: The ICON mission may be further delayed, potentially beyond the current launch readiness date of October 2017	NASA is closely following the progress of the ICON observatory and the Pegasus launch vehicle toward launch readiness. If all continues to go well with the motor inspections, the launch vehicle and observatory will be launch ready by late August/early September 2017. LSP has agreed to protect launch opportunities for ICON in September and October in case an opening in the range manifest becomes available. As a back-up, the NASA will launch ICON at the next available opportunity for the range, which is expected to be in November.

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	Orbital ATK	Dulles, VA
Payload integration	Space Dynamics Laboratory	Logan, UT
Launch Vehicle	KSC	KSC, FL

IONOSPHERIC CONNECTION EXPLORER (ICON)

Formulation	Development	Operations

INDEPENDENT REVIEWS

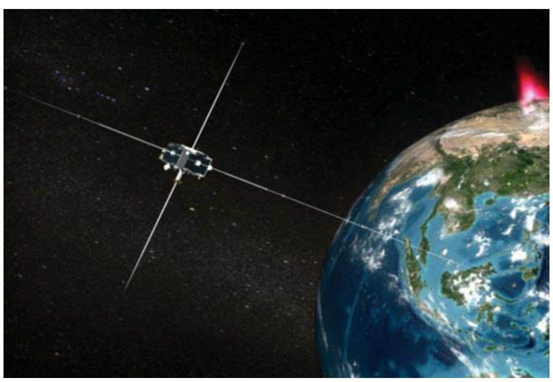
Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Jan 2014	SRR to evaluate ICON requirements	Successful	Jul 2014
Performance	SRB	Jul 2014	PDR to assess readiness for KDP-C	Successful	Apr 2015
Performance	SRB	Apr 2015	CDR	Successful	Aug 2016
Performance	SRB	Aug 2016	SIR to evaluate ICON readiness for KDP-D	Successful	Jan 2017
Performance	SRB	Jan 2017	Mission Pre-Environmental Review		May 2017
Performance	SRB	May 2017	Observatory Pre-Ship Review		June 2017
Performance	SRB	June 2017	ORR for KDP-E		Oct 2017

OTHER MISSIONS AND DATA ANALYSIS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Global-scale Observations of the Limb an	15.3	--	**8.6**	4.6	2.0	0.0	0.0
Heliophysics Explorer Future Missions	0.0	--	**9.5**	75.4	151.0	142.6	135.2
Heliophysics Explorer Program Management	11.4	--	**7.8**	8.3	6.0	9.4	7.0
Interface Region Imaging Spectogr (IRIS)	7.6	--	**6.8**	7.0	6.5	6.5	6.5
Interstellar Boundary Explorer (IBEX)	3.4	--	**3.3**	3.4	3.4	3.4	3.4
TWINS	0.6	--	**0.6**	0.6	0.6	0.6	0.6
CINDI	0.6	--	**0.2**	0.0	0.0	0.0	0.0
Aeronomy of Ice in Mesophere (AIM)	3.0	--	**3.0**	3.0	3.0	3.0	3.0
Time History of Events and Macroscale In	5.4	--	**5.4**	5.1	4.5	4.5	4.5
ACE	3.0	--	**2.9**	3.0	3.0	3.0	3.0
RHESSI	1.9	--	**1.9**	1.9	1.9	1.9	1.9
Total Budget	**52.3**	--	**50.0**	**112.2**	**181.8**	**174.9**	**165.1**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.



On Feb. 17, 2017, NASA's THEMIS mission marked its 10th anniversary in space. The spacecraft have now spent a decade discovering how mass and energy move through the near-Earth environment in order to determine the physical processes initiating auroras – and they are still making new discoveries.

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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/.

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.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

GOLD integrated and successfully passed environmental testing as a dual channel instrument. It began its preparation for shipping to the commercial satellite vendor.

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 support the Explorer procurement activities, including the pre-formulation activities for missions not yet approved as projects.

EXPLORER PROGRAM MANAGEMENT

Explorer Program Management encompasses the program office resources required to manage the formulation and implementation of all 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.

Recent Achievements

The Explorers program reviewed and provided comments to the draft 2016 Explorers AO. They also ensured the delivery of the GOLD instrument to Airbus within schedule and cost. They provided weekly GOLD and ICON weekly status during meetings for management. Office provided insight and supported reviews for the ICON and GOLD missions.

Operating Missions

INTERFACE REGION IMAGING SPECTROGRAPH (IRIS)

IRIS is a SMEX 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.

Recent Achievements

The solar transition region is sandwiched between the relatively cool (10,000 degrees Fahrenheit) chromosphere and the scorching hot corona. Recent IRIS observations that suggest that the transition region plasma is usually not in ionization equilibrium, complicating the interpretation of the emissions from that region. In particular, high-resolution (IRIS observations of emission from silicon and oxygen ions in a variety of solar regions and structures show a surprisingly strong ionized silicon emission compared to that of ionized oxygen. While scientists have long hypothesized the non-equilibrium nature of the solar transition region, these new results reveal the evidence and indicate that numerical simulations are required to interpret emission from this critical region in the solar atmosphere properly.

INTERSTELLAR BOUNDARY EXPLORER (IBEX)

IBEX 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

In 2009, observations from NASA's IBEX revealed a narrow, bright emission feature surrounding the sky, the so-called "ribbon." The Voyager 1 spacecraft adds critical interstellar magnetic field observations since mid-2012. IBEX and Voyager science team members made significant advances in understanding the relationship between the ribbon and the interstellar magnetic field. By utilizing sophisticated simulations of the solar-interstellar interaction and IBEX observations of the ribbon, scientists were able to derive the precise magnitude and direction of the pristine interstellar magnetic field far from the Sun, showing its direction to be close to, but slightly offset from, the center of the ribbon. The combined results, while also consistent with SOHO and Ulysses observations, hint at the large-scale structure of the interstellar magnetic field in the direction of motion of the 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 approved for extended operations until September 2016.

Recent Achievements

TWINS have obtained new observations, which have provided a more systematic and expanded understanding of storm phases, and geomagnetic activities. These observations show these phenomena are party dependent on the overall population of different ions found in the magnetosphere. It has also been found that the time between when we detect these storms in the low altitude emission region, versus the ring current emission region, can be traced by following the transport of singly ionized oxygen (O+), and in addition appears to be dependent on the solar cycle.

THE COUPLED ION-NEUTRAL DYNAMICS INVESTIGATIONS (CINDI)

CINDI is a mission to understand the dynamics of Earth’s ionosphere. This mission studies the behavior of equatorial ionospheric irregularities, which can cause disruptions in communications and navigation systems. CINDI data incorporated into state-of-the-art physics models is leading to advances in specification and prediction of space weather events. The mission consists of two instruments on the Communication/Navigation Outage Forecast System (C/NOFS) satellite, a project of the U.S. Air Force. The CINDI spacecraft re-entered Earth's atmosphere in November 2015; this request supports final closeout costs.

Recent Achievements

During most of its lifetime, CINDI never came closer than about 250 miles above the ground. However, as solar activity increased, CINDI began to orbit at lower and lower altitudes—ultimately descending to less than 160 miles above Earth.

During its last 13 months of operations, as its orbit decayed and it spiraled into lower altitudes and eventual re-entry into Earth’s atmosphere, CINDI satellite captured a unique set of comprehensive observations as it traveled through the very space environment that can directly cause premature orbital decay. Such regions have rarely been studied directly for extended periods, because orbits in this denser region of the atmosphere are not sustainable long-term without on board propulsion. The CINDI data at these lower altitudes show that the upper atmosphere and ionosphere react strongly to even small changes in near-Earth space.

The CINDI observations show that the neutral wind creates piles of neutral gas pushed up against ionospheric density variations – similar to how blowing snow piles up in drifts against a building wall. This results in density striations in the atmosphere that researchers had never previously observed. Such density variations are necessary data to include when modeling interference with radio waves or excess drag on a travelling spacecraft. The CINDI low altitude observations were critical to form a complete picture of these disturbances, as the satellite ventured to the possible root of the largest ionospheric upheavals -- those that emanate from the bottom ledge of the ionosphere at night. The observations revealed the presence of strong shears in the horizontal ionosphere motions at the base of the ionosphere, places where charged particles flow by each other in opposite directions. CINDI observed shears and undulations along this boundary. Researchers believe that such shears and undulations -- spotted throughout the nighttime, equatorial ionosphere -- are the source of large-scale instabilities that ultimately drive the detrimental scintillations.

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

OTHER MISSIONS AND DATA ANALYSIS

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 until September 2016.

Recent Achievements

Polar Mesospheric Clouds (PMCs) occur roughly 50 miles above the Earth's surface in polar summer. Analysis of 36 years of PMC data measured by the Solar Backscattered Ultra Violet (SBUV) series of instruments show that PMC ice mass has been increasing with time. This suggests the environment in which the clouds form has been changing. AIM mission Solar Occultation For Ice Experiment (SOFIE) observations allow a rigorous interpretation of SBUV PMC change, revealing that PMC temperatures are decreasing by 0.5 ± 0.2 degrees Kelvin per decade and water content is increasing by 0.07± 0.03 parts per million by volume per decade. These results show that changes in both temperature and water are equally important in causing PMCs to vary. These upper atmospheric changes are consistent with global climate model predictions. Researchers further suggest that these changes in PMCs relate to increased concentrations of greenhouse gases, carbon dioxide, and methane. While the release of carbon dioxide warms the surface of the Earth, it cools the upper atmosphere; and, at the same time, increases in atmospheric methane lead to increases in water vapor at high altitudes. These facts point to growing evidence that greenhouse gases and global change have increased the number and brightness of PMCs.

TIME HISTORY OF EVENTS AND MACROSCALE INTERACTIONS DURING SUBSTORMS (THEMIS)

THEMIS is a MIDEX mission that launched on February 17, 2007, and is currently operating in extended phase until September 2016. 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

Shocks at boundaries between flowing plasmas are a major particle accelerator in the universe, and are responsible for solar energetic particles and cosmic rays. Scientists do not yet fully understand how these shocks accelerate particles to the extremely high energies observed. NASA's THEMIS mission makes observations of the shock that forms sunward from Earth in the supersonic solar wind. The THEMIS spacecraft found that this foreshock creates a special population of particles accelerated and reflected from the bow shock towards the Sun. Bubbles of heated plasma in the region ahead of the foreshock can trap some of these sunward-reflected particles. THEMIS revealed that such foreshock bubbles, when large enough, also create a small-scale shock wave that can accelerate solar wind prior to reaching the parent shock at Earth. Multiple accelerations can result in far greater particle energies than can be achieved by classical interactions of particles with a single shock. Foreshock bubbles are therefore a key component of particle acceleration problems in many astrophysical and planetary settings.

OTHER MISSIONS AND DATA ANALYSIS

ADVANCED COMPOSITION EXPLORER (ACE)

ACE 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

Scientists of the ACE team examined the long-term time evolution (1965-2015) of the relationships between solar wind proton temperature, speed, and density using ACE solar wind observations and observations made before the ACE launch. The scientists found a long-term change in the proton temperature-speed relationship that lasted from 1972 to 2010, and reversed thereafter. Recognizing and understanding long-term trend is important since empirical relationships are used to fit solar wind parameters to identify when a spacecraft encounters a CME, but these formulas do not yet include any such trends.

RAMATY HIGH ENERGY SOLAR SPECTROSCOPIC IMAGER (RHESSI)

The RHESSI satellite focuses on the highest energy X-rays and gamma rays produced by the Sun, helping to observe solar flares of all shapes and sizes.

Recent Achievements

Radio observations are an ideal complement to RHESSI hard X-ray flare observations since they provide physically distinct perspectives on energetic electrons, hot plasma, and the magnetic field. Combining X-ray and radio observations at different wavelengths leads to important new diagnostics. RHESSI celebrated its 15th anniversary on February 5, 2017. It continues to be the only active observatory that can provide imaging spectroscopy of the energetic electrons that carry such a predominant part of the energy released in a flare.

RHESSI has now covered more than a complete 11-year solar cycle, and it is continuing to observe as activity decreases to solar minimum (expected sometime in 2019). During that time, it has recorded over 114,000 X-ray events, 42 with gamma-ray emission above 300 keV, and 27 with gamma-ray line emission.

AERONAUTICS

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Airspace Operations and Safety Program	147.1	--	**108.7**	107.7	107.1	107.8	109.7
Advanced Air Vehicles Program	254.9	--	**232.7**	223.8	233.2	236.7	241.8
Integrated Aviation Systems Program	128.3	--	**173.5**	178.5	167.8	139.2	132.9
Transformative Aero Concepts Program	103.5	--	**109.2**	114.5	116.3	140.7	139.9
Total Budget	**633.8**	**660.0**	**624.0**	**624.4**	**624.4**	**624.4**	**624.4**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

AERONAUTICS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
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Transformative Aero Concepts Program	103.5	--	**109.2**	114.5	116.3	140.7	139.9
Total Budget	**633.8**	**660.0**	**624.0**	**624.4**	**624.4**	**624.4**	**624.4**
Change from FY 2017			**-36.0**				
Percentage change from FY 2017			**-5.5%**				

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

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NASA Aeronautics begins a new era of X-Planes with the Low Boom Flight Demonstrator (LBFD).

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.

Aviation accounts for more than $1.5 trillion annually of total U.S. economic activity and is one of the few industries that generates a positive trade balance: $78 billion in 2014 alone.[1] The aviation industry supports more than 11.8 million direct and indirect jobs, including more than one million high-quality manufacturing jobs.[2]

Through NASA, the U.S. government has, for decades, had a highly productive partnership with the U.S. aviation industry and the nation's foremost universities. This partnership has led to breakthroughs that have improved the efficiency, performance, and safety of aviation for all citizens. For example, the FY 2015 completion of the Environmentally Responsible Aviation (ERA) project demonstrates the potential impact of NASA Aeronautics research –

1 *"Bureau of Transportation Statistics* http://www.transtats.bts.gov/Data_Elements.aspx?Data=2

2 *"The Economic Impact of Civil Aviation on the U.S. Economy," FAA June 2014*

estimates for potential fuel savings through the application of ERA technologies through 2050 could approach 80 billion gallons.

Today, we stand on the cusp of the next era in aviation. Recent technology advances in many different fields are coming together to enable breakthroughs in the speed and efficiency of transport aircraft that are the backbone of the aviation system. These breakthroughs will also enable new markets for smaller aircraft, from unmanned aircraft systems (UAS) that serve search and rescue, agriculture, and commerce applications to the potential for new modes of personal transport. These innovations will support new jobs, new opportunities, and new ways for the U.S. to lead the world in technology and innovation.

To ensure research focus on enabling the next era in aviation, NASA's Aeronautics Research Mission Directorate (ARMD) guides its efforts with its visionary 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 major challenges 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 (SIP) identifies six research thrusts:

- Thrust 1: Safe, efficient growth in global operations;
- Thrust 2: Innovation in commercial supersonic aircraft;
- Thrust 3: Ultra-efficient commercial vehicles;
- Thrust 4: Transition to alternative propulsion and energy;
- Thrust 5: Real-time, system-wide safety assurance; and
- Thrust 6: Assured autonomy for aviation transformation.

NASA has an investment strategy supporting long-term research roadmaps to enable major outcomes in each of these thrusts. The roadmaps are implemented in partnership with the aviation community and reflect visionary solutions to aviation system needs that will ensure major benefits in mobility, environmental sustainability, and safety, while ensuring continued long-term aviation technology leadership in this rapidly expanding global industry.

With this request, NASA Aeronautics takes the next significant step in the New Aviation Horizons (NAH) initiative, a bold series of experimental aircraft (X-Plane) demonstrations aimed at sustaining U.S. technological leadership in the aviation industry. The NAH initiative is led by the Integrated Aviation Systems Program (IASP). In FY 2018, NASA will award a competitive contract for detailed aircraft design, build, and validation of the first X-Plane, a Low Boom Flight Demonstrator (LBFD) that will demonstrate quiet overland supersonic flight and open a new market to U.S. industry. The LBFD X-Plane is expected to achieve first flight by FY 2021, initially focused on safe expansion of the flight envelope and then proceeding to its sonic boom noise testing flight campaign. The second X-Plane will be a subsonic flight demonstrator that will show revolutionary improvements to fuel efficiency and airport noise to establish transformational U.S. leadership in the next generation of commercial aircraft.

EXPLANATION OF MAJOR CHANGES IN FY 2018

None.

AERONAUTICS

ACHIEVEMENTS IN FY 2016

Thrust 1: Safe, efficient growth in global operations

NASA completed the integration of technologies for Air Traffic Management (ATM) Technology Demonstration – 1 (ATD-1) that provides efficient airport arrival routes for aircraft from just prior to top-of-descent through touchdown on the runway. ATD-1 technologies enable more orderly, precise, and direct traffic flow making the National Airspace System (NAS) more predictable. Airspace users will be able to better respond to unexpected delays caused by weather and other airspace constraints. NASA conducted a complex operational integration assessment at the Federal Aviation Administration's (FAA) William J. Hughes Technical Center that showed ATD-1 technology suite improved throughput of efficient arrival operations during peak traffic conditions in the terminal area.

Thrust 2: Innovation in commercial supersonic aircraft

NASA studied the effects of atmospheric turbulence on sonic boom noise which is vital to community response testing and noise standards development. The data is important to improve the understanding of sonic boom effects and will be important in understanding future aircraft design barriers, and the effects of low boom noise on the community. Ultimately, this research will assist in the ability to establish a new low boom regulation that opens the door to a commercial supersonic transport market.

Thrust 3: Ultra-efficient commercial vehicles

NASA successfully conducted a key wind tunnel test in the Ames Research Center (ARC)'s Unitary Tunnel to examine the fuel efficiency benefits of a new aircraft configuration called the truss braced wing. This design uses an innovative bracing structure to allow longer, more efficient wings to be designed into the aircraft. The initial performance test demonstrated an estimated 57 percent reduction in fuel consumption compared to an equivalently-sized baseline conventional aircraft. These results show that this concept continues to be a viable technology for greatly improving the performance of future aircraft.

In partnership with the Navy and Army, NASA completed flight testing of two different helicopters, each flown with different control settings for the main rotor. The data from these flight tests provided a basis for identifying how helicopter main rotor control processes can be altered and adjusted to reduce perceived vehicle noise. Such insight can be very valuable to helicopter pilots and operators to help them reduce community noise impacts, which can limit helicopter operations.

Thrust 4: Transition to alternative propulsion and energy

NASA completed an initial feasibility assessment of the Distributed Electric Propulsion (DEP) concept, which has the potential for significant reductions in aircraft emissions, noise, and operating cost. Results of the DEP concept assessment showed that the technology is ready for flight testing. NASA has commissioned an X-Plane to validate the power and efficiency of this new wing and electric motor design which is based on the DEP concept.

Thrust 5: Real-time, system-wide safety assurance

NASA developed and refined specialized data analytics that identify anomalies in aviation operational data and provide information about precursors to aviation safety risks. These analytical tools analyze data from multiple sources such as flight and radar track data, and written safety reports. Additionally, NASA refined prognostic and decision-making tools that support the development of a system that can predict emerging risks and provide decision support for mitigation strategies.

Thrust 6: Assured autonomy for aviation transformation

The use of analysis, simulation and flight testing furthered the integration of UAS in the NAS for commercial, science, security, and other uses. In FY 2016, NASA’s UAS Integration in the NAS Phase 1 project delivered data, analysis, and recommendations, based on two flight test series with simulated traffic and live vehicles, to Radio Technical Commission for Aeronautics (RTCA) Sub-Committee 228 on Minimum Operational Performance Standards (MOPS) for unmanned aircraft systems. NASA’s data, analysis, and recommendations were integral to RTCA’s development of the standards necessary to achieve partial UAS integration into the NAS. The progression of the flight test series increased levels of technology integration and test condition complexity. Specifically, the tests integrated UAS and manned aircraft with ground control stations and air traffic data in a flight environment representing the NAS using the Live, Virtual, Constructive, Distributive Environment (LVC-DE), which is a virtual simulation and flight test environment used to provide realism in demonstrating actual system capabilities. The focus for the flight test series was UAS detection and avoidance of other traffic, UAS command and control communications, and advanced ground control station display technologies.

Cross-Cutting Capabilities

NASA developed next-generation, high-performance, computational methods and tools that have the potential to dramatically reduce the cost and error of simulating complex turbulent flows. NASA completed wind tunnel tests to determine the effect of wing design on the type and quality of experimental flow separations. Based on these results, final tests will result in unique wind tunnel validation data to compare against computational turbulence predictions. NASA also developed a method for combined uncertainty and error bound estimates for generic aerodynamic flow computations.

NASA matured technologies using high-temperature materials to address the needs of future air vehicles and propulsion systems. NASA characterized the structural properties of a new generation ceramic matrix composite architecture, optimized an innovative process for applying the thin, smooth, durable environmental coating to a turbine airfoil subcomponent, and then demonstrated the durability of the new subcomponent system at desired engine conditions.

WORK IN PROGRESS IN FY 2017

Thrust 1: Safe, efficient growth in global operations

NASA will complete ATD-1 with flight demonstration of flight-deck interval management technologies. NASA will install and evaluate prototype flight hardware and software in commercial airliners that allows pilots to manage the merging of their aircraft into the airport arrival stream and maintain safe spacing. Upon successful demonstration, the final analysis, documentation, and technology transfer to the FAA will occur late FY 2017.

NASA will conduct an ATD-2 Departure Metering demonstration at Charlotte Douglas International Airport, the test site for this initial simulation of a NextGen capability. This demonstration supports the FAA's joint government/industry initiative aimed at improving air traffic flow management through increased information exchange among airline and airport stakeholders and demonstrates NASA's commitment to supporting public-private partnerships.

Thrust 2: Innovation in commercial supersonic aircraft

NASA will complete a Preliminary Design Review (PDR) for a supersonic, low-boom noise experimental aircraft. NASA awarded the preliminary design effort to Lockheed Martin. The design will be the most complete supersonic low-boom noise aircraft ever achieved. The aircraft will be designed to fly at supersonic speeds and produce a sonic boom noise which will be acceptable to affected communities, as opposed to the highly disruptive levels of noise generated by prior commercial supersonic aircraft. Results from this PDR will pave the way for the final design and manufacture competition of this first-of-its-kind X-Plane.

Thrust 3: Ultra-efficient commercial vehicles

NASA will complete an investigation of the benefits of partially embedding engines on top of an airframe in a way that is much more efficient than traditional under-the-wing mountings. A major technical challenge of this design is whether an engine's fan can handle the uneven airflow. A first-of-its-kind wind tunnel test at Glenn Research Center (GRC) will be performed to understand fan design for such engine installations. If successful, this work will lay the path to new integrated engine-airframe designs that offer significant performance benefits. This technology is a candidate for testing on a future X-Plane.

NASA will also complete two complementary efforts to help improve the efficiency and higher-speed performance of new helicopter concepts. The first of these two efforts is demonstrating power turbine component designs for the jet engine that can operate highly efficiently across a wide range of engine speeds. The complementary second effort is the demonstration of a two-speed transmission (drive) system that enables helicopter main rotor speed reduction by 50 percent while ensuring no loss of power. Commensurate with this second effort is the development and demonstration of new transmission technologies that will reduce weight while improving operation. The combination of these two complementary approaches will enable vertical flight vehicles that operate very efficiently at much higher speeds than those today.

Thrust 4: Transition to alternative propulsion and energy

NASA is currently developing the X-57 Maxwell, a general aviation-scale aircraft to test highly integrated distributed electric propulsion technology. This demonstration is an important first step toward assessing the benefits and challenges of operating more electrified aircraft. In support of X-57 flight testing, NASA is integrating the battery system using a mockup and conducting a Critical Design Review of the wing. Also, NASA is releasing a Request for Information (RFI) to solicit industry ideas for electrified aircraft propulsion X-Planes to follow the X-57.

NASA will continue public-private partnerships with several universities, industry and other government agencies to investigate, develop, and test small-core, fuel-flexible combustor technologies to reduce NOx emissions and particulate matter pollutants to 80 percent below the international standard with minimal impacts on weight, noise and component life. Reaching higher engine operating pressures and increasing engine efficiency with small-core combustors in advanced large-diameter ultra-efficient turbofan engines will support the development of engines that are compatible with both gas-only and hybrid-gas electric architectures, as well as ducted and unducted propulsors, which will allow for earlier adoption of alternative drop-in fuels for future aircraft. To help investigate the barriers being faced with small-core combustor concepts, preliminary tests with United Technologies Research Center and Pratt & Whitney will continue in FY 2017 to study a new combustor concept to obtain Landing-to-Take-Off (LTO) NOx emissions data at relevant engine operating conditions. Additional combustor testing will also be conducted to understand the operating characteristics of this technology better.

Thrust 5: Real-time, system-wide safety assurance

NASA will achieve a key milestone in enabling development of real-time, system-wide safety tools. In late FY 2017, the Beta build of the Shadow Mode Assessment Using Realistic Technologies for the National Airspace System (SMART-NAS) Test Bed will achieve the capabilities to (1) evaluate emergent air traffic behavior due to novel air traffic control concepts and (2) provide the FAA and airspace users the ability to evaluate mature concepts/technologies. Critical for development of a real-time safety system, the Test Bed will enable safety analysis for novel technologies as well as testing and evaluation of tools that support a real-time system-wide safety capability. The Test Bed will be used to evaluate and refine data capture and fusion techniques, hazard identification and alerting using operational data, and decision support tools. By the end of FY 2017, matured hazard identification tools and initial decision support tools, featuring prognostic state awareness, will be ready for assessment in the Test Bed environment.

Thrust 6: Assured autonomy for aviation transformation

NASA will close out Phase 1 of the UAS Integration in the NAS project and start up the initial execution of Phase 2. NASA delivered the final Phase 1 Detect and Avoid (DAA) Minimum Operational Performance Standards (MOPS) to the Radio Technical Commission for Aeronautics (RTCA) Special Committee 228. The MOPS will enable the FAA to develop Technical Standard Orders so that industry can build and certify flight hardware.

NASA is working with the FAA to flight test the Airborne Collision Avoidance System (ACAS) – Xu. The ACAS is the replacement for the Traffic Alerting and Collision Avoidance System (TCAS) and ACAS Xu is designed specifically for UAS. Validation of ACAS is a critical step toward integrating UAS into the NAS.

Cross-Cutting Capabilities

NASA will execute the first competitive University Leadership Initiative awards under the University Innovation Challenge (UIC) project. These awards are the result of university leaders independently analyzing the technical barriers inherent in achieving the ARMD strategic outcomes and proposing multi-disciplinary technical challenges along with supporting activities to address those barriers.

NASA will complete studies to determine the most promising super cooled large droplet (SLD) icing (i.e. freezing drizzle and rain) experimental simulation methods. The ability to provide an SLD freezing drizzle/rain environment in a ground test facility will allow for the efficient and effective testing of aircraft components, computer simulation validations and SLD freezing drizzle/rain protection systems. The ability to provide an SLD freezing drizzle/rain environment in a ground test facility does not currently exist, and future air vehicles will need to operate safely under SLD-like conditions.

Hypersonic Capabilities

NASA began the Hypersonic Technology project to consolidate ongoing hypersonics research activities. NASA coordinated hypersonics research plans closely with the Department of Defense (DoD) to leverage flight test data to support NASA's research while simultaneously reducing risk and enhancing the effectiveness of these programs. In the field of hypersonics, uncertainty plays a large factor with test environments, sensor technology, and test hardware. NASA's efforts are aimed at reducing the uncertainty in computational models, ground testing, as well as flight testing operations. Overcoming this key barrier, the ability to quantify potential inaccuracies in component models and combine them to understand the potential system-level inaccuracy, will contribute to reducing system-level risk. Additionally, overcoming this barrier will enable more effective technology risk tools, allowing for a better understanding of the true potential of future technologies. NASA will also conduct ground test experiments to advance the feasibility for future systems that use a turbine engine at slow speeds and transition to a supersonic combustion ramjet (scramjet) for high-speed operations which would greatly increase the flexibility and utility of high-speed vehicles.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

Thrust 1: Safe, efficient growth in global operations

ATD-2 testing will be conducted in three phases. Beginning in FY 2018, Phase 1 will demonstrate a baseline integrated arrival, departure and surface system, to include the FAA's Surface Collaborative Decision Making concept, at the Charlotte-Douglas International Airport in Charlotte, NC and the air traffic control center (ATC) in Washington, DC. Phase 2 will continue through 2019 to expand the demonstration to include scheduling scenarios and a more complete fusion of NASA and FAA technologies. ATD-2 continues with Phase 3 involving a field demonstration with participation of NASA and ATCs in Charlotte, NC; Washington, DC; and Atlanta, GA in FY 2020. Phase 3 also will test the system used to coordinate departures from variou metropolitan area airports competing for the same constrained airspace – specifically, the Metroplex Coordinator at the Dallas-Fort Worth Airport in Texas.

Thrust 2: Innovation in commercial supersonic aircraft

After the preliminary design is completed in FY 2017, NASA will have a competition to award a contract for the LBFD detailed aircraft design, build and validation. The LBFD X-Plane is expected to achieve first flight by FY 2021, initially focused on safe expansion of the flight envelope and then proceeding to its sonic boom noise testing flight campaign.

In support of these future low-boom aircraft flight experiments, NASA will complete development of initial models that predict community response to noise created by the overflight of future supersonic commercial aircraft. Based on simulations conducted in NASA's Interior Effects Laboratory, the first of these models will be capable of predicting the response of a person who hears supersonic overflight noise while indoors. This model estimates the level of noise required to prevent annoyance due to supersonic overflight. The second of these models will be able to predict the indoor noise created by supersonic overflight in a wide variety of homes with different room arrangements and construction techniques. With the combination of these models, NASA will perform analytical studies of community response to the overflight of low noise supersonic commercial aircraft, enabling NASA to design the community overflight experiments that the LBFD will utilize in its flight campaign.

Thrust 3: Ultra-efficient commercial vehicles

Through the use of public-private partnerships, NASA is exploring new subsonic aircraft configurations that offer significant efficiency and performance improvements. The new configurations require technology advancements such as advanced lightweight aircraft structures. NASA will complete key tests to demonstrate a concept of tailoring the structure to reduce weight in less critical areas. To achieve this, it is important to both understand how to design the structure as well as to predict loads accurately. In FY 2018, NASA will complete key tests to help demonstrate the viability of this concept.

Thrust 4: Transition to alternative propulsion and energy

In FY 2018, X-57 will conduct flights in the Mod II configurations. These flights represent a crucial step in the flight test process as the conventional fuel engines will be replaced with electric motors and the electrical storage and power distribution systems needed for all-electric flight. Thereafter, the Mod III wing will be delivered, and the X-57 aircraft will be modified to the Mod III configuration that includes integration of the newly designed, high-aspect ratio wing. This will enable demonstration of cruise efficiency gains that are anticipated for the X-57 during Mod III flights that are planned for FY 2019.

NASA will conclude preparations for the testing of a superconducting motor. This motor test represents a major advancement in a key technology needed to realize practical larger-scale hybrid electric propulsion systems for the future. Further, in partnership with industry, NASA will advance a 1-megawatt non-superconducting inverter to a higher technical maturity level. This advancement complements the superconducting motor and adds to the technology options available to hybrid electric propulsion system designers as they identify and develop larger ground and flight demonstration opportunities.

Thrust 5: Real-time, system-wide safety assurance

NASA will simulate piloted models that support stall training requirements. This is significant because loss of control in flight caused by stalls has been a leading cause of fatal aircraft accidents for many years. In a recent study of loss-of-control accidents and incidents, the federal Commercial Aviation Safety Team (CAST) identified a growing trend in loss of airplane state awareness by the flight crew. This has led to recommended safety enhancements that include flight deck technologies with the potential of enhancing flight crew awareness of airplane energy state. NASA will also coordinate with the FAA and manufacturer research organizations to develop enhanced tools and methods to represent flight crew responses in situations associated with loss of energy state and/or attitude state awareness.

Thrust 6: Assured autonomy for aviation transformation

The next phase of the UAS Traffic Management (UTM) Technology Capability Level (TCL) demonstrations, TCL3, will focus on developing requirements to manage separation by vehicle and ground-based capabilities under higher densities. The focus areas will be all research validated under TCL2 (demonstrating operations beyond the visual line-of-sight) over moderately populated land with some interaction with manned aircraft. In addition, vehicle tracking/internet connectivity will enable validation of requirements for active monitoring of trajectory conformance. This capability is relevant to public safety concerns (i.e., emergency and disaster response, fire management, hazardous materials (HAZMAT), etc.) and commercial interests (i.e., package delivery, security, telecommunications, etc.) and will culminate in a final TCL4 demonstration in FY 2019 for large-scale contingency mitigation.

Cross-Cutting Capabilities

NASA will complete a major wind tunnel experiment that will allow turbulence models to achieve a 40 percent reduction in predictive error against standard test cases. In this experiment, researchers will take detailed measurements of the flow near the wing-body junction of an aircraft. The complex turbulent flows occurring around this region cannot be accurately represented by today's computational tools. Understanding these flows will greatly improve the quality of computational models, thereby having a positive impact on the design of future aircraft. The experiment will provide a complete validation dataset, including upstream boundary conditions, detailed measurements of the separated flow region, and off-body turbulence measurements. At a following workshop with industry and academia, NASA will explore the advanced computational tools and experimental data, and together the community will validate the quality of high-fidelity, physics-based turbulence modeling.

Hypersonic Capabilities

A key experiment is planned to demonstrate an autonomous mode transition in a turbine-based combined cycle system. Such a system uses a turbine engine at lower speeds and then transitions to a scramjet. NASA has developed the underlying theory and technologies to allow this to happen, but having autonomous system control such a transition is a key enabler for a practical system. NASA will develop the underlying algorithms and techniques that will allow industry to implement this concept in a variety of systems and provides a flexible operational capability that does not exist today

Programs

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 is on the leading edge of research into 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 the 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.

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 sustaining hypersonic competency for national needs while advancing fundamental hypersonics research. 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 also works in partnership with the DoD to ensure both NASA and DoD vehicle-focused research is fully coordinated and leveraged. The program sustains and advances key national testing capabilities that support aeronautics research and development needs. The program takes lead responsibility for three of the 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 leads NASA Aeronautics' NAH X-Plane initiative. 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.

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 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	**147.1**	**--**	**108.7**	**107.7**	**107.1**	**107.8**	**109.7**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

In collaboration with Boeing, United Airlines, and Honeywell, NASA flight-tested a new cockpit-based air traffic management tool over central Washington. The prototype hardware and software is designed to automatically provide pilots with more precise aircraft spacing information on approach into a busy airport so that more planes can safely land in a given time.

AOSP creates technologies that enable NextGen to fulfill its promise to transform the Nation's ATM systems. Moving key concepts and technologies from the laboratory into the field benefit the public ultimately by increasing capacity and reducing the total cost of air transportation. The current U.S. air transportation system is widely recognized to be among the safest in the world. While NextGen will meet growing air traffic demand by enabling efficient passage through the increasingly crowded skies, it will come with increased operating complexity. Therefore, advanced automation technologies that work in harmony with human operators are critical for the United States to meet the public expectations for safety in this complex, dynamic domain.

NextGen technologies will also provide advanced levels of automated support to air navigation service providers and aircraft operators for reduced travel times and travel-related delays both on the ground and in the sky. These advanced technologies provide shortened routes for time and fuel savings, with associated improvements in noise and emissions, and permit controllers to monitor and manage aircraft for greater safety in all weather conditions.

AOSP (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 NextGen. The deployment of new operational concepts, capabilities, and 21st century technologies will be supported by the exploration and development of a test bed for safe global, gate-to-gate trajectory-based operations to achieve and transition beyond the NextGen vision.

Current aviation and the ATM system face many challenges related to global competitiveness, efficiency, productivity, higher mobility needs, and emergence of newer airspace uses (such as commercial space launches, and UAS in low and high altitudes). NASA looks to ensure that the future airspace management 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 autonomous technologies for aircraft/platforms as well as managing the airspace to support diverse operations.

EXPLANATION OF MAJOR CHANGES IN FY 2018

None

ACHIEVEMENTS IN FY 2016

Thrust 1: Safe, Efficient Growth in Global Operations

NASA completed the integration of technologies for ATD-1 that provided efficient airport arrival routes for aircraft from just prior to top-of-descent through touchdown on the runway. The more orderly, precise, and direct traffic flow enabled by the ATD-1 technologies will make the NAS more predictable overall. Airspace users will be able to better respond to unexpected delays caused by convective weather and other airspace constraints. By means of complex Operational Integration Assessment at the FAA William J. Hughes Technical Center, the ATD-1 technology suite demonstrated high throughput of efficient arrival operations during peak traffic conditions in the terminal area allowing arrival aircraft to safely fly closer together on more fuel-efficient routes to increase capacity, reduce delay, and minimize fuel burn, noise, and emissions. This work will culminate in field demonstrations of ATD-1 technologies in FY 2017.

In collaboration with the FAA, Virgin America, and Alaska Airlines, NASA received FAA authorization to commence “traffic aware strategic aircrew requests” (TASAR) operations. TASAR is a NASA-developed, cockpit-based tool that provides traffic-free optimizations to an aircraft’s route. TASAR connects to avionics via standard interfaces, reads external data sources via internet connectivity, computes real-time route/altitude optimizations, and analyzes pilot-entered route/altitude changes providing time and/or fuel saving to the airline. Operational evaluations will continue through FY 2020 to enable full integration of flight deck and ground-based trajectory optimization tools for advanced traffic flow management.

NASA developed tools to reduce take-off time variances using the Integrated Arrival, Departure, and Surface Operations (i.e., ATD-2) operational concept. Increasing predictability allowed airlines to reduce schedule block-times for flights during high-demand periods resulting in significant cost reduction. This included a schedule of simulations to support advancement of component technologies and their integration in addition to development of requirements, processes, and procedures. Mid-FY 2016 marked the official opening of the new ATD-2 laboratory at the Charlotte Douglas Airport. In partnership with the Department of Transportation and the FAA, NASA’s “CLTlab” is the first external installation of ATD-2 technologies outside of existing NASA laboratories, and provides a collaboration space for working with air traffic controllers and airline operations to develop technologies and conduct evaluations. Two initial engineering shadow evaluations of surface management tools were conducted at CLTlab in collaboration with the airport, airlines, and FAA traffic managers.

AIRSPACE OPERATIONS AND SAFETY PROGRAM

Thrust 5: Real-time, System-wide Safety Assurance

AOSP pursued improved operational safety by real-time system monitoring and assurance through development and refinement of specialized data analytics that identified anomalies in operational data and provided information about precursors to safety risks. These tools were scaled to analyze and incorporate data from multiple sources such as flight and radar track data, and written safety reports. Prognostic and decision-making tools were refined to support development of a system that can predict emerging risks and provide decision support for mitigation strategies. Continued development of run-time monitoring capabilities for software and system assurance enabled progress toward continuous lifecycle assessment of aviation systems.

NASA continues collaboration with the FAA within the System Wide Safety Assurance Research Transition Team. NASA's delivery of Software and Digital Systems Research Technology Roadmap (RTR) research products to the FAA was formally recognized through a Research Transfer Ceremony at FAA Headquarters. RTR teams focused on issues such as "New Approaches for Software Assurance" and "Safety Assurance for Complex, Digitally Intensive Systems." The NASA/FAA RTR identifies the most crucial airspace systems certification needs and organizes complementary cross-agency research activities.

Thrust 6: Assured Autonomy for Aviation Transformation

NASA completed the UTM TCL1 to enable capability for safe operation of small UAS at low altitudes. The system supports the development of autonomous concepts, technologies, and procedures, and demonstrated a research capability that enables operations of UAS while sharing airspace with other users. The TCL1 system includes initial trajectory management by offering geo-fencing, initial wind/weather integration, rules of the road, and procedural separation. NASA transitioned UTM TCL1 to FAA UAS test sites for demonstrations of initial concepts. This allowed a limited number of homogeneous vehicles to explore uses like search and rescue, agriculture applications, humanitarian, or science missions. Future TCLs planned through FY 2019 will add additional capabilities.

WORK IN PROGRESS IN FY 2017

Thrust 1: Safe, Efficient Growth in Global Operations

The development of ATD-1 flight-deck interval management technologies will culminate in flight test demonstrations planned for mid-FY 2017. NASA will install and evaluate prototype flight hardware and software that allows pilots to manage the merging of their aircraft into the airport arrival stream and maintain safe spacing. Upon successful integration of the systems in the demonstration, final analysis, documentation, and technology transfer to the FAA will occur late FY 2017.

NASA will conduct an ATD-2 Departure Metering demonstration at Charlotte Douglas International Airport, the test site for this initial simulation of a NextGen departure metering capability. This demonstration supports the FAA's joint government/industry initiative aimed at improving air traffic flow management through increased information exchange among airline and airport stakeholders.

Thrust 5: Real-time, System-wide Safety Assurance

In late FY 2017, the Beta build of the Shadow Mode Assessment Using Realistic Technologies for the National Airspace System (SMART-NAS) will deliver capabilities to (1) evaluate emergent air traffic behavior due to novel air traffic control concepts and (2) provide the FAA and airspace users the ability to evaluate mature concepts/technologies in complex NextGen environments. These capabilities will enable the community to perform high-fidelity concept and technology evaluations using on-demand Human-In-The-Loop (HITL) simulation capabilities with realistic traffic and weather conditions. These capabilities do not exist in modeling and testing environments available today.

Thrust 6: Assured Autonomy for Aviation Transformation

NASA will continue to develop and mature UTM technology by way of TCL2, which will incorporate weather/wind integration, trajectory routing, object avoidance, and congestion management in the first quarter of FY 2017. These additional capabilities will support more complex and beneficial operations in low altitude airspace. TCL2 will leverage TCL1 results and focus on beyond-visual line-of-sight operations in sparsely populated areas. Researchers will test technologies that allow dynamic adjustments to user-requested flight plans based on availability of airspace and contingency management.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

Thrust 1: Safe, Efficient Growth in Global Operations

Technologies will be tested during ATD-2 to explore how to best use shared operational information to better plan and schedule aircraft movement. The ATD-2 computer-driven scheduling tools will help traffic managers coordinate flight schedules at the ramp, tower, terminal and center control facilities, and make better decisions about how to reduce congestion during the busiest times at airports and improve departure times saving fuel, time, and money. ATD-2 testing will be conducted in three phases. Beginning in FY 2018, Phase 1 will demonstrate a baseline integrated arrival, departure and surface system, to include the FAA’s Surface Collaborative Decision Making concept, at the Charlotte-Douglas International Airport in Charlotte, NC and the ATC in Washington, DC. Additional Phases 2 and 3 will follow involving a field demonstration with participation of NASA and ATCs in Charlotte, NC; Washington, DC; and Atlanta, GA in FY 2020.

Thrust 5: Real-time, System-wide Safety Assurance

The use of models is becoming ubiquitous in the specification, design, and analysis of complex, safety-critical systems—including assurance of system safety properties. The application of model-based safety analysis to these systems must be carefully structured to assure that the models provide a sufficiently accurate representation of the system, and that model analysis techniques provide a sufficiently rigorous assessment of emergent system safety properties. An aim of the Safe Avionics and ATM Future Evolution Technical Challenge, within the System-Wide Safety (SWS) project, is to develop tools, techniques, and architectural patterns to enable efficient verification and validation of complex safety-critical systems. In FY 2018, NASA will complete safety assessment of selected air traffic management systems in a distributed environment and demonstrate a composable framework for evaluating ATM and avionics systems. Upon successful demonstration, these tools will be transferred to the FAA and the avionics industry in FY 2019.

Loss of control in flight has been a leading cause of fatal aircraft accidents for many years. In a recent study of loss-of-control accidents and incidents, the Federal CAST identified a growing trend in loss of airplane state awareness by the flight crew. This has led to recommended safety enhancements that include flight deck technologies with the potential of enhancing flight crew awareness of airplane energy state. As deliverables to the CAST safety enhancement activity, NASA will simulate piloted models that support stall training requirements. NASA will also coordinate with the FAA and manufacturer research organizations to develop enhanced tools and methods to represent flight crew responses in situations associated with loss of energy state and/or attitude state awareness.

Thrust 6: Assured Autonomy for Aviation Transformation

The next phase of the UTM TCL demonstrations, TCL3, will focus on developing requirements to manage separation by vehicle and/or ground-based capabilities under higher densities. The focus areas will be all research validated under TCL2 (demonstrating operations beyond the visual line-of-sight) over moderately populated land with some interaction with manned aircraft. In addition, vehicle tracking/internet connectivity will enable validation of requirements for active monitoring of trajectory conformance. This capability is relevant to public safety concerns (i.e., emergency and disaster response, fire management, HAZMAT, etc.) and commercial interests (i.e., package delivery, security, telecommunications, etc.) and will culminate in a final TCL4 demonstration in FY 2019 for large-scale contingency mitigation.

Program Elements

AIRSPACE TECHNOLOGY DEMONSTRATIONS (ATD)

The ATD project is comprised of a suite of critical technology development and demonstration activities geared toward delivery of near-term benefits to air transportation system stakeholders. ATD supports the ARMD safe efficient growth in global operations strategic thrust by two sub-projects with each focused on a technical challenge.

- ATD-1 (Interval Management - Terminal Area Precision Scheduling and Spacing) will directly address terminal area congestion, and evaluate the benefits of advanced flight arrival management technologies across a range of aircraft equipment levels during moderate to high levels of traffic demand. When integrated, the ATD-1 technologies will allow the pilots to achieve precise spacing separation between aircraft, and the controllers to manage the variability between flights and respond to disturbances to the schedule. This integrated set of capabilities will enable increased fuel efficiency while maintaining runway throughput to high-density airports.
- The Integrated Arrival, Departure, Surface (ATD-2) 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. Integrated Arrival, Departure, and Surface Operations (IADS), also known as 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.
- The Domestic Applied Traffic Flow Management activity (ATD-3) aims to reduce weather-induced delays through sharing of information to better manage aircraft, traffic flow, and airspace and schedule limitations. Benefits to the community are smarter alterations of routes to avoid hazardous weather utilizing modern data connectivity, and real-world testing for big improvements in delay reductions and fuel and time savings.

AIRSPACE OPERATIONS AND SAFETY PROGRAM

TRAJECTORY-BASED OPERATIONS SERVICES (TBOS)

The Trajectory-Based Operations Services (TBOS) 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. To achieve the goal of greater universal access with safe efficient operations for all users and allow for more flexible flight routes, TBOS will explore an open airspace management system architecture and flexible airspace and technologies that will allow greater industry participation to develop air traffic software for more rapid modernization by incorporating innovations at “industry” speeds. The open architecture will also integrate air traffic technologies and data to provide comprehensive situational awareness and improved coordinated decision-making and disruption management using trajectory-based advisories to enable flexible, user-preferred, predictable, and robust operations. To achieve these capabilities, TBOS will leverage the FAA infrastructure modernization investments and NASA’s Airspace Technology Demonstrations with research to advance knowledge in auto-negotiation, human-machine teaming, and increasingly autonomous decision-making.

SYSTEM-WIDE SAFETY (SWS)

The SWS project will perform research to (1) explore, discover, and understand the impact on safety of the growing complexity introduced by advances aimed at improving the efficiency of flight, the access to airspace, and/or the expansion of services provided by air vehicles; and (2) develop and demonstrate innovative solutions that enable these advances, and the aviation transformation envisioned by ARMD, through proactive mitigation of risks in accordance with target levels of safety. The project will develop tools, methods and technologies to enable capabilities envisioned by ARMD’s Strategic Thrust 5, Real-Time System-Wide Safety. Expanded system safety awareness will be achieved through increased access to relevant data, integrated analysis capabilities, improved real-time detection and alerting of hazards at the domain level, decision support, and, in some cases, automated mitigation strategies. The System-Wide Safety project also addresses the need, called out in Strategic Thrusts 1 and 6, for safety-related advances in methods used for the verification and validation of advanced increasingly autonomous systems.

SWS R&D achieves its two-fold goal while aligning with the Strategic Thrust outcomes, 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.

AIRSPACE OPERATIONS AND SAFETY PROGRAM

UAS TRAFFIC MANAGEMENT (UTM)

In support of ARMD's strategic thrust toward assured autonomy for aviation transformation and safe, efficient growth in global operations, the UTM project will conduct research and development activities to ensure that the future airspace management system will initially accommodate small UAS operating in low-altitude airspace beyond the visual line of sight with far greater levels of system complexity. The needs are characterized by greater diversity of aircraft performance, user business models, and airspace requirements for 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, roles, responsibilities, and procedures to demonstrate feasibility of autonomous aircraft operations in populated areas. This development must enable autonomous traffic flow management that allows more robust decision making in the presence of weather forecast uncertainties, developing alternative plans and dynamically changing the plans as forecasts change, and using learning algorithms/automation based on historical analysis of performance.

AIRSPACE OPERATIONS AND SAFETY PROGRAM

Program Schedule

Date	Significant Event
Jun 2017	ATD – Field test to demonstrate surface departure metering components of metroplex departure metering with airline partner at Charlotte Douglas International Airport.
Sep 2017	ATD – Final ATD-1 flight deck interval management avionics research technology transfer to the FAA and technology challenge closeout. Initial beta build of a safety analysis and assurance toolkit, which include data mining and analysis, automated prognostics, and safety risk modeling capabilities in the SMART-NAS Testbed.
Dec 2017	SWS – Validate technologies to enhance flight crew attitude and energy state awareness; develop tools and methods for collecting and analyzing real-time flight crew performance data.
Mar 2018	UTM – Initiate TCL3 to incorporate TCL2 and manage separation by vehicle and/or ground-based capabilities under higher densities.
Aug 2018	SWS – Demonstration of safety countermeasures for spatial disorientation and attentional performance limitations in relevant environment at the DoD Naval Medical Research Unit Disorientation Research Device facility.
Mar 2019	SWS – Evaluation of displays and predictive alerting algorithms that indicate systems status and the interaction of systems in time-critical situations involving system failures
Jun 2019	UTM – Initiate TCL4 to incorporate TCL3 and manage large-scale contingencies.
Dec 2019	TBOS – Simulation demonstration of the Integrated Demand Management concept of operations with weather disruptions
Jun 2020	ATD – Full-system demonstration of the IADS metroplex departure scheduling concept. SWS – Demonstration of tools for identifying, measuring, and tracking proximity to a variety of heterogeneous safety margins during airport terminal area operations.
Sep 2020	TBOS – Release of the SMART-NAS Test Bed Build with modeling of emergent vehicles and missions

AIRSPACE OPERATIONS AND SAFETY PROGRAM

Program Management & Commitments

Program Element	Provider
ATD	Provider: ARC, Langley Research Center (LaRC), GRC Lead Center: ARC Performing Center(s): ARC, LaRC, GRC Cost Share Partner(s): FAA, Honeywell, General Electric, Boeing, Raytheon, Rockwell Collins, Goodrich, Cessna Aircraft Co., American Airlines, United Airlines, EasyJet, Southwest Airlines, DoD, French Aerospace Lab (ONERA)
TBOS	Provider: ARC, LaRC, GRC Lead Center: TBD Performing Center(s): ARC, LaRC, GRC Cost Share Partner(s): FAA, General Electric, American Airlines, Delta Airlines, Southwest Airlines
SWS	Provider: ARC, LaRC, GRC Lead Center: TBD Performing Center(s): ARC, LaRC, GRC Cost Share Partner(s): FAA, DoD-AFRL, DoD-NAMRU, NRC, NITRD, Rockwell-Collins, Honeywell, Boeing, American Airlines, Commercial Aviation Safety Team, Unmanned Aircraft Safety Team
UTM	Provider: ARC, LaRC, GRC Lead Center: ARC Performing Center(s): ARC, LaRC, GRC Cost Share Partner(s): FAA, Boeing, General Electric, American Airlines, United Airlines, Rockwell Collins, DoD, Honeywell, ONERA

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.

AIRSPACE OPERATIONS AND SAFETY PROGRAM

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Formulation: TBOS and SWS Projects	ARMD Senior Management and Expert Review	Feb 2017	The 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.	To be determined	Summer 2017
Performance (Annual)	Expert Review	Oct 2016	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 2017

ADVANCED AIR VEHICLES PROGRAM

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	**254.9**	**--**	**232.7**	**223.8**	**233.2**	**236.7**	**241.8**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

In January, a model of a future aircraft design called a truss-braced wing, which dramatically cuts fuel use and emissions was put through wind-tunnel tests at NASA's ARC.

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. NASA research is incorporated into all major modern U.S. aircraft, and the type of research performed by AAVP will prime the technology pipeline, enabling continued U.S. leadership, competitiveness, and high-quality jobs in the future. Technologies and design capabilities developed for these advanced vehicles will integrate multiple, simultaneous vehicle performance considerations including fuel usage, noise, emissions, and intrinsic safety. Efficiency and environmental factors will play a significant role as the aviation market expands across the globe in which the technologies developed by AAVP will help ensure continued U.S. leadership that also benefits the world. Across the AAV Program, NASA will continue to engage partners from industry, academia, and other government agencies to maintain a sufficiently broad perspective on technology solutions to these challenges; to pursue mutually beneficial collaborations; and to leverage opportunities for effective technology transition. AAVP directly supports three of the ARMD Strategic Thrusts (Thrust 2: Innovation in Commercial Supersonic Aircraft, Thrust 3: Ultra-efficient Commercial Vehicles, and Thrust 4: Transition to Alternative Propulsion and Energy. In addition, the Program is responsible for advancing key hypersonic technologies for the country and enabling ground test capabilities that support the research, technology demonstration, and validation requirements of NASA, other government agencies, and commercial partners.

ADVANCED AIR VEHICLES PROGRAM

EXPLANATION OF MAJOR CHANGES IN FY 2018

None.

ACHIEVEMENTS IN FY 2016

Thrust 2: Innovation in Commercial Supersonic Aircraft

NASA reached a major milestone in support of further development of low noise commercial supersonic aircraft by completing the Low Noise Propulsion for Low-Boom Aircraft technical challenge. This technical challenge addressed the development of computational design tools and innovative concepts for low-noise supersonic propulsion systems which enabled verification and validation of advanced concepts through extensive testing. NASA developed new concepts that should enable future airport noise regulations to be met, and also enhanced developmental tools that will allow industry to better design such systems in the future.

NASA studied the effects of atmospheric turbulence on sonic boom noise, which is vital to community response testing and noise standards development. The data generated by these studies is important for improving the understanding of sonic boom effects and will improve understanding of future aircraft design barriers and the effects of low boom noise on the community. Ultimately, this research will assist in the ability to establish a new low boom regulation that opens the door to a commercial supersonic transport market.

Thrust 3: Ultra-efficient Commercial Vehicles

Building on earlier testing that showed the potential of the Truss Braced Wing configuration, NASA successfully conducted a key wind tunnel test in the ARC Unitary Tunnel to examine the efficiency benefits of the design. The Truss Braced Wing utilizes an innovative bracing structure to allow more efficient wings to be designed for an aircraft. The initial wind tunnel test demonstrated a 57 percent reduction in fuel consumption compared to an equivalently sized baseline conventional aircraft. These results show that this concept continues to be a viable technology for greatly improving the performance of future aircraft.

NASA also completed the majority of work in Phase I of the Advanced Composites project, which is focused on reducing the time and/or cost of implementing new composites structures in future air vehicle designs. A key aspect of the completed Phase I work was the assessment and initial development of computational tools that would accurately predict the strength and life of composite designs. In addition, NASA also advanced key technologies to rapidly test and inspect composite structures for possible damage. Improvements in the ability to simulate advanced composite manufacturing processes were critical in this phase for ensuring that these new capabilities could be implemented in industry.

In partnership with the Navy and Army, NASA completed flight testing of two different helicopters, each flown with different control settings for the main rotor. The data from these flight tests provide a basis for identifying how helicopter main rotor control processes can be altered and adjusted to reduce perceived vehicle noise. Such insight can be very valuable to helicopter pilots and operators to help them reduce noise affecting the communities over which they fly. This data also helps lay the foundation for more focused efforts that target not only helicopter operations for reduced noise, but also vehicle and rotor designs that are quieter. This work also provides useful insight to future work that will pinpoint the human perception nuances that cause helicopter noise to be annoying.

Thrust 4: Transition to Alternative Propulsion and Energy

NASA worked with airframe and engine manufacturers as well as universities to identify and analyze propulsion and power system options for next generation aircraft. These analyses verify benefits of the new propulsion systems for a single aisle class of transport airplane and will be used to guide the technology development efforts on specific components. For example, turboelectric and hybrid electric designs are showing promising energy reductions of up to 15 percent for the propulsion system alone, which can also be augmented by improvements in other technologies, such as materials, and wing design.

Cross-Cutting Capabilities

As part of NASA's Capability Management Model, a new approach for supporting critical ground test facilities was approved for FY 2016 planning and FY 2017 implementation. NASA successfully re-planned its facilities portfolio management efforts to align to this new approach which enables full operational cost coverage for NASA users for a key set of test facilities. Starting in FY 2019, facility testing consumables (e.g. power, fuel, etc.) will also be covered. The primary objective of this approach is to increase technology innovation and improve technology risk reduction efforts by providing easier facility access along with reducing costs to the research community. This new business model also emphasizes facilities as a NASA centrally managed resource, improves facility utilization, enables capability and discipline sustainability, and provides an improved approach for facility decisions involving partnerships, investments, and divestments. During this re-planning effort, new facility capability advancements and test technologies continued. NASA has successfully matured an aircraft engine experimental test capability at the GRC Propulsion System Laboratory that can simulate engine ice crystal icing conditions – a recent aviation safety concern. NASA successfully tested a highly instrumented engine in a broad range of engine ice crystal conditions and altitudes, enabling future NASA and external users to have greater confidence in the engine data collected under these simulated conditions as compared to natural atmospheric conditions in flight. This new capability will provide NASA with reliable datasets to develop engine ice accretion tools that assist in assessing new and existing engines.

ADVANCED AIR VEHICLES PROGRAM

WORK IN PROGRESS IN FY 2017

Thrust 3: Ultra-efficient Commercial Vehicles

NASA will complete a key technical challenge investigating the potential benefits of engines that can be mounted, partially embedded, on top of the airframe in a way that is much more efficient than traditional under-the-wing mountings. Recent results from wind-tunnel testing show a vehicle efficiency benefit, but another key factor is whether an engine's fan can be designed to handle the uneven air flow resulting from this configuration. A first-of-its-kind complex wind tunnel configuration at Glenn Research Center (GRC) will be used to better understand how to design the fans in such an installation system. If successful, this work will lay the path to new designs that offer significant aircraft performance benefits.

In order to help improve the efficiency and higher-speed performance of new vertical flight concepts, in 2017 NASA will complete two complementary efforts that target the ability to effectively reduce a helicopter's main rotor speed. The first of these two efforts is demonstrating the ability to design the power turbine component of the jet engine such that it can operate highly efficiently across a wide range of engine speeds. The complementary second effort is the demonstration of a two-speed transmission (drive) system that enables main rotor speed reduction by 50 percent while ensuring that power is not lost in the process. Commensurate with this second effort is the development and demonstration of new transmission technologies that will help reduce its overall weight while improving its operation. The combination of these two complementary approaches will enable vertical flight vehicles that operate very efficiently at much higher speeds than those today.

Thrust 4: Transition to Alternative Propulsion and Energy

NASA will continue in partnerships with several universities, industry and other government agencies to investigate, develop, and test small-core, fuel-flexible combustor technologies to reduce NOx emissions and particulate matter pollutants to 80 percent below the international standard with minimal impacts on weight, noise and component life. These advanced benefits, of reaching higher engine operating pressures and increasing engine efficiency with small-core combustors in advanced large-diameter ultra-efficient turbofan engines, will be compatible with both gas-only and hybrid-gas electric architectures, as well as ducted and unducted propulsors, which will allow for an earlier adoption of alternative drop-in fuels for future aircraft. To help investigate the barriers being faced with small-core combustor concepts, preliminary tests with UTRC and P&W will continue in FY 2017 to study a new combustor concept in order to obtain LTO NOx emissions data at relevant engine operating conditions. Additional combustor testing will also be conducted to better understand the operating characteristics of this technology.

Cross-Cutting Capabilities

NASA will complete studies to determine the most promising SLD icing experimental simulation methods. The ability to provide an SLD freezing drizzle/rain environment in a ground test facility will allow for the efficient and effective testing of aircraft components, computer simulation validations and SLD freezing drizzle/rain protection systems. The ability to provide an SLD freezing drizzle/rain environment in a ground test facility does not currently exist, and future air vehicles will need to operate safely under SLD-like conditions.

Hypersonic Capabilities

NASA began the Hypersonic Technology project to consolidate ongoing hypersonics research activities. NASA will continue to coordinate closely with the DoD to leverage flight test data to support NASA's research while simultaneously reducing risk and enhancing the effectiveness of these programs. Hypersonic research will focus on reducing the uncertainty in test environments, sensor technology and test hardware. NASA's efforts will mainly be in the area of reducing the uncertainty in computational models, ground testing, as well as flight testing operations. Being able to quantify potential inaccuracies in component models and combine them to understand the potential system-level inaccuracy will contribute to reducing the system-level risk of hypersonics technologies. Additionally, overcoming this barrier will enable more effective technology risk tools, which in turn will allow for a better understanding of the true potential of future technologies. NASA will also conduct ground test experiments to advance the feasibility for future systems that use a turbine engine at slow speeds and transition to a scramjet for high-speed operations. This would greatly increase the flexibility and utility of high-speed vehicles.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

Thrust 2: Innovation in Commercial Supersonic Aircraft

In support of the future low boom aircraft flight experiments, NASA will complete the development of an initial set of models for the prediction of the community response to noise created by the overflight of future supersonic commercial aircraft. Based on simulations conducted in NASA's Interior Effects Laboratory, the first of these models will be capable of predicting the response of a person who hears supersonic overflight noise while indoors. This model estimates the maximum level of noise that can be generated while still preventing annoyance due to supersonic overflight. The second of these models will be able to predict the indoor noise created by supersonic overflight in a wide variety of homes with different room arrangements and construction techniques. With the combination of these models, NASA will begin analytical studies of community response to the overflight of future low noise supersonic commercial aircraft, which will provide the underlying data needed for NASA to design the necessary community overflight experiments.

Thrust 3: Ultra-efficient Commercial Vehicles

Many of the new subsonic aircraft configurations that NASA is exploring in partnership with industry offer significant potential for efficiency and performance improvements, but require advancements in key areas in order to realize these theoretical benefits. One such crucial area is advanced aircraft structures. NASA is exploring a concept of tailoring aircraft structures so that weight is minimized in areas where it is not needed. In order to achieve this, it is important to both understand how to design the structure as well as to accurately predicting loads. NASA will complete key tests to help demonstrate the viability of this concept. In addition, the program will continue to coordinate with the Integrated Aviation Systems Program to help plan and prepare for potential experimental subsonic aircraft that are part of the NAH initiative. AAVP will conduct testing and studies that help show the potential for some of the various aircraft concepts that are being considered. This work does not just impact a potential X-Plane, but also the eventual concept that will be realized by industry in the future.

Additionally, NASA will lay the foundation for establishing a new multi-disciplinary design capability that will benefit a wide variety of vertical lift vehicle sizes. This new design approach will enable industry to develop conceptual designs of advanced vertical lift vehicles while taking into account multiple disciplines and aspects of the configuration design (including, for example, projected noise, emissions, handling qualities and structural behavior). In addition to the new ability to take into account multiple disciplines, the new conceptual design capability will also allow the design engineers to have confidence in the results of their analysis. In FY 2018, NASA will demonstrate the capability by providing conceptual designs for three size class of vertical lift vehicles ranging from 4-80 passengers with improvements in propulsion efficiency and noise over conventional rotorcraft configurations.

Thrust 4: Transition to Alternative Propulsion and Energy

NASA will conclude preparations for the testing of a superconducting motor. This motor test represents a major advancement in a key technology needed to realize practical larger-scale hybrid electric propulsion systems for the future. Further, in partnership with industry, NASA will advance a 1MW non-superconducting inverter to a higher technical maturity level. This advancement complements the superconducting motor and adds to the technology options available to hybrid electric propulsion system designers as they identify and develop larger ground and flight demonstration opportunities.

Cross-Cutting Capabilities

NASA will complete design and installation of new acoustical treatment in the GRC 9x15-Foot Low-Speed Wind Tunnel. This improvement will further reduce the facility background noise to levels that enable testing of next-generation low-noise propulsion system concepts. Additionally, NASA will incorporate the previously-described new funding model for operational costs of NASA ground test facilities. This funding model enhances the value of ground testing for generating the data necessary to both better understand the performance of new technologies and help validate key computational models. NASA will benefit from the additional facility utilization for program/project technology risk reduction and Center innovation initiatives. In particular, it is expected that this new model will facilitate the risk reduction testing needed to support the NAH initiatives. It will provide consistent usage, stewardship of ground test capabilities, and increased level of actual strategic investments to sustain and improve the portfolio of covered capabilities.

Hypersonic Capabilities

A key experiment is planned to demonstrate an autonomous mode transition in a turbine-based combined cycle system. Such a system uses a turbine engine at lower speeds and transitions to a scram jet. NASA has developed the underlying theory and technologies to enable this to happen, but having autonomous system control, such a transition is a key enabler for a practical system. NASA will develop the underlying algorithms and techniques that will allow industry to implement this concept in a variety of systems and provide a flexible operational capability that does not exist today. Ultimately, such a system may allow more effective and flexible access to space.

Program Elements

ADVANCED AIR TRANSPORT TECHNOLOGY

NASA's vision for advanced fixed wing subsonic transport aircraft is to enable revolutionary advances in energy efficiency and environmental compatibility of future generations of aircraft. These technological solutions are critical to reduce the impact of aviation on the environment even as this industry and the corresponding global transportation continue to grow. Research will explore and advance knowledge, technologies, and concepts to enable 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 will identify and address potential new safety considerations associated with these advanced technologies and concepts. This research supports the sustained growth of commercial aviation that is so vital to the U.S. economy and our quality of life. 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, and greener 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 key risk reduction activities for potential subsonic demonstrators in the NAH initiative as well as the core propulsion research needed to develop new engines that will ultimately power the new vehicles.

REVOLUTIONARY VERTICAL LIFT TECHNOLOGY

The NASA Revolutionary Vertical Lift Technology (RVLT) project develops and validates tools, technologies, and concepts to overcome key barriers to the expanded use of vertical lift vehicles in the Nation's airspace. The unique ability of vertical lift vehicles to hover has significant applications in the civil market for human and cargo transportation, delivery systems, inspection and surveillance missions, oil and gas exploration, disaster relief and many more critical operations. RVLT research advances technologies that will increase speed, range, payload, and safety as well as decrease noise, weight, and fuel burn. 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 all classes and sizes, ranging from very small configurations to configurations that are viable commercial transports in the NAS. For example, the project is currently working with the Transformative Aeronautics Concepts Program to explore ideas that may combine autonomy and hybrid/ full electric systems with a vertical lift capability to enable a variety of new civil missions. The RVLT project primarily supports ARMD Strategic Thrust 3, but in the future will likely incorporate more electric and autonomy technologies that will also support Strategic Thrusts 4 and 6.

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, 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. Research conducted will establish the necessary approaches and techniques for objectively measuring the levels of sonic boom acceptable to communities living in the vicinity of future commercial supersonic flight paths. These approaches, techniques, and resulting data will inform both national and international regulatory organizations that set the standards for commercial entities and vehicles to achieve. The research also lays the groundwork for overcoming other challenges facing commercial supersonic flight including energy efficiency, reduced pollutants emitted into the atmosphere, and acceptable engine noise levels in the airport area. The Commercial Supersonic Technology project directly supports ARMD Strategic Thrust 2 and will conduct the research leveraging the purpose-built low boom experimental aircraft in conducting the community response mission.

ADVANCED COMPOSITES

NASA is addressing new test protocols and methods to reduce the development and certification timeline for composite materials and structures. It is inevitable that composite structures will see increased application due to the pressure to develop more efficient, sustainable vehicles. Testing is the primary basis of the present approach for the development and certification of composites. It is time-consuming and expensive but does provide rigorously validated results. NASA will focus on the development and use of high fidelity and rigorous computational methods, improved test protocols, and standardized inspection techniques to shorten the timeline to bring innovative composite materials and structures to market. NASA will engage key players from Government (FAA and DoD), industry, and academia to mature and verify the methodology, to ensure effective transition to industry, and to assure safety for certification authorities, such as the FAA. The goal of the project is to reduce the estimated five to nine year timeline for composite structures development and certification by 30 percent. The Advanced Composites project directly supports ARMD Strategic Thrust 3 because it will facilitate the design of new advanced vehicles that are highly efficient. In addition, the project is applicable to Thrust 2 because future supersonic aircraft will likely make significant use of composites.

AEROSCIENCES EVALUATION AND TEST CAPABILITIES

The ground test capabilities (facilities, systems, workforce, and tools) necessary to achieve the future air vehicles and operations described above require efficient and effective investment, use, and management. Efforts in this area preserve and enhance those specific ground test capabilities that are necessary to achieve the missions. Among these assets are subsonic, transonic, supersonic, and hypersonic wind tunnels and propulsion test facilities at ARC, GRC, and LaRC. These NASA-unique test facilities and capabilities may also serve the needs of the nation. The integrated approach to asset planning, use, and management will consider the complementary computational tools, software, and related systems to effectively acquire and process research data. An additional benefit is to offer the research customer high-quality data that accurately reflects the simulated test environment and the interactions of test articles in those test environments in conjunction with the ground experimentation capabilities. Furthermore, it includes the NASA expertise that helps ensure safe and successful use of the assets and high quality of the research outcomes. The project is cross-cutting and supports ARMD Strategic Thrusts 2, 3, and 4 as well as other Agency efforts and those of key industry partners.

HYPERSONIC TECHNOLOGY PROJECT

The development of new hypersonic capabilities is important for the country. In the near-term, application of hypersonics is likely to be on enhanced defense systems, but this could eventually expand to include improved access to space capabilities that would directly benefit NASA. NASA maintains unique specialized facilities and experts who will focus on key fundamental research areas that explore key challenges in high-speed flight. This project will coordinate closely with partners in the DoD so that

ADVANCED AIR VEHICLES PROGRAM

NASA can leverage their investment in flight activities to develop and validate advanced physics-based models and at the same time, the DoD can benefit from NASA expertise, analyses, testing capabilities and computational models. Focus areas for the project include high-speed propulsion systems, re-usable vehicle technologies, high-temperature materials, and systems analysis.

Program Schedule

Date	Significant Event
Sep 2016	RVLT – Complete component testing of a variable speed power turbine with potential to greatly improve turboshaft engine efficiency over a wide operating range.
Sep 2016	AATT – Complete an integrated analysis of advanced, candidate technologies contributing to a 1.5-2 times increase in the aspect ratio of a lightweight wing with safe flight controls and structures.
Dec 2016	AETC – Complete the second phase of test section improvements of the optical access, physical access, and the related support infrastructures designed in previous phases, which will enable advanced optical test techniques such as Pressure Sensitive Paint, Infrared Thermography, High Speed Schlieren, Model Deformation, and Particle Imaging Velocimetry to be routinely used in ARC Unitary Plan Wind Tunnel testing.
Sep 2017	AETC – Define the natural ice-crystal cloud environment in terms of altitude, temperature, ice water content, particle size, and morphology to guide the engine ice crystal ingestion testing in the Propulsion Systems Laboratory at NASA GRC.
Sep 2017	AETC – Complete the replacement of the facility control system and steady state data acquisition systems at both the GRC 8x6-Foot Supersonic Wind Tunnel and 9X15-Foot Low Speed Wind Tunnel to enable world-class steady state data capabilities including higher reliability, channel count, processing rates, analyses, improved plotting, a higher reliability, and more versatile control system.
Sep 2017	RVLT – Demonstrate a two-speed drive system for vertical lift applications that can operate with a 50 percent shaft speed change and efficiently transfer high torque with no weight penalty.
Sep 2017	RVLT – Complete functional checkout and assessment of the Tiltrotor Test Rig (TTR) to demonstrate a new test capability for high-speed vertical lift configurations.
Sep 2018	AATT – Complete fan model testing with a Single-Degree of Freedom (SDOF) and Multiple-Degree of Freedom (MDOF) in the NASA GRC 9x15 Foot Low Speed Wind Tunnel to provide significant improvement in the noise reduction capability of liners.
Sep 2018	AATT – Complete Tests of N+3 low-emission, fuel-flexible combustor concept

Program Management & Commitments

Program Element	Provider
Advanced Air Transport Technology (AATT)	Provider: ARC, Armstrong Flight Research Center (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, DLR, U.S. small business and universities
RVLT	Provider: ARC, GRC, LaRC Lead Center: LaRC Performing Center(s): ARC, GRC, LaRC Cost Share Partner(s): FAA, UTRC, U.S. Army, DLR, U.S. Navy, Sikorsky Aircraft, U.S. small businesses and universities
Commercial Supersonic Technology	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, Rockwell Collins, Lockheed Martin, Aerion Corporation, U.S. Navy, U.S. small businesses and universities
Advanced Composites	Provider: ARC, GRC, LaRC Lead Center: LaRC Performing Center(s): ARC, GRC, LaRC Cost Share Partner(s): Boeing, General Electric Aviation, Lockheed Martin, McNAIR, NIAR, NASA, United Technologies Corporation, Collier, Aurora, Orbital ATK, NIA, FAA, DoD
Aerosciences Evaluation and Test Capabilities	Provider: ARC, GRC, LaRC Lead Center: N/A Performing Center(s): ARC, GRC, LaRC Cost Share Partner(s): DoD
Hypersonic Technology	Provider: GRC, LaRC Lead Center: LaRC Performing Center(s): AFRC, GRC, and LaRC Cost Share Partners: DoD, Boeing, Lockheed Martin, Aerojet Rocketdyne, Orbital ATK, Northrup Grumman, Rolls Royce Liberty Works, SPIRITECH, ACENT, and Williams International

ADVANCED AIR VEHICLES PROGRAM

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	Nov 2016	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.	Nov 2017

INTEGRATED AVIATION SYSTEMS PROGRAM

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Low Boom Flight Demonstrator	0.0	--	**79.2**	88.3	80.0	45.8	30.0
Total Budget	**128.3**	**--**	**173.5**	**178.5**	**167.8**	**139.2**	**132.9**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

Building a series of X-Planes fueled by alternative energy, and that use half the fuel and are only half as loud, as well as the world's first "quiet" supersonic X-Plane, are under consideration for NASA's future development and flight campaigns.

One issue that NASA faces is bridging the gap between the maturity level of technologies developed through fundamental research and the maturity levels required before new technology can be incorporated into future air vehicles and operational systems.

The goal of 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 ARMD research, not just the culmination of research 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 UAS into the 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, and broadcasting. The FAA is developing new policies, procedures, and approval processes to address the increasing civil market. Developing and implementing new standards, procedures, and guidance to govern civil UAS operations in the NAS has become more important than ever. NASA's UAS Integration in the NAS project 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 leads the NAH initiative, a bold series of X-Plane demonstrations aimed at sustaining U.S. technological leadership in the aviation industry. The first X-Plane is the Low Boom Flight Demonstrator (LBFD) that will demonstrate quiet supersonic flight and open a new market to U.S. industry. The second

X-Plane is a subsonic demonstrator that will show significant fuel efficiency and help maintain U.S. leadership in the next generation of commercial aircraft. Due to the high profile nature of this activity, a separate section dedicated to the LBFD follows the IASP program description.

EXPLANATION OF MAJOR CHANGES IN FY 2018

None.

ACHIEVEMENTS IN FY 2016

Thrust 3: Ultra-Efficient Commercial Vehicles

Work conducted in the ERA project culminated in a Closeout Review in FY 2016. This review described the culmination of the ERA effort through Phase 2 ITDs as well as the overall benefit realized through next generation technology investigations conducted and assessed during the 6-year life of the ERA project. The NASA ERA project was the recipient of Aviation Week 2016 Laureate Award in the category of Technology with the UAS Integration in the NAS project being nominated as well. In FY 2016, NASA leveraged success from the ERA project, as well as other NASA Aeronautics initiatives, to begin multiple studies focused on informing the solicitation process for advanced configuration subsonic demonstrator aircraft. In addition to the aircraft configurations themselves, these studies help evaluate candidate technologies as well as novel methods for conducting flight demonstrations. In addition to conducting these studies, NASA also developed an initial roadmap for executing the Ultra-Efficient Subsonic Transport demonstrators to prepare for future decisions on these projects.

As with ERA, NASA conducted high-impact collaborations with multiple industry partners to better understand advanced configurations and associated impacts to reduce aircraft operational costs. NASA developed integrated system-level flight demonstration plans focused on the most promising technologies to assess feasibility of integrated benefits and to advance technology readiness levels. To this end and to inform New Aviation Horizons decisions, NASA conducted a risk reduction cockpit simulation aimed at increasing design maturity of an X-Plane configuration that is based on the Aurora’s D8 aircraft concept which has a wide fuselage to provide lift and engines mounted on the top of aircraft in the tail section. The simulation objective was to evaluate ability to land the X-Plane with highly restricted forward visibility and to provide pilot evaluations supporting recommendation on nose camera safety criticality.

NASA also began a series of flight demonstrations to both mature and transfer new aircraft technologies to U.S. industry. These technologies include: X-56 Light Weight Flexible Wing; Adaptive Compliant Trailing Edge Flaps for Noise Reduction; and Landing Gear Noise Reduction. In order to demonstrate these technologies, NASA selected the most appropriate assets available (NASA, other Government agencies, industry, or international partners) to support the chosen technology demonstrations. These technologies further capitalize on successful technology development from the ERA project.

Thrust 6: Assured Autonomy for Aviation Transformation

Automation continued to transform the civil aviation industry and is a rich area for continual research. NASA seeks to forge applications of automation in aircraft operations and air traffic management, and generate validated data through testing for regulatory bodies. NASA developed technologies and concepts that promote safety, reliability, and future economic development. The use of analysis, simulation, and flight testing furthered the integration of UAS in the NAS for commercial, science, security, and other uses. In FY 2016, NASA delivered data, analysis, and recommendations, based on two flight test series with simulated traffic and live vehicles to the Radio Technical Commission for Aeronautics (RTCA) Sub-Committee 228 on Minimum Operational Performance Standards (MOPS) for unmanned aircraft systems. This effort was critical to the success of RTCA’s effort and the standards necessary to achieve UAS integration into the NAS. The planned progression of the flight test campaign demonstrated high levels of technology integration and higher complexity of test conditions. The testing integrated UAS and manned aircraft with ground control stations and air traffic data. The integration of UAS in the NAS included three major flight test campaigns to demonstrate detect and avoid, command and control and advanced ground control station display technologies in a flight environment representing the NAS using the Live, Virtual, Constructive, Distributive Environment (LVC-DE). The LVC-DE is a virtual simulation and flight test environment used to provide realism in demonstrating actual system capabilities.

WORK IN PROGRESS IN FY 2017

Thrust 3: Ultra-Efficient Commercial Vehicles

The Flight Demonstrations and Capabilities (FDC) project continues to collaborate with Aurora Flight Sciences to validate operational benefits and any aircraft integration challenges. This is done by assessing the D8 configuration by completing a Conceptual Design Review of the aircraft configuration and a Preliminary Design Review for the aircraft structure. These reviews are key elements to understand the feasibility and risks associated with pursuing a flight demonstration of this unconventional configuration.

In FY 2017, ACTE II sub-project of FDC will complete the Adaptive Compliant Trailing Edge (ACTE) II and Landing Gear Noise Reduction Flight experiments. These will serve to further verify aerodynamic characteristics, as well as noise reduction benefits, of the ACTE flap, originally shown feasible in flight under the ERA project.

In addition, multiple studies associated with advanced concept subsonic aircraft configurations are being used to develop system requirements that could inform the solicitation process for one or more Ultra-Efficient Subsonic Transport (UEST) Demonstrator aircraft. In addition to providing NASA insight to understand the nuances of each configuration, the studies also enable identification of risk reduction activities needed for the success of each demonstrator. NASA also continues to facilitate small flight demonstrations, maintain capabilities that make assets available for flight experiments, and develop/maintain the ARMD flight test roadmap. Continuing these practices aids in making informed decisions regarding new flight demonstrations.

Thrust 4: Transition to alternative propulsion and energy

NASA is currently developing the X-57 Maxwell, a general aviation-scale aircraft to test highly integrated distributed electric propulsion technology. This demonstration is an important first step toward assessing the benefits and challenges of operating more electrified aircraft. In FY 2017, the FDC X-57 Subproject conducted Mod II battery system integration using a mockup. In addition, a CDR was conducted on the X-57 Mod III wing. These events are key contributors in preparation for flight testing planned for FY 2018.

Also in FY 2017, NASA is releasing an RFI to solicit industry ideas for electrified aircraft propulsion X-Planes to follow the X-57.

Thrust 6: Assured Autonomy for Aviation Transformation

In FY 2017, the UAS Integration in the NAS project will close out Phase 1 in parallel with the execution of Phase 2. The final delivery of inputs to the Phase 1 Detect and Avoid Minimum Operational Performance Standards (MOPS) was completed this fiscal year to the RTCA Special Committee 228. The MOPS will enable the FAA to develop Technical Standard Orders so that Industry can build flight hardware for initial steps to integrate UAS into the NAS.

In addition, the UAS-NAS project works with the FAA to flight test the Airborne Collision Avoidance System (ACAS) – Xu. The ACAS is the replacement for the TCAS and ACAS Xu is designed specifically for UAS. The flight test will benefit the FAA and Industry in the steps to integrating UAS into the NAS.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

Thrust 3: Ultra-Efficient Commercial Vehicles

In FY 2018, NASA will focus on the Landing Gear Community Noise to demonstrate novel landing gear porous fairing and wheel cavity treatments. The goal is to reduce the airframe component of community noise by 1.5 PLdB [Perceived Level (PL), decibels (dB)] or approximately 30 percent with minimal impact on aircraft weight and performance, and validate an advanced, physics-based methodology for the accurate prediction of airframe noise.

In addition, the FDC project will conduct a Preliminary Design Review of a flight demonstration to validate technologies to improve the performance of Ultra-High Bypass (UHB) Engine Nacelles. An engine nacelle is the housing, separate from the fuselage, which holds engines, fuel, or equipment on an aircraft.

Thrust 4: Transition to alternative propulsion and energy

In FY 2018, X-57 will conduct flights in the Mod II configuration. These flights represent a crucial step in the flight test process as the conventional fuel engines will be replaced with electric motors and the electrical storage and power distribution systems needed for all-electric flight. Thereafter, the Mod III wing will be delivered, and the X-57 aircraft will be modified to the Mod III configuration that includes integration of the newly designed, high-aspect ratio wing. This will enable demonstration of cruise efficiency gains that are anticipated for the X-57 during the Mod III flights planned for FY 2019.

Thrust 6: Assured Autonomy for Aviation Transformation

During FY 2018, the UAS-NAS project will continue the development of Phase 2 MOPS. As a key part of this development, the project will work with Industry to develop an alternative airborne surveillance sensor system for mid-size UAS. The sensor will be designed to be Low Size, Weight, and Power (Low SWaP) due to the size constraints for a mid-size UAS. RTCA SC-228 will be the primary stakeholder to develop a MOPS for the sensor. The sensor will then be flight tested to validate the simulations.

INTEGRATED AVIATION SYSTEMS PROGRAM

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.

The UAS-NAS project approach is to contribute 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 ran through the end of FY 2016. The primary focus of the Phase 1 work was the development of research findings, through a series of demonstrations and simulations, to enable development of DAA and Command and Control (C2) MOPS by RTCA for large UAS.

The Phase 2 effort is currently underway and will be completed in FY 2020. During Phase 2, the project will focus on the development of research findings, through a series of demonstrations and simulations, to enable Phase 2 DAA MOPS development to expand operations to other classes of UAS. In addition, C2 MOPS development will consider the use of Satellite Communications (SatCom) in multiple bands as a C2 Data Link to support 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 will validate benefits associated with critical technologies through focused flight experiments. As part of the FDC project, NASA will demonstrate the feasibility and maturity of new technologies through flight tests, utilizing collaborative partnerships from across the aeronautical industry, and include 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, regardless of whether the capabilities and assets are available from NASA, through other Government agencies, or from industry, the FDC project will 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 will be at relatively high TRLs, the FDC project will support all phases of technology maturation.

The FDC project will utilize 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 will also utilize flight research and test capabilities across the U.S. aeronautical industry and international partners as appropriate.

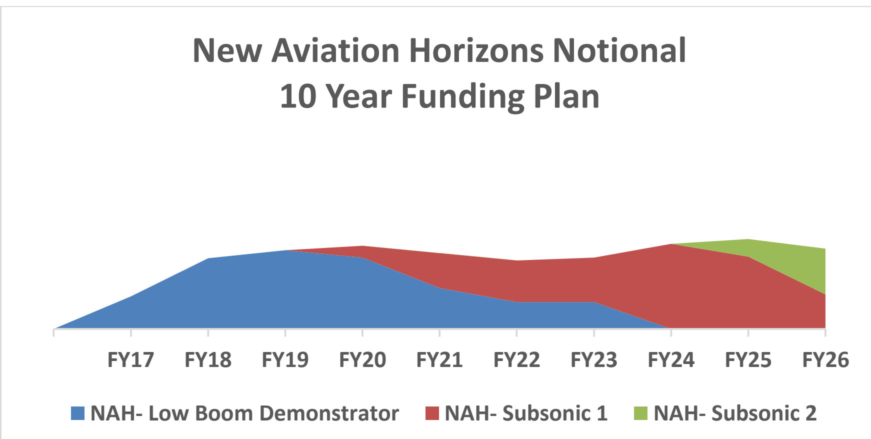
INTEGRATED AVIATION SYSTEMS PROGRAM

NEW AVIATION HORIZON (NAH) INITIATIVE

IASP leads the NAH initiative, a bold series of X-Plane demonstrations aimed at sustaining U.S. technological leadership in the aviation industry. The first X-Plane is a Low Boom Flight Demonstrator (LBFD) that will demonstrate quiet supersonic flight and open a new market to U.S. industry. The second X-Plane is planned to be a subsonic demonstrator that would show significant fuel efficiency and help maintain U.S. leadership in the next generation of commercial aircraft.

NASA awarded a contract to Lockheed Martin for the preliminary design of a LBFD. In addition, NASA has just recently awarded contracts for Ultra-Efficient Subsonic Technology (UEST) system requirements studies with Boeing, Aurora Flight Sciences, Dzyne Technologies, and Lockheed Martin. Results from these studies will inform the competitive solicitation of preliminary design efforts for UEST X-Planes (both Integrated and Purpose Built UEST). The design studies will be coordinated with AAVP ground experiments on key technology enablers. This preliminary work will position NASA to be able to begin work on a subsonic demonstrator project as early as FY 2020.

The X-Plane project life cycle includes phases for concept development, preliminary design, design and build, and flight test. As a project enters each life cycle phase, the budget will be updated, reflecting higher confidence levels resulting from more precise technical and schedule requirements and improved contractor cost estimates. The chart below shows notional phasing of X-Planes over the next 10 years. Detailed cost estimates for future X-planes will become available as designs mature, test plans evolve, and partnerships with industry develop. However, the chart demonstrates that, with modest adjustments to other programs in the NASA Aeronautics portfolio, a series of experimental X-planes is achievable under the funding levels requested for FY 2018 and the funding levels depicted in the notional out years.



NAH-LOW BOOM FLIGHT DEMONSTRATOR (LBFD)

The goal of the NAH-LBFD project is to overcome the sonic boom barrier and pave the way for eventual over-land supersonic flights. The primary objectives of the NAH-LBFD are two-fold: flight validation of design tools and technologies applicable to low sonic boom commercial supersonic aircraft, and creation of community response data that will support the development of a noise-based standard for supersonic overland flight. NAH-LBFD will provide the tools and database that enables regulatory agencies to lift the current prohibition on overland supersonic flight.

INTEGRATED AVIATION SYSTEMS PROGRAM

Program Schedule

Date	Significant Event
Jan 2016	ERA – Complete close-out activities for the ERA project
May 2016	FDC – Conduct Concept Design Review for Landing Gear Fairings
Nov 2016	UAS-NAS – Deliver data, analysis, and recommendations based on integrated simulation and flight test series with simulated traffic or live vehicles to the RTCA Special Committee for UAS to support development of the final MOPS
Aug 2017	FDC – Complete Flight Readiness Review (FRR) for X-56
Mar 2017	FDC – Complete Mod III Wing Delta CDR for X-57
Mar 2017	NAH – Complete System Requirements Definition and Mission Concept Review for UEST
May 2017	UAS-NAS – Conduct UAS-NAS Phase 2 Key Decision Point (KDP)-C Review
Jun 2017	FDC – Conduct D8 Concept Design Review
Dec 2017	CFDC – Complete Phase 1 Flights for X-56

Program Management & Commitments

Program Element	Provider
UAS Integration in the NAS	Provider: ARC, AFRC, GRC, LaRC Lead Center: AFRC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): TBD
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

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.

INTEGRATED AVIATION SYSTEMS PROGRAM

MAJOR CONTRACTS/AWARDS

NASA's Aeronautics programs award multiple smaller contracts which are generally less than $5 million. However, contracts for the final design and construction of X-planes will be substantially larger, depending on the scale and complexity of the plane. Smaller contracts are widely distributed across academia and industry. All design and build contracts will be widely competed through full and open competitions.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Expert Review	Dec 2016	The 12-month review is designed for the purpose of tracking and documenting the Program's progress made towards the Strategic Thrusts and Outcomes during the fiscal year.	The Review Panel expressed "kudos" for the good work done by all projects within IASP to remain relevant to its stakeholders. There were no findings.	Dec 2017

IASP - NAH- LOW-BOOM FLIGHT DEMONSTRATOR

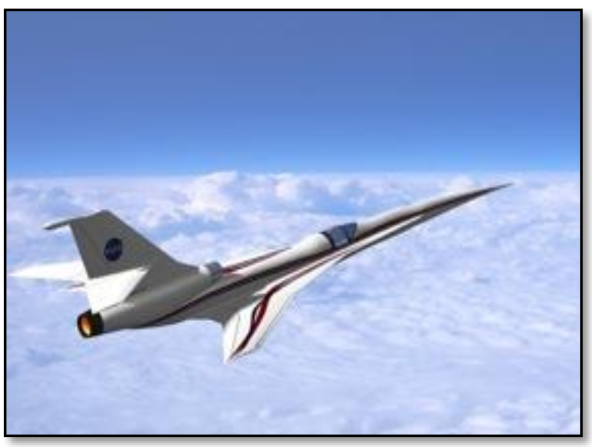
Formulation	Development	Operations

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	0.0	--	79.2	88.3	80.0	45.8	30.0

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



The LBFD concept is in the preliminary design phase and on its way to being the world's first quiet supersonic aircraft.

PROJECT PURPOSE

Over the past decade, fundamental research and experimentation has demonstrated the possibility of supersonic flight with much reduced sonic boom noise. The LBFD X-Plane will demonstrate these advancements in flight by utilizing a purpose-built experimental aircraft. It will provide validation of design tools and technologies applicable to low sonic boom aircraft and create a database of community response information supporting the development of a noise-based standard for supersonic overland flight.

The LBFD project will be executed in two distinct phases, with a third phase envisioned as a follow-on activity. Phase 1 includes the LBFD aircraft development activities, 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 will conclude with an initial community response overflight study to validate community test designs and explore initial community acceptance of low-boom noise. For the Phase 3 follow-on, a NASA-led team will conduct low-boom community response overflight studies with multiple test campaigns using the LBFD aircraft over varied locations. The ultimate goal of Phase 3 will be 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.

IASP - NAH- LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2018

None.

PROJECT PRELIMINARY 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 considerable improvement over the Concord's level of 105 PLdB. Although the aircraft will be smaller in size than 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.

ACHIEVEMENTS IN FY 2016

In FY 2016, the Aircraft System Requirements Review (ASRR) and Key Decision Point (KDP) A/B were successfully completed for the LBFD project. The ASRR assessed whether the baseline requirements, concept preliminary design, and formulation and planning documentation were mature enough to proceed towards a Preliminary Design Review (PDR). The LBFD project initiated the preliminary design for a low boom demonstrator aircraft that will culminate in a PDR in FY 2017.

WORK IN PROGRESS IN FY 2017

NASA will complete a PDR for the LBFD aircraft, which was awarded to Lockheed Martin in 2016. The design will be the most complete, practical concept of a low-boom supersonic aircraft ever conceived. The PDR will be a key input to an upcoming solicitation for the final design and build of the LBFD aircraft. PDR completion is also required prior to conducting KDP-C that is planned for August 2017. Successful completion of KDP-C will validate plans for execution phase of the LBFD project.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

In FY 2018, after the preliminary design is complete and pending a budget decision, NASA will award a contract for the LBFD detailed aircraft design, build, test, and flight validation. This demonstrator will be used to collect the flight and community response data necessary to establish overland supersonic noise regulations.

IASP - NAH- LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

ESTIMATED PROJECT SCHEDULE

Milestone	Formulation Authorization Document	FY 2017 PB Request
Formulation Authorization	Sep 2016	Sep 2016
KDP-B	Aug 2016	Aug 2016
ASM	Nov 2016	Dec 2016
PDR	Jun 2017	Jun 2017
KDP-C	Late Summer 2017	Aug 2016
Delta PDR		Jun 2018
CDR		May 2019
KDP-D		Aug 2019
FRR		July 2020
First Flight		Oct 2020

IASP - NAH- LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

Formulation Estimated Life Cycle Cost Range and Schedule Range Summary

The Formulation Authorization Document (FAD) documents the LBFD project cost at approximately $290 million over 4 years during the aircraft design and build phase, and excludes costs associated with PDR. The total lifecycle cost of $390 million includes 3 additional years of acoustic validation and community response flight. The KDP A/B Review showed a slight increase to LCC of approximately $5.0 million.

The LBFD project will officially baseline the cost after the contract is in place, and after KDP-C. A delta baseline review will occur subsequent to KDP-C to formally baseline the project.

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
Aug 30, 2016	390–395	First Flight	Oct 2020

Project Management & Commitments

Element	Description	Provider Details	Change from Formulation Agreement
NAH - LBFD		Provider: ARC, AFRC, GRC, LaRC Lead Center: None or TBD Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): TBD	N/A

IASP - NAH- 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 OML 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 (GFE) 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	TBD	TBD

IASP - NAH- LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Independent Review Team (IRT)	Jun 2016	Aircraft System Requirements Review	Successfully Completed	Jun 2017
Performance	LBFD Independent Review Board (IRB)	Jun 2017	PDR	TBD	Jun 2018
Performance	LBFD IRB	Jun 2018	Delta PDR	TBD	May 2019
Performance	LBFD IRB	May 2019	CDR	TBD	Jul 2020
Performance	LBFD IRB	Jul 2020	FRR	TBD	N/A

TRANSFORMATIVE AERO CONCEPTS PROGRAM

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	103.5	--	109.2	114.5	116.3	140.7	139.9

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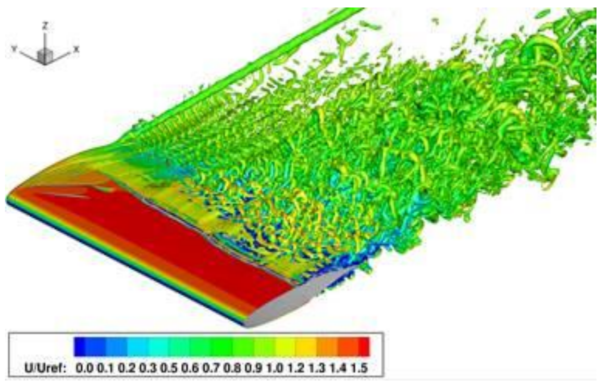

Shown above is airflow over a wing.

Physics-Based Turbulence Models & Simulations: Identify and downselect critical turbulence, transition, and numerical method technologies for 40 percent reduction in predictive error against standard test cases for turbulent separated flows, evolution of free shear flows, and shock-boundary layer interactions on state-of-the-art high performance computing hardware.

TACP cultivates multi-disciplinary, revolutionary concepts to enable aviation transformation. ARMD’s strategic analysis has identified challenges in the global demand for mobility, significant energy and sustainability, and ongoing affordability issues, for which technology can be a key part of the solutions. TACP fosters innovative solutions to these problems, 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 internally- and externally-originated concepts into all six ARMD strategic research thrusts, creating innovation for the aviation system.

Using sharply focused activities, the program provides flexibility for innovators to explore technology feasibility and provide the knowledge base for radical transformation. 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 ideation into new concepts. TACP also places attention on computational and experimental tools that are critical for supporting technology development and enabling aviation transformation. Therefore, the program’s investments are in never-done-before areas that can provide paradigm-shifting analysis and experimental capabilities. Further, the program addresses the technical barriers that need to be overcome in order to realize the potential for aviation transformation via applications of autonomy. All of this research is done while aggressively engaging the traditional aeronautics community as well as non-traditional partners through public-private partnerships.

Across all ARMD programs, NASA researchers are developing innovative capabilities to advance the strategic thrusts and enable their outcomes. TACP challenges and supports the realization of the thrust outcomes with early stage innovations and with revolutionary technologies and methods.

TRANSFORMATIVE AERO CONCEPTS PROGRAM

EXPLANATION OF MAJOR CHANGES IN FY 2018

None.

ACHIEVEMENTS IN FY 2016

NASA developed next-generation, high-performance, computational methods and tools that have the potential to dramatically reduce the cost and error in simulating complex turbulent flows. The Transformational Tools and Technologies (TTT) project completed wind tunnel tests to evaluate new methods to predict the effect wing design has on airflow separation. The tests validated the predicted results. Improving simulation methods and tools allows researchers to evaluate new designs in a fraction of the time required by current methods.

NASA matured technologies using high temperature materials to address the needs of future air vehicles and propulsion systems. NASA characterized the structural properties of a new generation ceramic matrix composite architecture and optimized an innovative process for applying the thin, smooth, durable environmental coating to a turbine airfoil subcomponent. TACP demonstrated the durability of the new subcomponent at the desired turbine engine conditions (fatigue loading, temperature, and water vapor).

NASA completed a study of low-cost, fast-turnaround methods for obtaining realistic vehicle performance and flying quality data in flight research. Several methods were explored, including towing an X-Plane, and other innovations in flight research vehicle design and fabrication. TACP transferred the results of this research to the ARMD flight demonstration planning teams increasing the probability of success during ARMD’s early design, fabrication, and flight research stages.

NASA completed an initial feasibility assessment of the Distributed Electric Propulsion (DEP) concept which has the potential for significant reductions in aircraft emissions, noise, and operating cost. Preparations for flight-testing began by initiating 2nd generation wing and electric cruise motor design and fabrication. With successful feasibility shown, the CAS research team also successfully transitioned the activity to the ARMD IASP where all further activity will be managed, including the flight test to assess the feasibility of the DEP concept to provide high-speed cruise efficiency. Further, the flight test article being developed for flight testing the DEP concept was giving official X-Plane status by the USAF, designated as X-57 Maxwell.

NASA initiated a prize competition intended to engage the U.S. computational community and develop faster methods to solve the non-linear partial differential equations used in key simulations of aeronautics-specific fluid dynamics. The goal is to speed up calculations by a factor of 100 to 1,000 times without resorting to custom hardware. The goal of faster calculations on standard hardware would enable fast, cost-effective iterations while evaluating aircraft design changes, resulting in better designs in both a typical as well as in an accelerated aircraft development cycle.

WORK IN PROGRESS IN FY 2017

NASA will mature critical turbulence models and numerical methods for separated flows that provide a 40 percent reduction in predictive error against standard test cases. Current fluid models continue to be unreliable in representing turbulent flow regions (including separated flows). These limitations have prevented the broader use of numerical modeling for aircraft design, leading to higher costs and less than optimal designs. NASA’s turbulence models are one key contribution to the CFD 2030 Vision, a collaborative effort recently established by leading fluid dynamics experts from government, industry, and academia. After demonstration and validation with the community, NASA will use these advanced computational models, in collaboration with industry, to meet ambitious fuel efficiency goals associated with fundamentally new aircraft and propulsion systems and to enable faster and more efficient design processes.

NASA will demonstrate a high-temperature material system for turbine engine components that enable a 6 percent reduction in fuel burn while meeting 2700 F use temperature and durability metrics. Higher temperature materials reduce the amount of cooling needed in engine turbines, improve fuel efficiency, lower operating cost, and reduce emissions. As part of this effort, NASA has been collaborating with a U.S. engine company to advance these high-temperature ceramic matrix composites (CMC) materials. The company plans to incorporate CMCs into the hot section of a new engine that will power the next generation of commercial airplanes.

NASA will complete feasibility assessments for several activities within CAS project. Given the challenging nature of CAS activities, many technologies will not demonstrate feasibility, but NASA will use all results from the assessments to guide future investments and to provide essential knowledge that can benefit all ARMD programs. In one CAS activity, NASA will show the how historically extensive and complex engineering tools can be applied to the conceptual design of small and novel vertical lift vehicle configurations, while at the same time augmenting those tools with advancements in noise, automation, and propulsion technologies. This is expected to be an enabler for future acoustic-aware, autonomous, vertical-lift vehicle research and development. In another activity, NASA will evaluate a set of “smart apps” for autonomous UAVs in flight. If successful, these apps can provide a low barrier to entry for prospective software developers, while also providing capabilities that allow autonomous UAVs to behave like certified pilots. In a third activity, NASA will complete feasibility testing of an innovative aircraft design and build concept that merges digital manufacturing, light-weight materials, and novel flight control techniques. This concept has the potential to enable new aircraft designs that are quieter and more fuel efficient, while greatly reducing manufacturing costs.

NASA will execute the first competitive University Leadership Initiative awards under the UIC Project. These awards are the result of university leaders independently analyzing the technical barriers inherent in achieving ARMD’s strategic outcomes, and proposing set of multi-disciplinary technical challenges along with supporting activities to address those barriers.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

NASA will continue progress toward improved turbulence modeling and achieving a 40% reduction in predictive error against standard test cases by completing a major wind tunnel experiment. In this experiment, researchers will take detailed measurements of the flow near the wing-body junction of an aircraft. The complex turbulent flows occurring around this region cannot be accurately represented by today’s computational tools. Understanding these flows will greatly improve the quality of computational models, thereby having a positive impact on the design of future aircraft. The experiment will provide a complete validation dataset, including upstream boundary conditions, detailed measurements of the separated flow region, and off-body turbulence measurements. At a following workshop with industry and academia, NASA will explore the advanced computational tools and experimental data, and together the community will validate the quality of high-fidelity, physics-based turbulence modeling.

TRANSFORMATIVE AERO CONCEPTS PROGRAM

NASA will complete feasibility assessments for four activities in the CAS project. In one activity, new technologies including solid-oxide fuel cells may provide a path toward a viable hybrid-electric power system for commercial aircraft. In a second activity, NASA will assess the feasibility of a “span-wise adaptive wing.” If successful, this wing can be commanded to change shapes in flight. The ability to re-configure the wing would allow a smaller-sized rudder, reduced vehicle weight, and improved flight efficiency. Another revolutionary concept would allow the aircraft structure itself to store energy. A transformative multi-functional airframe material would enable necessary structural components to contribute toward the aircraft’s power and propulsion systems. The weight savings incurred by combining these two systems would greatly improve fuel efficiency. Finally, a fourth concept will try to overcome a key barrier in enabling electric propulsion for commercial aircraft. Distributing power across these aircraft currently requires heavy and inefficient mechanical and electrical systems. If successful, the concept will leverage new technologies in high-voltage, variable drive systems to reduce the size and weight of needed equipment.

Program Elements

CONVERGENT AERONAUTICS SOLUTIONS

The CAS project performs rapid feasibility assessments of early-stage innovations that challenge existing technical approaches, create alternate paths to solutions, or enable new strategic outcomes. The 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 whether the developed solutions have met their feasibility goals, or 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. In a dynamic environment of early stage innovation, NASA obtains significant value from the new knowledge gained and widely disseminates it among the aeronautics community at large.

TRANSFORMATIONAL TOOLS AND TECHNOLOGIES

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 will provide first-of-a-kind capabilities to analyze, understand, and predict performance for a wide variety of aviation concepts. Applying these revolutionary tools will enable and accelerate NASA’s research and the community’s design and introduction of advanced concepts. Examples include 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 broadly critical to advancing ARMD strategic outcomes, such as: understanding new types of strong and lightweight materials; innovative controls techniques; and experimental methods. Such technologies will support and enable concept development and benefit assessment across multiple ARMD programs and disciplines.

TRANSFORMATIVE AERO CONCEPTS PROGRAM

UNIVERSITY INNOVATION AND CHALLENGES

The University Innovation and Challenges (UIC) project contains a portfolio of disruptive technologies and other entirely new concepts in order to meet the challenging goals established for each strategic thrust established by ARMD. The project utilizes NASA Research Announcement (NRA) solicitations where university-led teams are asked to assess the most critical technical challenges that must be solved to achieve the SIP strategic outcomes; and to propose independent, innovative research projects to solve those technical challenges, including developing the success criteria, progress indicators, and technical approach. It is expected that multi-faceted solutions to these complex technical challenges will involve high technical risk, multi-disciplinary approaches, industry partnerships, and that they will provide opportunities to work on challenging problems that inspire the next generation of U.S. aeronautics engineers. The competitively-selected research activities will open alternate avenues for accelerated progress by ARMD and the aerospace community toward the strategic outcomes, and will leverage new thinking and foster development of the next-generation workforce critical to the long-term development of low carbon aviation.

Also utilized are challenges and prizes issued to the broad external community to catalyze external investments toward solving problems aligned with ARMD’s strategic interests. Funded challenges and prizes on specific needs will be designed to attract and incentivize non-traditional entities (e.g., low carbon air transport systems would involve companies in energy storage/batteries and electric motor manufacturing).

Program Schedule

Date	Significant Event
Mar 2017	UIC project will make University Leadership Initiative (ULI) Awards
Sep 2017	CAS Activities – Design Environment for Novel Vertical Lift Vehicles (DELIVER), Mission Adapt Digital Comp AeroTech (MADCAT), Digital Twin and Learn2Fly to Close Out/Transition
Sep 2017	TTT TC2 – High-Temperature Materials for Turbine Engines completes
Dec 2017	CAS Activity – Autonomy Operating Systems for UAV (AOS4UAV) to Close Out/Transition
Mar 2018	CAS Activities – High Voltage Hybrid Electric Prop (HVHEP) and Multifunction Structure Energy Storage (M-SHELLS) to Close Out/Transition
May 2018	TTT TC1– Revolutionary Computational Aerosciences (RCA) completes

TRANSFORMATIVE AERO CONCEPTS PROGRAM

Program Management & Commitments

Program Element	Provider
CAS	Provider: ARC, GRC, LaRC, AFRC Lead Center: GRC Performing Center(s): ARC, GRC, LaRC, AFRC Cost Share Partner(s): JOBY Aviation, PCKrause & Associates, National Institute of Aerospace, Boeing, AFRL, ESAero, Tecnam MTProp, Launch Point, Cape Air, Straight Up Imaging, DoT Volpe, Moog Inc., IDEO, Idea Couture, Tecolote Research Inc., AFRL, WP AFB, Universities
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
UIC	Provider: N/A Lead Center: HQ Performing Center(s): N/A 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.

TRANSFORMATIVE AERO CONCEPTS PROGRAM

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	ARMD Mission Program Directors	No previous review	Review of initial CAS project activities to determine whether they have met their goals, established initial feasibility, and identified potential for future aviation impact.	Expected result is the identification of the promising capabilities for further development by other ARMD programs or for direct transfer to the aviation community.	TBD
Performance	Expert Review	Nov 2016	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 2017

SPACE TECHNOLOGY

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Agency Technology and Innovation	31.5	--	**31.9**	31.9	31.9	31.9	31.9
SBIR and STTR	200.9	--	**180.0**	180.0	180.0	180.0	180.0
Space Technology Research and Development	454.0	--	**466.7**	467.4	467.4	467.4	467.4
Total Budget	**686.4**	**686.5**	**678.6**	**679.3**	**679.3**	**679.3**	**679.3**

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SPACE TECHNOLOGY

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Agency Technology and Innovation	31.5	--	**31.9**	31.9	31.9	31.9	31.9
SBIR and STTR	200.9	--	**180.0**	180.0	180.0	180.0	180.0
Space Technology Research and Development	454.0	--	**466.7**	467.4	467.4	467.4	467.4
Total Budget	**686.4**	**686.5**	**678.6**	**679.3**	**679.3**	**679.3**	**679.3**
Change from FY 2017			**-7.9**				
Percentage change from FY 2017			**-1.2%**				

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The Deep Space Atomic Clock is ready for flight in 2017. Moving hardware from the laboratory to space meant conquering a number of technological challenges, including achieving unprecedented performance with substantial power and size reduction. One potential future use for the Deep Space Atomic Clock is using the technology to help investigate possible undersea oceans within Europa—a moon of Jupiter. Sharing a ride on the Orbital Test Bed satellite owned by Surrey U.S., the Deep Space Atomic Clock will undergo a year-long shakeout in space.

Space Technology conducts rapid development and infusion of transformative space technologies that increase the Nation’s capabilities and further NASA's drive to discover, explore, develop and enable. Managed by the Space Technology Mission Directorate, the strategy and corresponding investments within this portfolio are guided by the following themes:

- Expanding utilization of near-Earth space;
- Developing efficient and safe transportation through space;
- Increasing access to planetary surfaces;
- Enabling humans to live and explore on planetary surfaces;
- Enabling the next generation of Science missions; and
- Growing and utilizing the U.S. industrial and academic base.

These themes allow for further definition of thrust areas, which define targeted technology challenges with desired outcomes. A driving requirement of the STMD strategy is to the shared interests of stakeholders, customers, and partners from across the Nation to develop technology that dramatically enhances current U.S. space capabilities by increasing performance, reducing technological risk, and increasing affordability and reliability. This approach includes technologies that enable capabilities for the U.S. space industry, other government agencies, NASA’s future science missions, and human spaceflight endeavors within and beyond low-Earth orbit. To provide a framework for content generation and to better inform the formulation of the crosscutting technology portfolio, STMD developed quantified performance metrics with corresponding investment strategies. The quantified capabilities define targeted performance requirements, partnership opportunities, and investment pathways that provide maximum flexibility to meet technology development requirements. For example, by quantifying the need to land a 20-ton payload on the Mars surface in support of human exploration class missions, Entry, Descent, and Landing technology investment strategies have been refined, focused, and optimized.

To advance these critical technologies, NASA develops technology utilizing a broad and diverse set of researchers and technologists from industry, academia, small businesses, other government agencies, individual entrepreneurs, and NASA centers. By engaging the brightest minds on the toughest technological challenges, NASA spurs innovation throughout the aerospace economy.

U.S. technological leadership is 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 fuel our Nation's economic engine for decades to come.

For more on Space Technology, go to: http://www.nasa.gov/spacetech.

EXPLANATION OF MAJOR CHANGES IN FY 2018

STMD will transition the Restore-L project to reduce its cost and better position it to support a nascent commercial satellite servicing industry. In addition, this project will support technologies that feed into NASA's science and exploration missions. STMD will pursue collaborations with the Defense Advanced Research Projects Agency and industry to most effectively advance satellite servicing technologies and ensure broad commercial application.

ACHIEVEMENTS IN FY 2016

Space Technology made notable progress in fiscal year 2016, particularly with work on high-power Solar Electric Propulsion – an enabler for cost-effective deep space exploration. The project completed development and testing of the prototype engine at NASA's Glenn Research Center. NASA has contracted with Aerojet Rocketdyne to develop the flight system. In addition, both Space Systems Loral and Orbital ATK are transitioning solar array technology into commercial applications.

The Green Propellant Infusion Mission hardware was delivered for launch on the U.S. Air Force's Space Test Program (STP-2) mission. This mission will test the distinctive quality of a high-performance, non-toxic, "green" fuel in orbit. The mission's green propellant is significantly less toxic than hydrazine, will reduce spacecraft processing costs, and has approximately 40 percent higher performance by volume than hydrazine. This mission also includes the first flight of a novel thermal insulation material developed by Aspen Aerogels, a small business located in Massachusetts. Aerojet Rocketdyne, builder of the spacecraft thrusters, is now marketing the novel thrusters as a commercial product. The aerospace firm is also working with NASA's Glenn Research Center to further enhance the thrusters to reduce cost and improve reliability.

In 2016, STMD leveraged public-private partnerships by awarding nine cost sharing contracts, with at least 25 percent funded by industry partner(s), and 13 Space Act Agreements (where NASA provides technical support and/or facilities for testing) to develop emerging technologies in the areas of in-space robotic manufacturing and assembly, small spacecraft subsystems, small launch vehicle rocket engines, and advanced structures for small boosters.

NASA continued to accelerate and increase the number of NASA developed technologies transferred to industry. Patent licenses were up 41 percent, and software licenses were up 25 percent.

WORK IN PROGRESS IN FY 2017

Among a host of STMD-supported activities, FY 2017 will see flight of small satellites to demonstrate several technologies enabling NASA and industry applications of these systems. The Optical Communications and Sensory Demonstration satellite will flight test optical laser communications. In addition, the Integrated Solar Array and Reflectarray Antenna will demonstrate advanced communications and the CubeSat Proximity Operations Demonstration will demonstrate autonomous rendezvous and docking capabilities for small spacecraft.

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. NASA's Jet Propulsion Laboratory (JPL) oversees project development of DSAC, which offers the promise of 50 times greater accuracy than today's best navigation clocks. The DSAC development team has successfully overcome many technical challenges, representing a STMD tenet to accept reasonable risk while pushing technology development. The DSAC demonstration unit is a hosted payload on a spacecraft provided by Surrey Satellite Technologies U.S. of Englewood, Colorado, lofted spaceward as part of the U.S. Air Force STP-2 mission aboard a SpaceX Falcon Heavy booster. Riding along with Space Technology's Green Propellant Infusion Mission, the launch of both are slated for late 2017.

Laser Communication Relay Demonstration successfully entered into the implementation phase to support a 2019 Launch Readiness Date. Set to fly as a hosted payload on the Air Force STPSat-6 mission, this technology demonstration 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 (TDRS) satellites or by other government agencies and commercial space communications providers.

Following up on pre-formulation activities in FY 2016, the in-space robotics satellite servicing team will establish the requirements, goals, and complete the preliminary design for Restore-L, a technology demonstration mission capable of servicing a U.S. government satellite in low-Earth orbit. The Agency will begin exploring a collaboration with the Defense Advanced Research Agency (DARPA) and industry to enable a flight demonstration. STMD will start Phase B before the end of FY 2017. The FY 2018 Budget proposes restructuring this mission to reduce its cost and better position it to support a nascent commercial satellite servicing industry.

The directorate is investing in high-priority technologies to enable Mars and outer planetary exploration, including high performance spaceflight computing, autonomous and hazard avoidance landing, all terrain robotics, extreme environment solar power, and advanced materials (Bulk Metallic Glass) to improve rover mobility performance at low temperatures.

Led by JPL, Deep Space Optical Communications technology will provide high bandwidth communications for deep space on an upcoming Discovery Program mission. In FY 2017, Space Technology will complete ground testing of the technology to retire risk for its demonstration flight. The Psyche Mission, selected early FY 2017, will fly to a metallic asteroid, testing laser communications along the way. In partnership with Science, Space Technology also has incentivized heat shield technology through the recently released Discovery 2016 solicitation.

NASA selected the Boeing Company in St. Louis for the High Performance Spaceflight Computing Processor contract. This processor will provide 75 times the computing power over the current state-of-the-art radiation hard computers while enabling more effective power and fault management. Boeing will provide prototype radiation hardened multi-core computing processor Chiplets, system software which will operate on them, and evaluation boards to allow Chiplet test and characterization.

Space Technology selected two Space Technology Research Institutes led by a consortium of universities that will focus on the development of technologies critical to extending human and robotic presence deeper into our solar system. These institutes will bring together researchers from various disciplines and organizations to collaborate on the advancement of cutting-edge technologies in bio-manufacturing and high performance space structures utilizing transformative composite materials, with the goal of creating and maximizing Earth-independent, self-sustaining exploration mission capabilities.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

Upon a successful launch (no earlier than late 2017) and on-orbit operations of the Green Propellant Infusion Mission, STMD 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.

Upon completion of hardware build, the Laser Communications Relay Demonstration project will start system integration and test to support a FY 2019 Launch Readiness Date.

The Mars Oxygen In-Situ Resource Utilization Experiment and Terrain Relative Navigation projects will complete hardware development, and will enter into integration and test to support the Mars 2020 schedule. In addition, the Mars Environmental Dynamics Analyzer and Mars Entry, Descent, and Landing Instrument 2 will successfully complete technology development, and will deliver the hardware to Mars 2020 for system integration and testing.

NASA will restructure its investment in satellite servicing technology to reduce its cost and position it to support a nascent commercial satellite servicing industry. In addition, this project will support technologies that will feed into NASA's needs in human exploration, such as the Orion capsule and science missions.

The Solar Electric Propulsion project will complete ground testing of the engineering development units for the magnetically-shielded Hall effect thrusters and begin fabrication of the flight units for demonstration.

Made in Space Inc., Orbital ATK, and Space Systems Loral will complete the ground based portion of the In-Space Robotic Manufacturing & Assembly public-private partnerships aimed at reducing risks associated with robotic manipulation of structures and remote manufacture of structural trusses. Space Technology will evaluate the progress and determine whether to proceed with a Phase II flight demonstration.

Space Technology will complete testing of a 1kW reactor that will aid in the future design of a 10kW-class system that would provide abundant energy for surface exploration. This project will conduct full ground testing at design temperatures in early FY 2018 at the Nevada Nuclear Security Site.

Upon a successful launch in FY 2017, the Station Explorer for X-Ray Timing and Navigation project will demonstrate deep space navigation capability by FY 2018.

Building off the successful FY 2016 demonstration of an integrally stiffened cylinder on a sounding rocket, Space Technology will characterize a scaled up, 10-foot diameter integrally stiffened cylinder using the Advanced Near Net Shape technology. This technology uses innovative metal forming techniques to manufacture integrally stiffened aerospace structures such as cryogenic tanks. The resulting product is 50 percent lower cost and 10 percent lighter due to fewer welds and minimized machining.

Astrobee will complete on-orbit commissioning and prepare for transition to International Space Station (ISS), replacing 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 2018, STMD will continue the use of public-private partnerships to develop and demonstrate mission-enabling capabilities through small launch vehicle technologies and small spacecraft demonstration missions. These activities are deliberately aggressive from a technological, budgetary, and schedule perspective and seek to accelerate new capabilities of mutual interest to private industry and the U.S. government.

Space Technology continues to partner with researchers across academia, industry, and NASA to explore transformative technologies and approaches. Upcoming Early Stage activities will investigate areas such as breakthrough propulsion, challenges in deep space human habitation, space-optimized energy systems, radiation protection, autonomy, materials, and computational modeling. 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

AGENCY TECHNOLOGY AND INNOVATION

This program supports several Agency integration functions, including the Office of the Chief Technologist and the Agency's Technology Transfer efforts. The Office of the Chief Technologist provides the strategy and coordination that guide NASA's technology and innovation activities. The Chief Technologist documents and analyzes NASA's technology investments and tracks progress, ensuring alignment with the Agency's Strategic Plan. STMD leads technology transfer and technology commercialization activities, extending the benefits of NASA's technology investments so they have a direct and measurable impact on daily life. This approach ensures that NASA technologies energize the commercial space sector and provide the greatest benefit to the United States.

SBIR AND STTR

Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) continue to support early-stage research and mid-Technology Readiness Level (TRL) development, performed by small businesses through competitively awarded contracts. These programs produce innovations for both government and commercial applications. SBIR and STTR provide the high technology, small business sector with opportunities to develop space technology for NASA and commercialize those NASA-funded technologies that have the potential to address national needs in the aerospace industry and other sectors.

SPACE TECHNOLOGY RESEARCH AND DEVELOPMENT (STR&D)

Space Technology Research and Development (STR&D) develops and demonstrates near-term and far-reaching technological capabilities and enhancements, making space activities more capable, affordable, and reliable. STR&D includes: Early Stage Portfolio, Game Changing Development, Technology Demonstration Missions, Small Spacecraft Technology, and Commercial Partnerships Portfolio, which work with various technical communities at the appropriate levels of development for each stage of the technology maturation process. Through this portfolio, Space Technology develops the transformative, broadly applicable technologies necessary for NASA's future science and exploration missions while supporting the space technology needs of other U.S. government agencies and the commercial space sector.

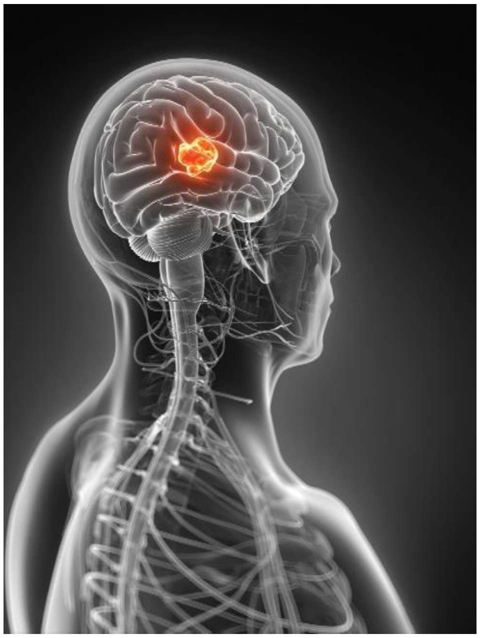
AGENCY TECHNOLOGY AND INNOVATION

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	31.5	--	31.9	31.9	31.9	31.9	31.9

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



Using their expertise in designing small yet powerful tools for spacecraft and rovers, researchers at the Jet Propulsion Laboratory worked with the neurosurgeon who directs the Skull Base Institute in Los Angeles to create the first endoscope fit for brain surgery and capable of producing 3D video images. It is also the first to be able to steer its lens back and forth. These improvements to visibility are expected to improve safety, speeding patient recovery and reducing medical costs.

Agency Technology and Innovation funds the operations of the Office of the Chief Technologist (OCT), the Agency's Technology Transfer activities 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.

In addition, OCT is the Agency champion for promoting a culture of innovation at NASA, particularly in regard to workforce development. The office identifies innovative technology partnerships and initiates collaboration to reduce costs and increase the return on investment through commercial partnerships with American innovators. The office also serves as the NASA lead for the Interagency Science and Technology Partnership, 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. For more information about the OCT, go to: http://www.nasa.gov/offices/oct.

AGENCY TECHNOLOGY AND INNOVATION

Through Technology Transfer, NASA responds to the legislative requirements and Administration priorities to promote technology transfer, including commercialization of technologies that emerge from NASA's research and development activities. As part of this work, STMD documents and communicates the benefits of NASA technology investments to the Nation through various mechanisms, including the media and publications, such as Spinoff. NASA's technologies provide advanced capabilities, new tools, equipment, and solutions for industry. This investment spurs economic growth, creates new markets, increases competition in U.S. industry, and maintains U.S. global technological leadership.

Space Technology also provides Agency-level leadership and coordination of NASA's organizations that conduct prizes and challenges to spur innovation and increase the number and type of individuals participating in innovation activities. NASA uses prizes and competitions to provide technology breakthroughs that lower mission costs and strengthen expertise to develop solutions for tomorrow.

EXPLANATION OF MAJOR CHANGES IN FY 2018

There are no major changes in FY 2018.

ACHIEVEMENTS IN FY 2016

In FY 2016, OCT held several Technical Interchange Meetings in support of NASA's participation in the Science and Technology Partnerships activity. The exchanges with the Department of Defense, the intelligence community, and other federal agencies shared progress on topics of mutual interest and drafted new partnerships that may lead to a reduction in duplication of effort and investment across government, while advancing the technology readiness levels of technology applications that will benefit Agency missions. This innovative collaboration has created new opportunities for advancing technology while reducing costs to the taxpayer. OCT also continued to update the Agency's technology roadmaps, laying out the promising new technologies that will help NASA achieve its aeronautics, science, and human exploration missions, including future deep space exploration to destinations such as Europa and Mars. The roadmaps are a key part of NASA's Strategic Technology Investment Plan (STIP) that lays out the strategy, guiding principles, and priorities for developing technologies that are essential to NASA's mission and help achieve national goals.

Technology Transfer continues to accelerate and increase the amount of technology it shares with industry. Patent licenses were up 41 percent, and software licenses were up 25 percent from the previous year. This outcome follows the trend in increased licenses that has been underway over the past five years. Since 2011, a 293 percent increase has been realized in patent licensing and 145 percent increase in software release. These astounding improvements are due to improvements in the overall Technology Transfer Program infrastructure. OCT streamlined and automated processes, reduced policy hurdles, amplified interactions with industry, and developed and deployed new tools. When they are shared with industry, these technologies create jobs, generate revenue, improve quality of life, and help build the U.S. innovation economy.

Among the many licenses executed with industry in 2016 are inventions big and small. One technology, originally devised to keep astronauts safe during the rigors of rocket launches, can now be found stabilizing a skyscraper in Brooklyn and might soon find its way into new construction across the country (https://spinoff.nasa.gov/Spinoff2017/ps_2.html).

AGENCY TECHNOLOGY AND INNOVATION

WORK IN PROGRESS IN FY 2017

NASA is completing an update of the 2017 STIP, which includes the prioritization and guiding principles for NASA’s technology portfolio. NASA will continue to lead the Agency's participation in the Science and Technology Partnership Forum, holding several more Technical Interchange Meetings while also pursuing new collaborations and partnerships to save the government time and money. NASA also is in the process of developing a framework for encouraging innovation in the workforce and missions to ensure the Agency is innovative in all efforts, enabling the new knowledge and capabilities necessary to accomplish our strategic goals. As part of the Agency's innovation activities, the OCT led the Agency's first Innovation Day, involving all NASA centers and employees with activities designed to foster a culture of innovation. The Agency used prizes and challenges to encourage creative solutions to research and technology problems and organizational needs.

NASA’s Technology Transfer Program has a broad set of initiatives underway for FY 2017. These include automating routine notices to contractors, making them more aware of their invention reporting requirements, thereby freeing up NASA employee time to work with inventors; promoting the new Software Catalog; creating linkages with other NASA datasets and tools for increased efficiency; launching an automated technology licensing tool to streamline and simplify industry access; and exploring use of other government initiatives for entrepreneurs.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

OCT will develop and execute innovation pilot programs and Agency activities to encourage and foster innovative best practices. Working with the NASA Technology Executive Council and key stakeholders inside and outside the Agency, OCT will continue to help inform the prioritization of the Agency's technology investment portfolio by updating as needed the STIP and Technology Roadmaps tailored to Administration, Congressional, and national economic priorities. The OCT will continue 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 in of mutual interest and priority. Through collaborations, NASA will gain insight into other federal science and technology policy and investment priorities, using that knowledge to forge federal and American commercial partnerships. Through these partnerships, NASA will assure America's continued global leadership in aerospace while supporting our national and economic security.

The Technology Transfer Program will continue to streamline and automate internal processes in order to increase our ability to conduct outreach to industry. The Technology Transfer Program intends to increase NASA’s exhibit and conference presence, as well as continuing to explore new and improve existing tools to maximize use of online marketing of our portfolios.

AGENCY TECHNOLOGY AND INNOVATION

Program Elements

TECHNOLOGY TRANSFER

Technology Transfer provides Agency-level management and oversight of NASA-developed and NASA-owned intellectual property, and manage 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, 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). Several specific initiatives NASA’s Technology Transfer Program launched this year include:

- Startup NASA: Startup NASA allows high-tech entrepreneurs to turn NASA inventions into viable commercial products with as few barriers as possible. New companies pay nothing up front to license a NASA technology and have no minimum payments for three years. In just its first year of operation, the Startup NASA initiative resulted in 20 startups, and more are continuing to form.
- Space Race: Also, aimed at startups, Space Race is a competition and business accelerator for teams of entrepreneurs looking to turn NASA technologies into new products. Co-managed with the Center for Advancing Innovation, the contest selected 11 NASA patents with particular commercial promise. Participants developed elevator pitches for commercial applications and worked with business experts to develop robust business plans. The winners received cash prizes, and finalists will have the opportunity to pitch their ideas to a panel of independent investors who are willing to commit up to $1.2 million in seed funding for deserving candidates. Following the event, more than a dozen new companies are expected to form and license NASA technology.
- Gift to the Public Domain: Not all NASA technologies must be licensed to be used. In addition to the huge repository of free software the Technology Transfer Program manages and makes available, in 2016 the program also expanded the portfolio of inventions that have been gifted into the public domain. In May of 2016, NASA announced that it was disclaiming 56 patents, which joined a newly available database of thousands of other formerly patented technologies now offered for unrestricted commercial use. Most of these technologies relate to spacecraft systems, such as propulsion and life support, and they could find use among emerging commercial space companies.

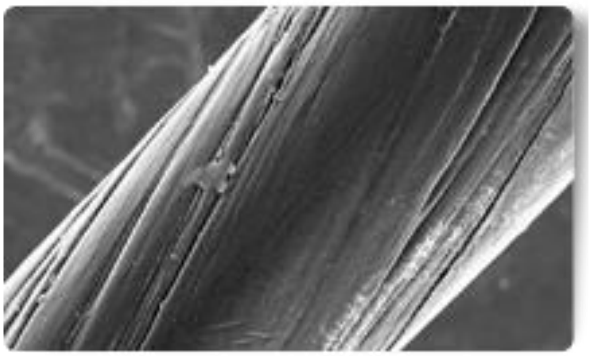
SBIR AND STTR

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	**200.9**	**--**	**180.0**	**180.0**	**180.0**	**180.0**	**180.0**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



Nanocomp Technologies, Inc. of Merrimack, NH has developed Miralon, a line of carbon nanotube materials in macro formats that can be used to replace heavier materials for spacecraft, defense platforms, and a host of other commercial applications. Since carbon nanotubes at the nanoscale have a diameter smaller than a strand of hair, the challenge is to scale up without losing their superior properties. NASA was able to leverage funding originally provided by the Air Force to work with Nanocomp for its specialized objectives through a 2014 SBIR Phase III contract. In NASA's Juno spacecraft, Miralon sheets were used to provide protection against electro-static discharge as the spacecraft made its way to Jupiter on July 4, 2016 (Photo provided by Nanocomp Technologies).

NASA's SBIR and STTR program leverages the Nation's innovative small business community to support early-stage research and development in support of NASA's mission in science and technology, human exploration, and aeronautics. This program provides the small business sector with an opportunity to compete for funding 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 of these activities include in-space propulsion systems to reduce travel time and cost, revolutionizing space travel with new technologies to generate electrical power and store energy, technologies that will enable a growing number of potential applications for small spacecraft, and instrument advancement to be used as inspection tools for locating and diagnosing material defects like a micro meteoroid impact. The SBIR and STTR programs are investing in technologies ranging from those for robotic mobility, manipulation, and sampling needed to acquire and handle samples for in-situ analysis or return to Earth from planetary and solar system small bodies to technologies for breaking through barriers to enable greater use of Unmanned Aircraft Systems (UAS) in NASA research and in civil aviation. SBIR/STTR developed technologies will be able to support applications elsewhere. For example, UAS related technologies support aircraft applications which are dangerous to humans, long in duration, require great precision, and require quick reaction such as remote sensing, disaster response, delivery of goods, agricultural support, and many other known and yet to be discovered. These investments seek to achieve the program's vision of empowering small

SBIR AND STTR

businesses to deliver technological innovation that contributes to NASA's interests, provides societal benefit, and grows the U.S. economy.

NASA issues annual SBIR and STTR program solicitations, setting forth a substantial number of topic areas open to qualified small businesses. Both the list and description of topics are sufficiently comprehensive to provide a wide range of opportunities for small businesses, research institutions, and universities to participate in NASA's research and development programs. There are three phases for SBIR and STTR funding awards. Competitively selected Phase I awards give small businesses the opportunity to establish the scientific, technical and commercial merit, and feasibility 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) 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.

EXPLANATION OF MAJOR CHANGES IN FY 2018

The SBIR and STTR program was reauthorized in 2016 and the program's authorization now expires in December 2022 (Public Law No: 114-328). The reauthorization for the SBIR and STTR program did not extend the sunset clauses for two authorities in the program: (1) the ability to use up to 3 percent of the SBIR awards budget for administrative expenses such as outreach, eliminating fraud, waste and abuse, and providing commercialization assistance training, like i-Corps; and (2) the ability to use up to 10 percent of the SBIR awards budget for a civilian commercialization readiness pilot program, which provides additional post Phase II support to technology development activities with strong customer pull to bridge the Technology Readiness Level "valley of death." Space Technology plans to continue to support its post Phase II CCRPP technology investment through FY 2019, when the authority to implement such a program expires.

The required SBIR investment remains 3.2 percent of the Agency annual extramural R&D for SBIR and 0.45 percent for STTR, consistent with the current authorization. NASA anticipates a decline in total Agency annual extramural R&D as the Space Launch System and Orion programs advance past development into production which is reflected in the FY 2018 budget requests and the outyears.

ACHIEVEMENTS IN FY 2016

- NASA conducted an inaugural subtopic workshop at the Ames Research Center that resulted in a more integrated, streamlined SBIR solicitation. NASA also held a proposers workshop at Ames Research Center and virtually in September 2016 to increase engagement with current and potential participants in the program. The workshop was held for informational purposes and was an opportunity for the small business community to explore and share ideas related to the general technical topic areas.

SBIR AND STTR

- The program implemented an outreach strategy that focuses on increasing the overall percentage of applicants from underrepresented groups and areas. While it is too early to quantify, NASA did realize a 10 percent increase in applications for SBIR and a 20 percent increase in applications for STTR.
- STMD received 1,317 proposals in response to the 2016 SBIR and STTR solicitation and selected 340 Phase I awards valued at over $42.2 million. Women-Owned Small Businesses represented 9.6 percent of the awards and Small, Disadvantaged Businesses received 10.8 percent of the awards.
- 139 Phase II awards were made valued at over $104 million. Over 10 percent of those awards were to Women-Owned Small Businesses and over 5 percent were to Small, Disadvantaged Businesses. Topics from these solicitations include technologies to reduce the scale and cost of orbital access through nano and micro launch vehicles, improving the resource utilization for terrestrial explorers and settlers to acquire carbon dioxide and water from the Mars atmosphere and soil resources, and increasing the availability of power to support future power generation systems.
- The program facilitated transition to commercialization with 27 SBIR Phase II E/X awards valued at over $6 million and four STTR Phase II E/X awards valued at over $700k. In addition, over $10 million was infused into SBIR and STTR companies to utilize their NASA awarded technologies across 44 Phase III awards.

WORK IN PROGRESS IN FY 2017

- Phase II selections were announced in March 2017. The program selected 133 proposals for contract negotiation valued at nearly $100 million.
- The program initiated a new Civilian Commercialization Readiness Pilot Program to further advance innovative technology with high potential for commercial impact. This pilot is being offered to small businesses that have successfully completed Phase II awards under any federal agency's SBIR or STTR program whose technology maturation has strong customer pull and will advance NASA interests. NASA will match the investments with SBIR/STTR program funds up to $2 million for each pilot award.
- Space Technology established an interagency agreement with the National Science Foundation to implement a pilot program to provide training grants to approximately 25 of the 2017 solicitation's Phase I awardees to participate in the I-Corps program. The goals of the SBIR/STTR Program and the I-Corps overlap by encouraging the innovation and entrepreneurship of small businesses and enabling those businesses to commercialize their innovations. NASA made its Phase I award announcement in April, and will announce I-Corps selections from those awards in late May.
- The 2017 solicitation contained small satellite and small launch vehicle technologies as a new topic to address the needs of the academic and commercial small satellite communities with a goal of five percent of SBIR/STTR program funding.
- NASA's SBIR/STTR program has been actively working to increase engagement with industry. SBIR/STTR released a Request for Information (RFI) in February 2017. Through this RFI and a subsequent Industry Day in June 2017, the program is actively seeking to engage industry and small businesses to build awareness, gain insights, and obtain feedback to help shape the 2018 NASA SBIR/STTR Solicitation and identify potential programmatic improvements.
- The program invested in modernizing the systems and processes used to interface with small businesses in order to increase the efficiency and effectiveness of the program. These system and

process improvements were anchored in user research aimed at understanding the small business perspective.

- NASA SBIR/STTR outreach activities continues to focus on increasing the overall percentage of applicants from underrepresented groups and areas.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

- The SBIR and STTR Programs will continue to work with the mission directorates, centers and industry to identify subtopics for the annual solicitations. Space Technology plans to release the annual SBIR and STTR solicitations, and award new Phase I and Phase II selections.
- The SBIR/STTR programs will continue to offer Post-Phase II award opportunities to increase technology transitions and commercialization.
- The SBIR/STTR program will continue to modernize its business capabilities, reducing barriers to entry for firms, increasing the quality of proposals, improving the value proposition for firms, and increasing overall program effectiveness. Furthermore, the program will continue to modernize the technology used to manage the program to be more modern and resilient, while making the technology interfaces more intuitive and efficient for small business.
- The SBIR/STTR program will continue to explore pilot opportunities to accelerate the program's ability to advance NASA interests and those of the commercial aerospace sector through the program.

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. In FY 2018, the 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 Enhancement (II-E) contract options with incentives for cost sharing to extend the research and development efforts of the current Phase II contract. NASA also supports Civilian Commercial 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.

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 2018, the maximum value for an STTR Phase I contract is $125,000 for a period of performance of twelve 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 contract options and CCRPP are also available to STTR participants.

Program Schedule

SBIR and STTR solicitation and award schedule is below.

Date	Significant Event
July 2017	2016 Solicitation STTR Phase II Awards Selected (from prior Awards)
January2018	2018 SBIR and STTR Phase I Solicitation Opens
March 2018	2018 SBIR and STTR Phase 1 Solicitation Closes
March 2018	2017 Solicitation's SBIR Phase II Awards Selected (from prior Awards)
July 2018	2017 Solicitation's STTR Phase II Awards Selected (from prior Awards)
June 2017	2019 Solicitation Topics Requested from Mission Directorates and Centers
June 2018	2018 Solicitation's Phase I Awards Selected

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 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 SBIR and STTR up to $2,000,000 of non-SBIR and non-STTR investment(s) from a NASA project, NASA contractor, or third party commercial investor to continue a former Phase II project to perform additional research for strong customer pull for the technology maturation.

Acquisition Strategy

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. Space Technology writes SBIR and STTR topics and subtopics to address NASA's core competencies and align with the Agency's Technology Roadmaps.

INDEPENDENT REVIEWS

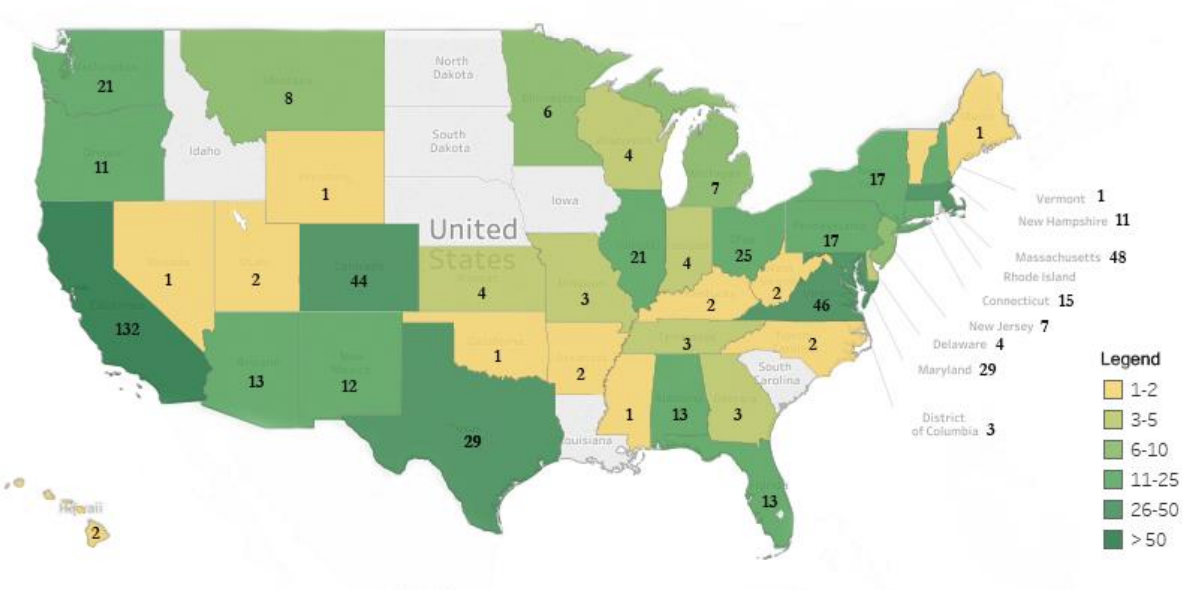
Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	National Academies	Completed	Assessment of the SBIR program.	The report recommended additional outreach to increase participation by underrepresented communities. The report is available here: https://doi.org/10.17226/21797.	No Further Review at this time
Performance	Government Accountability Office (GAO)	Ongoing	The GAO has been tasked to assess all SBIR and STTR programs for their performance in complying with spending requirements, and program efforts in combating Waste, Fraud, and Abuse.	GAO found no concerns to address.	Ongoing

SBIR AND STTR

Historical Performance

The map below represents the FY 2016 SBIR and STTR Phase I, Phase II, Phase II-E, and Select Awards that target technologies highly desired by NASA Mission Directorates, by geographic location.

SBIR/STTR FY16 Awards



SPACE TECHNOLOGY RESEARCH AND DEVELOPMENT

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
RESTORE-L	133.0	130.0	**0.0**	0.0	0.0	0.0	0.0
Laser Communications Relay Demonstration	30.5	25.7	**21.5**	17.2	0.0	0.0	0.0
Total Budget	**454.0**	**--**	**466.7**	**467.4**	**467.4**	**467.4**	**467.4**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

Space Technology's Bulk Metallic Glass project will improve rover mobility performance at low temperatures by eliminating the need for gear lubricant and associated heaters. The gears shown above can operate without lubricant, which will enable planetary surface missions where temperatures drop below the freezing point of typical lubricants.

Space Technology invests in space technologies to enable or significantly advance relevant capabilities for NASA missions while also providing for a more capable commercial aerospace sector. Through these efforts, NASA ensures the emergence of new ideas and the incorporation of advanced capabilities into its missions, while simultaneously contributing to the needs of other U.S. government agencies and the larger aerospace industry.

The Space Technology Research and Development portfolio supports a range of technology maturation levels including early stage conceptual studies that focus on discovering new concepts and technologies; rapid competitive development and ground-based testing to determine feasibility; and flight demonstrations in relevant environments to effectively transition technologies for NASA missions and for use by other government agencies and industry. By supporting projects at all readiness levels, Space Technology creates a technology pipeline, starting with diverse early stage innovations, progressing along multiple paths to deliver mature, ready-to-use technologies that increase the Nation's in-space capabilities. In the process of creating these new technologies, NASA generates research opportunities and inspires the next generation of inventors, scientists, and engineers.

Space Technology Research and Development investments target seven identified thrust areas important both within and outside of NASA, including: power and propulsion; advanced life support and resource utilization; entry, descent, and landing systems; robotics and autonomous systems; advanced communications; lightweight structures and manufacturing; and observatory systems. Significant advances are required in these areas to enable more capable science missions as well as human exploration missions that are both more affordable and reliable. In addition, technology investments within many of these areas have broad application within U.S. aerospace and other industries. As such,

SPACE TECHNOLOGY RESEARCH AND DEVELOPMENT

NASA takes advantage of and contributes knowledge toward common challenges across a network of government, academia, and industry. Space Technology conducts virtual workshops, creates technology infusion plans, and uses Space Act Agreements to share expertise with industry and academia and improve the probability of infusion into the user community. By collaborating on new manufacturing techniques, sharing knowledge in robotics and autonomy, and developing new materials using nanotechnology and materials genomics, NASA contributes to the growth of the Nation's innovation economy.

The Agency looks to Space Technology to develop entirely new approaches to future missions. For example, STMD established public-private partnerships through the Tipping Point solicitation to advance in-space robotic manufacturing and assembly technologies and capabilities. These capabilities have the potential to revolutionize the way NASA, other government agencies, and industry design, manufacture, integrate and operate spacecraft systems enabling new missions and commercial approaches. In addition, technology investments in propulsion, attitude determination and control, communications, power systems and autonomy technologies can rapidly advance small spacecraft capabilities making them a more viable platform for a broader set of NASA missions and commercial applications. STMD is also investing in low size, weight, and power remote sensing instruments to enable science missions utilizing small spacecraft. This investment is one of many activities, funded by STMD, to develop pioneering technologies that will increase the Nation's ability to perform space science, improve operations in space, and enable future deep-space exploration missions.

EXPLANATION OF MAJOR CHANGES IN FY 2018

Space Technology will transition the Restore-L project to a lower-cost demonstration to better position it to support a nascent commercial satellite servicing industry. The project will pursue collaboration with Defense Advanced Research Projects Agency (DARPA) and Industry to ensure broad application.

ACHIEVEMENTS IN FY 2016

- Completed software development and testing of Station Explorer X-ray Timing and Navigation Technology (SEXTANT) flight experiment at the Goddard Space Flight Center (GSFC), which will evaluate real-time X-Ray data from known regular pulsars to demonstrate more precise deep space navigation. This 2017 ISS demonstration will use pulsars for navigation similar to the way Global Positioning System functions on the Earth today.
- Solar Electric Propulsion project demonstrated full performance compatibility of the electric propulsion thruster and power processing units, with more than 2,500 total hours of total testing. The project subsequently awarded a contract to Aerojet Rocketdyne for the development and delivery of engineering development units of the Electric Propulsion String by the end of 2018, with an option for flight unit delivery by 2019.
- Successfully demonstrated the ability to receive and distribute commands between two satellites in space from the ground, while periodically exchanging scientific data from their onboard radiation instruments, through the Small Spacecraft Nodes mission. Small Spacecraft also completed the hardware build and delivered three small spacecraft missions for launch: the CubeSat Proximity Operations Demonstration for rendezvous and docking; Integrated Solar Array and Reflect Antenna for enhanced radio communications; and Optical Communications and Sensor Demonstration focused on laser communications and formation flight.

SPACE TECHNOLOGY RESEARCH AND DEVELOPMENT

- Completed demonstration of a spectrograph detector and read-out electronics for Coronagraph technology that will enable direct, multi-spectral imaging of exoplanets.
- Restore-L completed pre-formulation activities with a mission concept review, and developed system requirements and mission definition. The project issued awards for the spacecraft bus, vision and navigation sensors, and cameras.
- Completed fabrication and hot fire test of additively manufactured thrust chamber assembly for the Low Cost Upper Stage project.
- Completed prototype testing for free-flyer robot Astrobee in preparation for delivery to Advanced Exploration Systems for eventual demonstration on the International Space Station (ISS).
- Delivered a wax-based heat exchanger to the International Space Station in July 2016 for in-space demonstration with potential for infusion into Orion's thermal control system. The infusion of this technology, developed by Mezzo Technologies (Baton Rouge, LA), could support Orion in cis-lunar orbit operations.
- Initiated multiple awards to emerging commercial space companies for partnerships with NASA centers for maturing and validating technologies needed for air-launched liquid rockets, dedicated CubeSat launch vehicle, nanosat launch vehicle booster main engine, and upper stage engine.

WORK IN PROGRESS IN FY 2017

- Selected two multi-disciplinary university-led research institutes to increase collaboration and advance technologies in bio-manufacturing for deep space exploration, and high performance materials development for ultra-high strength lightweight structures.
- Awarded three Tipping Point projects for In-Space Robotic Manufacturing & Assembly to Orbital ATK of Dulles, Virginia; Made in Space, Inc. of Moffett Field, California; and Space Systems Loral of Palo Alto, California.
- Awarded a contract to Boeing Co. for the development of the next generation, high performance spaceflight computer processors that will allow for flexible operations, lower power computers for space operations with 75x-improved performance over the state of the art RAD750.
- Transitioned Deep Space Optical Communications to Technology Demonstration Missions to demonstrate high bandwidth communications on the Psyche Discovery mission.
- The Restore-L project is developing preliminary design reviews for major subsystems, and is conducting industry knowledge transfer workshops to increase collaboration.
- Will deliver the second of two options for high performance prototype astronaut extra-vehicular activity gloves and ultra-high energy storage battery cells to Human Exploration and Operations Mission Directorate.
- Will complete sounding rocket flight testing of carbon nanotube reinforced Composite Overwrapped Pressure Vessel to assess its durability during launch and landing.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

- Complete hardware development of the Mars Oxygen In-Situ Resource Utilization Experiment, Terrain Relative Navigation, Mars 2020 Entry, Descent and Landing Instrumentation and Mars Environmental Dynamics Analyzer technologies for the Mars 2020 mission to start system integration and test. These four instruments are part of the baselined Mars 2020 project in Planetary Science.

- NASA will mature satellite servicing technologies needed by government and the commercial satellite industry, and continue pursuing collaborations with DARPA and with industry to leverage and demonstrate satellite servicing technologies being developed by interested stakeholders.
- Complete ground testing of the Solar Electric Propulsion engineering development units for the magnetically-shielded Hall effect thrusters and begin fabrication of the flight units for demonstration.
- Complete Phase I of the In-Space Robotic Manufacturing & Assembly public-private partnerships with Orbital ATK, Made in Space, and Dragonfly, aimed at reducing risks associated with robotic manipulation of structures and remote manufacture of structural trusses. Space Technology will evaluate the progress and determine whether to proceed with Phase II; a flight demonstration of one or more of these technologies and systems.
- Complete testing of a 1kW fission reactor that will aid in the future design of a 10kW-class system that would provide abundant energy for surface exploration. This project will conduct full ground testing at design temperatures in early FY 2018 at the Nevada Nuclear Security Site.
- Complete cold-temp life testing of Bulk Metallic Glass Gears to support future extreme environment science missions.
- Characterize a scaled up, 10 foot diameter integrally stiffened cylinder using the Advanced Near Net Shape technology. Building off successful FY 2016 demonstration of an integrally stiffened cylinder on a sounding rocket, this technology uses innovative metal forming techniques to manufacture integrally stiffened aerospace structures such as cryotanks. The resulting product is 50 percent lower cost and 10 percent lighter due to fewer welds and minimized machining.

Program Elements

EARLY STAGE PORTFOLIO

Basic research, applied research, and early technology development spur innovations that transform future capabilities. It is not always clear which efforts will result in breakthroughs, effective improvements, or exciting new approaches. This process is nonlinear and takes time. This reason is why a balance of Early Stage, mid-TRL, and technology demonstration investments is critical for a healthy technology development portfolio.

Space Technology invests in early stage space technology 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. Through a steady cadence of competitive solicitations, Space Technology continuously solicits and develops new and innovative high-risk/high-payoff technologies. Early Stage studies cultivate new ideas and alternative approaches, leveraging the technical capabilities of the experts across the nation to fuel economic growth. Technologies are often developed with support and coordination between NASA and various external partners. Space Technology's Early Stage programs employ various approaches, to best engage technical experts at universities, companies, independent labs, NASA centers, and other government agencies. This portfolio includes Space Technology Research Grants, NASA Innovative Advanced Concepts, Center Innovation Fund, and Space Technology Research Institutes, which are described more in depth below.

SPACE TECHNOLOGY RESEARCH AND DEVELOPMENT

As of FY 2017 first quarter, there are approximately 420 Early Stage activities spanning all technology areas (14 NASA space technology roadmap areas plus Aeronautics) with over 75 percent focused on the aforementioned seven Space Technology thrust areas. With some activities serving multiple end users, approximately, 50 percent of the Early Stage Portfolio supports Science, 45 percent supports Exploration, and 8 percent supports Aeronautics. In addition, many projects are of interest to and developed in partnership with the commercial aerospace industry and other government agencies. For example, new materials developed in Early Stage programs have had downstream applications for diverse missions within and outside of NASA. Early Stage research has also seen national recognition. Dr. Marco Pavone from Stanford University was named a recipient of the prestigious Presidential Early Career Award for Scientists and Engineers in January 2017 for his novel guidance framework. His work included real-time, efficient and dependable algorithms for spacecraft autonomous maneuvering, with a focus on dynamic and highly cluttered environments. The Early Stage Portfolio is managed through the following efforts:

- Space Technology Research Grants annually conducts a series of 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. These grants harness the unique environment that resides within our nation’s universities to solve space technology’s most difficult long-term challenges. In the process, Space Technology fortifies the close collaborations between U.S. universities and NASA. In FY 2016, Space Technology awarded 58 fellowships, eight Early Career Faculty awards, and 15 Early Stage Innovations awards that resulted from the 2015 Early Stage Innovation solicitation. Early in FY 2017, Space Technology Research Grants selected 13 Early Stage Innovations efforts that resulted from the solicitation for proposals in FY 2016. The 2016 Early Career Faculty and Early Stage Innovations competitive opportunities featured 10 topics from 8 of the technology area roadmaps. Space Technology Research Grants has more than 250 active fellowships, Early Career Faculty and Early Stage Innovations awards. To date, Space Technology Research Grants has made 451 grant awards to 101 different U.S. universities in 42 states and one U.S. territory.

- 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 aeronautics, science, and 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 2016, NASA Innovative Advanced Concepts made 13 Phase I and eight Phase II awards across industry, academia, and NASA centers, while completing 15 Phase I and six Phase II studies. The 2016 Phase II Fellow Philip Lubin’s study on how to reach Alpha Centauri with a scientific probe has been used as the basis of a new externally funded institute called “Breakthrough Starshot.”

- Center Innovation Fund provides seed funding to all ten NASA Centers to stimulate aerospace creativity and grassroots innovation to transform future missions and advance the Nation’s capabilities. Center Innovation Fund project elements are competitively selected to explore alternative approaches or develop enhanced capabilities. They are solicited to address NASA strategic goals, Center capabilities, progress along technology roadmaps, and/or significant national needs. Partnerships with academia, private industry, individual innovators, as well as other NASA Centers and government agencies are highly encouraged. An integrated review of all

Center Innovation Fund candidates is conducted to ensure a coordinated agency-wide portfolio. These investments have led to multiple successful NASA and commercial applications. One such example was the Biomolecule Sequencer, developed at the Johnson Space Center, which has demonstrated for the first time that DNA sequencing is feasible in an orbiting spacecraft. A space-based DNA sequencer can identify microbes, diagnose diseases and understand crew member health, and potentially help detect DNA-based life elsewhere in the solar system. This device was initiated with Center internal research and development funding before progressing to further development in CIF and a series of partnerships.

- New in FY 2017, Space Technology selected two Space Technology Research Institutes that will focus on the development of technologies critical to extending human and robotic presence deeper into our solar system. These institutes will bring together researchers from multiple universities and other organizations to collaborate on the advancement of cutting-edge technologies in bio-manufacturing and high performance materials. The Center for Utilization of Biological Engineering in Space, led by the University of California, Berkeley, will advance research into an integrated, multi-function, multi-organism bio-manufacturing system to produce fuel, materials, pharmaceuticals and food. The Institute for Ultra-Strong Composites by Computational Design, led by Michigan Technological University, aims to develop and deploy a carbon nanotube-based, ultra-high strength, lightweight aerospace structural material within five years. The Space Technology request includes funding to initiate additional institutes in FY 2018.

Space Technology continues to enhance its involvement with academia and NASA centers to access unique ideas with breakthrough potential. In upcoming solicitations, NASA will place an emphasis on a balance of finding solutions through innovating with existing technologies, applying new methods and approaches to persistent challenges, and exploring altogether new ideas. It is expected that this comprehensive approach will most efficiently lead to discovery and development of exciting new space engineering and science capabilities.

GAME CHANGING DEVELOPMENT

Within Game Changing Development, 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 selected within key thrust areas as a driver, utilizing either the expertise at NASA centers as guided work or competitive solicitations, while also emphasizing capabilities most likely to be infused into the user community. These trust areas include: entry, descent, and landing systems; space power and propulsion; advanced life support and resource utilization; autonomy and space robotic systems; advanced communications, deep space navigation and avionics; lightweight structures and manufacturing; and space observatory systems. Space Technology favors technology investments that offer direct partnerships and co-funding from NASA, industry, and/or other government agencies, to advance specific transformative and cross cutting technologies. For example, Game Changing Development is addressing the need for next generation high performance spaceflight computing for NASA's space science and exploration missions, as well as military applications. Because of this shared interest and need, NASA and the Air Force Research Laboratory are working with industry to develop more capable spaceflight hardened flight computers. The program also partners with industry to explore solutions to common challenges in areas such as robotics, manufacturing, and materials and by establishing public-private partnerships through STMD's

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Announcement of Collaborative Opportunity and Tipping Point solicitations. Game Changing Development investments are described by the technology thrust area below.

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. Space Technology 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. The goal of specific investments within Game Changing Development is to mature technologies with an emphasis on decelerating spacecraft during atmospheric entry and protect them from extreme entry heating. Key projects that support this objective include:

- The Adaptable Deployable Entry and Placement Technology (ADEPT) and the Hypersonic Inflatable Aerodynamic Decelerator (HIAD-2) are both deployable heatshield systems designed to protect payloads and landers delivered to planetary bodies with atmospheres. ADEPT is mechanically deployed and applicable for high heating rates experienced at Venus, in high-speed Earth return, and potentially some outer planet missions. HIAD-2 is inflatable, applicable for less intense heating rates for Mars and lower-speed Earth return (orbital and stage returns).
- Mars 2020 Entry, Descent and Landing Instrumentation: HEOMD, SMD, and STMD are collaborating to 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.
- Cooperative Blending of Autonomous Landing Technology: This terrestrial test platform is used to develop and mature Guidance Navigation and Control technologies for precision landing and hazard avoidance. Doppler LIDAR hardware from LaRC will be integrated with a JPL lander vision system to provide navigation that enables controlled precision landing. By the end of 2017, this hardware will complete two flight demonstrations on Masten’s Xodiac vehicle.
- Retro-propulsion: STMD continues its partnership with SpaceX to obtain flight data to inform supersonic retro-propulsion landing at Mars.

Space Power and Propulsion

STMD is making critical advancements in power generation and energy storage technologies for science and human 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, development and testing of a scalable 1kW surface power generation system; and rapid transit technology utilizing low-enriched uranium that could potentially provide two month, one way travel to Mars. Key projects that support this thrust area include the following:

- Extreme Environment for Solar Power: In collaboration with SMD, this project seeks to develop new solar cell and array-level component technologies focused on space power applications in low intensity, low temperature and high radiation environments. The technology would support NASA missions focused on outer planets (such as Jupiter), which are subjected to intense

radiation while experiencing less than 10 percent of the solar flux relative to a mission in the general vicinity of Earth.
- Kilopower: Through a partnership with Department of Energy's National Nuclear Security Administration and small businesses Sunpower, Inc and Advanced Cooling Technologies, Space Technology is developing a 1kW prototype of a fission power subsystem that is scalable and will potentially provide surface power capability for space exploration. The Kilopower assembly went through vacuum testing at GRC for thermal cycling checkout, and will conduct full ground testing at design temperatures in early FY 2018 at the Nevada Nuclear Security Site.
- Nuclear Thermal Propulsion: STMD investments will enable more efficient spaceflight by developing improved fuel element sources to support potential future nuclear thermal propulsion efforts. The nuclear thermal propulsion project is completing feasibility and affordability study of low-enriched uranium based engine systems. Upon completion of this assessment study, the team will validate feasibility for a reactor design and a future ground-based demonstration. In addition, the project conducted studies regarding licensing for engine ground test activities, and completed preliminary concept design and system sizing of contained ground test facility.

Autonomy and Robotics

Autonomy and Robotic systems are critical when exploring or operating in an extreme environment, on Earth or in space (especially for outer planets exploration). This portfolio issues grants to academia for robotics technologies that benefit space exploration and also support manufacturers, businesses and other entities. Key robotic technology efforts include:

- Astrobee: This freeflyer robot is designed for use inside the ISS, and will improve the crew's efficiency by autonomously performing the more routine tasks such as inventory management and air quality assessments. In addition, with its open source software platform, it will continue to be available for use by universities and for telerobotics challenges on ISS. The project will build certification and flight units during FY 2017 and deliver the flight units for launch to the ISS later this year. During the remainder of FY 2018, the project will perform on-orbit commissioning activities, after which the technology will be transitioned to Advanced Exploration Systems.
- IBM Watson Collaboration: Through a partnership with IBM, the Human Robotics Systems project is developing autonomous robotic assistants and caretakers needing dexterous, mobile manipulation. The team has integrated IBM Watson with the Robot Operating System to establish a voice activated cognitive control between Robonaut (R2) humanoid robot and Watson.
- Human Robotics Systems: The project has provided the R5 robot to Massachusetts Institute of Technology (MIT) and to University of Massachusetts at Lowell (UML). MIT will explore walking and balancing, and UML, in collaboration with Northeastern, will utilize new user interfaces, manipulation tasks and obstacle avoidance tasks to enhance robotic functions. This effort also lends engineering expertise to the NASA Space Robotics Challenge funded by Centennial Challenges program.

Lightweight Structures and Manufacturing

STMD supports innovation in materials development and low-cost manufacturing that enable increases in payload mass 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:

- Advanced Near Net Shape Technology: This technology uses innovative metal forming techniques to manufacture integrally stiffened aerospace structures such as cryotanks. The resulting product is 50 percent lower cost and 10 percent lighter due to fewer welds and minimized machining. NASA will build on previous prototyping efforts focusing on scaling up the process for commercial launch vehicles. Industry partners include MT Aerospace, Lockheed Martin, and Leifeld Metal Spinning, in Ahlen, Germany. Characterization of a fabricated 10-ft. diameter integrally stiffened cylinder will begin in FY 2017 and continue into FY 2018.
- Additive Construction for Mobile Emplacement: will develop full-scale hardware to 3D print infrastructure components using analog planetary in-situ materials, while developing full-scale hardware with the United States Army Corps of Engineers for terrestrial applications. The project completed environmental modeling analyses in first quarter of FY 2017, and will complete a full-scale demonstration in late FY 2017 or early FY 2018. This project is in partnership with the Army Corps of Engineers.
- Bulk Metallic Glass: Using Bulk Metallic Glass to improve rover mobility performance at low temperatures by eliminating the need for gear lubricant and associated heaters. This technology will enable planetary surface missions where temperatures drop below the freezing point of typical lubricants. In FY 2017, Game Changing Development will conduct three tests including operation of unlubricated bulk metallic gears at approximately -274 degrees Fahrenheit.
- Composite Technology for Exploration: By developing new analytical methods to design, build and test innovative hardware, Space Technology looks to enable a significant increase in the use of new composite materials for the next generation of rockets and spacecraft needed for space exploration. In FY 2017, the project will develop designs for composite joints and perform testing at the subscale level to verify the designs and new high-fidelity analysis tools for predicting composite joint failure and residual strength. In FY 2018 the project will develop advanced concepts to build full-scale hardware to test (i.e. damaged, undamaged, and repaired) and validate that the structures can withstand launch vehicle loads and demonstrate analytical tailoring approaches that allows reducing conservatism in safety factors that limits the use of new composite materials.

Advanced Life Support and Resource Utilization

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

- Advanced Radiation Protection: Insufficient data exists to validate thick shield space radiation exposure predictions. The Advanced Radiation Protection project will validate the shielding efficiency of spacecraft materials and verify an optimum Galactic Cosmic Ray (GCR) shield thickness needed for minimal mass vehicle design. To this end, the project team will work with the NASA Space Radiation Laboratory to design and build radiation detector stands and targets to support a testing of various materials (aluminum, polyethylene, combination). This effort will result in data that will inform deep space habitat construction. This project can be viewed as the necessary first step in the development of a vehicle optimization capability for long duration, heavily shielded vehicles.

- 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. In coordination with HEOMD, STMD initially selected four vendors to develop technologies to 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. In February 2017, STMD selected two teams, Honeywell Aerospace and Umpqua Research Co., to continue development and demonstration of their technologies.

Advanced Communications, Navigation and Avionics

STMD 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:

- Station Explorer for X-Ray Timing and Navigation (SEXTANT): This project will enable GPS-like autonomous navigation anywhere in Solar System and beyond, using millisecond period X-ray emitting neutron stars (Millisecond Pulsars) as beacons. The GSFC-led project delivered flight hardware for checkout and launch vehicle integration. Upon a successful delivery to the ISS through SpaceX CRS-11 in FY 2017, SEXTANT will conduct its demonstration of real-time X-ray navigation capability.
- High Performance Spaceflight Computing: With the Air Force Research Laboratory and SMD, STMD is developing a next generation high performance space flight computing system that 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. In March 2017, NASA selected Boeing to develop a prototype radiation hardened multi-core computing processor Chiplets, system software, and evaluation boards to allow Chiplet test and characterization by the end of 2020.
- Affordable Vehicle Avionics: This effort will demonstrate operational capability of a reduced cost avionics system. This project will conduct its second test flight through the Flight Opportunities program in summer 2017.

Space Observatory Systems

Space Technology will enable new science missions through investment in high payoff technologies that increase the sensitivity of scientific instruments and sensors. Key projects within this portfolio include the following:

- Mars Environmental Dynamics Analyzer: The Mars Environmental Dynamics Analyzer makes weather measurements including wind speed and direction, temperature and humidity, and also measures the amount and size of dust particles in the Martian atmosphere. This project is being conducted in partnership with Science and the Center for Astrobiology – Spain, and will be integrated into the Mars 2020 mission for a flight demonstration.
- Coronagraph: With SMD, STMD advanced coronagraph technologies for the WFIRST/AFTA mission enable scientists to directly observe exoplanets, and interrogate the atmospheric properties of these distant worlds allowing humanity to discover habitable planets within our

galaxy for the first time. In FY 2017, STMD continues to collaborate with SMD to plan a demonstration of spectrograph detector and read-out electronics for Coronagraph.

- Advanced 1.65 micron seed laser for LIDAR remote sensing of methane: Through a Space Technology Tipping Point award, Game Changing Development is developing a high-power, tunable laser that will be used as a seed laser. The seed laser emits a specific frequency that will stabilize the main laser to improve the detection of methane through remote sensing. The project commenced in FY 2016 and will conclude in FY 2018. Freedom Photonics is partnering with GSFC and is contributing about 30 percent to this public-private partnership.

TECHNOLOGY DEMONSTRATION MISSIONS

To bridge the gap between early development and mission utilization, Technology Demonstration Missions matures system-level space technologies that can benefit multiple NASA missions, other government agencies, and aerospace industry stakeholders by demonstrating prototypes and demonstration units in relevant environments. To remain affordable, flight demonstrations of technologies that have passed feasibility ground testing are flown in space primarily through hosted payloads, rideshares, and secondary payloads. In addition to the Laser Communications Relay Demonstration, which is described in the following section, the current Technology Demonstration Missions portfolio is:

Satellite Servicing

GSFC will demonstrate robotic servicing of satellite technologies through the former Restore-L mission. NASA will transition the Restore-L project to reduce its cost and support a nascent commercial satellite servicing industry. In addition, the project supports technologies that will enhance and enable future science and exploration missions. Key technology areas of the project include rendezvous and proximity operations sensors, propellant transfer systems, and other robotic tools. NASA is pursuing a potential collaboration with the Defense Advanced Research Projects Agency (DARPA) and with industry to most effectively advance satellite servicing technologies and ensure broad commercial application. Additionally, NASA is continuing with the Robotic Refueling Mission 3 which focuses on servicing cryogenic fluid and xenon gas interfaces and will support future scientific missions as humans extend their exploration further into our solar system. Building on Robotic Refueling Mission technology demonstrations on ISS, Space Technology will advance servicing technologies and partner with domestic private enterprise to commercialize the results, establishing a new U.S. industry.

Deep Space Optical Communication

In partnership with Space Communication and Navigation (SCaN) and SMD, STMD is funding JPL to develop key technologies for the implementation 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 applicable planetary science missions including those to Mars and the Jovian systems.

The first phase of the Deep Space Optical Communication project 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. In late FY 2016, the project transitioned to a Technology Demonstration Mission from Game Changing Development to demonstrate a high bandwidth flight laser optical communication terminal. The technology will be ready to demonstrate on the SMD Discovery mission Psyche.

Deep Space Atomic Clock

The JPL is working 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. The DSAC project, funded in a partnership with SCaN, will demonstrate ultra-precision timing in space and its benefits for one-way radio-based navigation. If successful, it will free precious deep space communications bandwidth to perform greater scientific data return, instead of receiving and transmitting navigation updates. The enhanced navigation and opening of communications bandwidth permitted by the new clock will dramatically improve the science return capabilities of future Discovery and New Frontiers missions, particularly for outer planetary missions. The accurate timing and navigation provided by the clock could also dramatically improve gravitational measurements planned for a future Europa (and other icy moons) mission to characterize the under ice liquid water oceans. 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 through rideshare on a SpaceX Falcon Heavy (STP-2) as a hosted payload on the Surrey Orbital Test Bed by no earlier than late FY 2017.

Green Propellant Infusion Mission

Ball Aerospace and Aerojet Rocketdyne, with support from the Department of Defense designed, built, tested, and are launching 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. Hydrazine, which has been used extensively since the 1960s for space systems, is a reliable and effective storable monopropellant, but requires complicated transportation, handling and ground/flight operations because it is highly corrosive and highly toxic. Use of hydrazine also often requires extensive site clean-up and environmental remediation at the end of missions and programs due to the material's toxic properties. Spacecraft developers have actively sought safer alternatives to hydrazine propellant (in-space storable mono propellants). Higher performing and safer green propellant alternatives are at a tipping point. Once demonstrated within the context of an in-space application, 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 has secured a rideshare opportunity for technology demonstration through the STP-2 launch of a SpaceX Falcon Heavy. In addition, Space Technology continues to work with Aerojet Rocketdyne to revise the one-Newton thruster design to implement design improvements to better enable commercial infusion potential following the in-space demonstration, through a public-private partnership collaboration.

Solar Electric Propulsion

GRC will continue the development of Solar Electric Propulsion with higher-power, longer-life thrusters and power processing units. The use of electric thrusters on commercial satellites continues to increase, and recent NASA advancements in deployable solar array structures, with half of the mass and one-third of the packaging volume compared to the best current arrays, are already being incorporated into commercial satellite product lines. For example, Space Systems Loral and Deployable Space Systems are flight qualifying ROSA arrays 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 is conducting an experiment on the ISS using one of the NASA-funded solar array designs.

Hall-effect thrusters are being developed to operate at over 12 kilowatts and with magnetic shielding to permit years of continuous operations without degradation. A three-year contract for engineering and flight unit delivery of thrusters and power processing units was awarded in spring 2016 to Aerojet Rocketdyne, Inc. In FY 2018, NASA will complete ground testing of the engineering development units for the magnetically-shielded Hall effect thrusters and begin fabrication of the flight units for the spaceflight demonstration of solar electric propulsion. Once proven, high-powered Solar Electric Propulsion can 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 for satellites and accommodate the increasing power demands for government and commercial satellites.

Terrain Relative Navigation

Terrain Relative Navigation project will greatly improve targeting accuracy for landing and provide hazard avoidance to enable access to scientifically compelling sites with acceptable risk. All 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. In FY 2017, this project completed preliminary design and is moving into the detail design phase. The Landing Vision System camera detailed design review was completed in January. The project will complete hardware development, and will enter into integration and test (KDP-D) to support the Mars 2020 schedule.

Evolvable Cryogenics

Managing cryogenic fluids and minimizing boil-off of cryogenic propellants on long duration missions is a critical capability needed to enable high-performance in-space propulsion stages, a key component of future human spaceflight architectures. Advancements in cryogenic fluid management will address challenges experienced by NASA and commercial launch providers by demonstrating the capability of in-space long-term storage, transfer, and mass gauging of cryogenic propellants (i.e., liquid oxygen and liquid hydrogen). With the Evolvable Cryogenics project, STMD will conduct a series of ground demonstrations at MSFC and GRC to validate the performance of propellant storage tanks designed for long-term storage. In addition to managing the propellant boil-off by validating the effectiveness of advanced multi-layer insulation, the team will look to reduce ancillary system mass and complexity. The project will also investigate the utilization of remaining boil-off gases to replace existing pressurization and attitude control systems and to provide electrical power for the Space Launch System (SLS) Exploration Upper Stage and other launch vehicle systems. In addition, the team will develop 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—particularly upper stages—making them more efficient and capable. By taking an incremental ground test approach, Space Technology will prioritize technologies needed by 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.

Robotic In-Space Manufacturing and Assembly of Spacecraft and Space Structures

With commercial industry, Space Technology will develop and demonstrate 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 are factors that limit the size and capabilities of systems pre-assembled on the ground and deployed using a single launch. The following competitively awarded proposals were selected in November 2015:

- Public-Private Partnership for Robotic In-Space Manufacturing and Assembly of Spacecraft and Space Structures—Orbital ATK of Dulles, VA;
- Versatile In-Space Robotic Precision Manufacturing and Assembly System—Made in Space, Inc. of Moffett Field, CA; and
- Dragonfly: On-Orbit Robotic Installation and Reconfiguration of Large Solid RF Reflectors—Space Systems Loral of Palo Alto, CA.

With advances in ultra-lightweight materials, additive manufacturing, robotics, and autonomy, in space manufacturing, assembly, and aggregation concepts are now at a tipping point. 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.

SMALL SPACECRAFT TECHNOLOGY

To rapidly expand the U.S. capability to execute unique missions, Small Spacecraft Technology develops and demonstrates capabilities harnessing small spacecraft and associated technologies. NASA invests to enable new mission architectures through the use of small spacecraft and to enable the augmentation of existing assets and future missions with supporting small spacecraft. These low-cost platforms provide for responsive in-space testing of new technologies and capabilities applicable to exploration, science and across the commercial space sector. NASA supports and harnesses the rapid pace of innovation in the small spacecraft community through public-private partnerships, leveraging of advances in industry and universities, and technology transfer that supports new companies and creates new lines of business. Small Spacecraft Technology projects include the following:

- The Small Spacecraft Capability Demonstration Mission public-private partnerships will test new capabilities of mutual interest to private industry and the U.S. government. These missions are deliberately aggressive from a technological, budgetary, and schedule perspective. If successful, the two missions selected in 2017 will be ready for launch in 2019.
- The Pathfinder Technology Demonstrator series of missions will expand small spacecraft capabilities through in-space testing of subsystem technologies. The Pathfinder spacecraft will fly

technologies derived from public-private partnerships, SBIR projects and other sources, using 6U CubeSat buses procured from industry. The first spacecraft with integrated payload will be delivered for launch in 2018.

- The Smallsat Technology Partnerships, involving collaboration between U.S. universities and NASA researchers, will continue with completion of eight projects selected in 2016 and selection of new projects in 2018. Among the partnerships selected between 2013 and 2016, four have already gone on to suborbital or orbital flight opportunities in other NASA programs.
- Through NASA’s Small Spacecraft Coordination Group and the NASA Small Spacecraft Virtual Institute, NASA will participate in interagency activities, including the U.S. Government Rideshare Working Group, and engage with small spacecraft stakeholders in industry and academia. The Small Spacecraft Virtual Institute is jointly funded by Space Technology and Science.

COMMERCIAL PARTNERSHIPS PORTFOLIO

The Commercial Partnership Portfolio prioritizes investments in the commercial sector to address NASA needs and to stimulate space commercialization. In addition to the efforts described below, the portfolio works closely with the Small Business Innovative Research and Small Business Technology Transfer programs, which advance and commercialize new technologies developed by Small Businesses, and NASA’s Technology Transfer program, which leads technology transfer and technology commercialization activities across the agency.

Regional Economic Development

Regional Economic Development aims to help catalyze the innovation/economic ecosystem by bringing together assets from within a region and federal entities to form a sustainable economic engine. These collaborations serve as a catalyst for economic growth, leading to the generation of new jobs, creation of new companies, new products launched, and NASA technologies commercialized. Among the activities supported, NASA Centers partnered with Society of Manufacturing Engineers (SME) and conducted a Technology Interchange Meeting with over 13,000 personnel from a variety of manufacturing organizations attended. In addition, NASA's Glenn Research Center partnered with Catalyst Connection to hold additive manufacturing event featuring materials subject matter experts. Over 200 people representing various organizations involved in additive manufacturing attended the event in Pittsburgh.

Centennial Challenges

Centennial Challenges offers incentive prizes to generate revolutionary solutions aimed to support future NASA missions to Mars and beyond. 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. 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. The program has targeted a number of technology challenges including the advancement in humanoid robotics that one day might accompany humans on the surface of Mars to the development of vascularized tissue that could help make the journey to Mars safer for humans. For FY 2018, Space Technology is working to organize a new challenge with the Science Mission Directorate to advance portable technologies needed to detect signs of life in places like Europa. The status of current and completed challenges is as follows:

- Cube Quest Challenge ($5.0 million Prize Purse) - 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. Before getting a ride to space, participants face a series of four Ground Tournaments that will assess cubesat communication and propulsion technologies capable of operating in lunar orbit and deep space. Five teams were awarded $30,000 each after Ground Tournament Three. The winners of the Ground Tournament Four will be announced in June 2017 and up to three of these teams will be selected as secondary payloads on the first integrated flight of NASA's Orion spacecraft and SLS rocket.
- Space Robotic Challenge/ Phase 1 ($1.0 million Prize Purse) - The objective of this challenge is to advance software technology needed for autonomous perception and manipulation of dexterous humanoid robots on Mars and beyond. The Allied Organization, Space Center Houston and its partner, NineSigma opened the challenge in August 2016. Within weeks of the announcement, this challenge had over 400 teams from all over the world interested in participating. Twenty teams qualified to participate in the Phase 1 virtual competition, scheduled for June 2017. The Space Robotics Challenge will enter Phase 2 ($1.5 million) in FY 2018.
- 3D Printed Habitat Challenge/ Phase 2 ($1.1 million Prize Purse) - The purpose of the 3D Printed Habitat Challenge is to advance additive construction technology to create sustainable housing on Earth and beyond. The Design competition for this challenge awarded a total of $40,000 to the top three teams. Phase 2 of the challenge was opened last Fall with Bradley University as the Allied Organization. Caterpillar, Bechtel, and Brick & Mortar Ventures are providing many of the facilities and required funding support for the competition. The 19 Phase 2 teams will meet at the Caterpillar Testing Facility in Peoria, IL in August 2017 for competition focused on the core 3D-Printing fabrication technologies and materials properties needed to manufacture structural components from indigenous materials combined with recyclables, or indigenous materials alone. In FY 2018, the 3D Printed Habitat Challenge will enter Phase 3 with a prize purse of $1.4 million where habitats will be fabricated using additive manufacturing.
- After five successful years of competition, Centennial Challenges concluded the Sample Return Robot challenge with partner Worcester Polytechnic Institute. This final competition drew 18 Level 1 teams and saw seven teams progress into the Level 2 competition. A team of students from West Virginia University collected enough samples to win $750,000. After the competition, this team received funding from the National Science Foundation, National Institutes of Health, the U.S. Department of Agriculture, and the Department of Defense to use the rover developed for this challenge as a precision pollination robot.

Flight Opportunities

Flight Opportunities enables the maturation of technologies by providing affordable access to space environments using commercially available suborbital flights. This program helps fulfill the overall goal of advancing space technology to meet future mission needs while simultaneously fostering the growth of the commercial spaceflight market. The program achieves these objectives by selecting promising technologies from industry, academia, and government, and testing them on commercial suborbital launch vehicles. This approach takes technologies from a laboratory environment and advances their maturity through flight testing, while also feeding the development of the spaceflight technologies and infrastructure created by Flight Opportunities flight providers. The program supports flights for both externally funded payloads and NASA-funded technology payloads selected though NASA Research Announcements. Flight Opportunities also collaborates with other NASA programs and government agencies to provide suborbital platform flights for research and/or technology demonstrations.

In FY 2016, Flight Opportunities flew 23 technologies over the course of four parabolic, three high-altitude balloon and two commercial suborbital reusable launch vehicle test campaigns. In addition, NASA on-ramped Blue Origin through its commercial flight vendor solicitation to integrate and fly technology payloads on commercial suborbital reusable platforms. In addition, NASA's Materials International Space Station (MISSE)-Flight Facility has been incorporated into the Flight Opportunities program. MISSE offers researchers extended exposure to on-orbit environments for their research payloads through a facility on the ISS. Flight Opportunities will facilitate and evaluate proposals for payloads every six months, and make recommendations to ISS for inclusion on this platform.

In FY 2017, the Flight Opportunities program plans to fly 38 technologies over the course of two parabolic, nine high-altitude balloon and eight commercial suborbital reusable launch vehicle test campaigns. Technologies include ones that: measure propellant tank fill levels using vibration measurement; use robots that are able to move independently to inspect and assemble large structures; measure samples collected from comets to ensure adequate properties prior to return to earth; view planetary interior structures remotely using electric field measurements; investigate the behavior of fine particles in dusty environments in response to human and robotic activities on the Moon, Mars, and asteroids; and study the effect of surface tension control devices used in new less-hazardous propellant tanks.

In Fall 2016, the Flight Opportunities initiated six public-private partnerships to spur the development of nano-launch capabilities, enabling frequent launches of small spacecraft. These awards were accomplished through the release of the Tipping Point Appendix, which solicited proposals for small launch vehicle technology development. These firm-fixed-price contracts valued at $12 million were awarded to both flight service providers and the vendors/suppliers/support service providers that can significantly improve the prospects of the emerging small launch vehicle market.

Also in FY 2017, Flight Opportunities is pursuing partnerships with U.S. companies and NASA Centers through the release of an Announcement of Collaborative Opportunity solicitation. Awards for Space Act Agreements enable NASA centers to provide technical expertise and test facilities, as well as hardware and software, to the companies for the purpose of accelerating the development of promising technologies for small spacecraft launch systems with the goal of enabling commercial services that have potential for infusion into future NASA missions or infrastructure. Five awards were made for partnerships in the initial round, and the program expects to make two additional selections under the current solicitation.

In FY 2018, Flight Opportunities anticipates continuing its efforts to foster and encourage the development of nano-launch capabilities with aim to enable frequent launches of small spacecraft through public-private partnerships. In addition, testing technology payloads will continue on commercial suborbital reusable platforms technologies for exploration and the commercial utilization of space.

Program Schedule

Specific timelines for deliverables and achievement major milestones vary from project to project, and depend on successful demonstration of experimental capabilities and the results of design, development, fabrication, analyses, and testing.

SPACE TECHNOLOGY RESEARCH AND DEVELOPMENT

Program Management & Commitments

Program Element	Provider
Space Technology Research Grants	Provider: U.S. Universities Lead Center: NASA HQ, Level 2 GRC Performing Center(s): Various Cost Share Partner(s): N/A
NASA Innovative Advanced Concepts	Provider: Various Lead Center: NASA HQ Performing Center(s): Various Cost Share Partner(s): Cost sharing is encouraged
Center Innovation Fund	Provider: NASA centers Lead Center: NASA HQ Performing Center(s): All Cost Share Partner(s): Cost sharing is encouraged
Game Changing Development	Provider: Various Lead Center: NASA HQ, Level 2 Langley (LaRC) Performing Center(s): Various Cost Share Partner(s): Various
Technology Demonstration Missions	Provider: Various Lead Center: NASA HQ, Level 2 MSFC Performing Center(s): Various Cost Share Partner(s): Other NASA programs and other government agencies
Small Spacecraft Technology	Provider: Various Lead Center: NASA HQ; Level 2 ARC Performing Center(s): Various Cost Share Partner(s): Air Force Research Laboratory, Various universities
Centennial Challenges	Provider: Various Lead Center: NASA HQ, Level 2 MSFC Performing Center(s): Various Cost Share Partner(s): External and Internal partners fund competition events; NASA supplies prize money
Flight Opportunities	Provider: Various Lead Center: NASA HQ; Level 2 AFRC Performing Center(s): Various Cost Share Partner(s): Various

SPACE TECHNOLOGY RESEARCH AND DEVELOPMENT

Acquisition Strategy

Space Technology Research and Development uses a blended acquisition approach. Solicitations are open to the broader aerospace community to ensure engagement with the best sources of new and innovative technology. Awards are based on technical merit, cost, programmatic alignment, and impact to the Nation's future space activities. NASA issues an annual umbrella solicitation called Space Technology Research, Development, Demonstration, and Infusion (SpaceTech-REDDI). As program requirements are defined and funding is made available, specific research and technology development and demonstration opportunities will be defined and issued as Appendices to this solicitation. In addition to research grants and cooperative agreements with academia, solicitations targeted to U.S. industry emphasize cost sharing through public-private partnerships.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Technology Demonstration Missions		
Deep Space Atomic Clock	California Institute of Technology, JPL	Pasadena, CA
Solar Electric Propulsion	GRC; GSFC; JPL; Aerojet Rocketdyne Corporation; Deployable Space Systems; Orbital ATK	Cleveland, OH; Greenbelt, MD; Pasadena, CA; Sacramento, CA; Goleta, CA; Goleta, CA
Evolvable Cryogenics	GRC; MSFC, GSFC, KSC, ARC United Launch Alliance,	Cleveland, OH; Huntsville, AL, Greenbelt, MD; Cape Canaveral, FL, Moffett Field, CA Centennial, CO
Green Propellant Infusion Mission	Ball Aerospace (Prime); Aerojet Rocketdyne Corporation; USAF Research Laboratory; USAF Space and Missile Systems Center; GRC; LaRC; KSC	Boulder, CO; Redmond, WA; Edwards, CA; Albuquerque, NM; Cleveland, OH; Cape Canaveral, FL
Restore-L	GSFC; KSC, Space Systems Loral, Motiv Space Systems; Ball Aerospace	Greenbelt, MD; Cape Canaveral, FL; Pasadena, CA; Pasadena, CA; Boulder, CO
Deep Space Optical Communication	JPL	Pasadena, CA
In-Space Robotic Manufacturing and Assembly	Orbital ATK; Made in Space, Inc.; Space Systems Loral; LaRC; ARC	Dulles, VA; Moffett Field, CA; Palo Alto, CA; Hampton, VA; Moffett Field, CA

SPACE TECHNOLOGY RESEARCH AND DEVELOPMENT

INDEPENDENT REVIEWS

STMD conducts Directorate Program Management Council reviews, and representatives from the Office of Chief Engineer, the Office of Safety and Mission Assurance, and the Office of Chief Financial Officer assess performance during Agency-level Baseline Performance Reviews. In addition, Space Technology conducts standing review boards for projects with life cycle costs of greater than $250 million. Within the current portfolio, this includes Restore-L and Laser Communications Relay Demonstration.

CSTD TDM LASER COMM RELAY DEMO (LCRD)

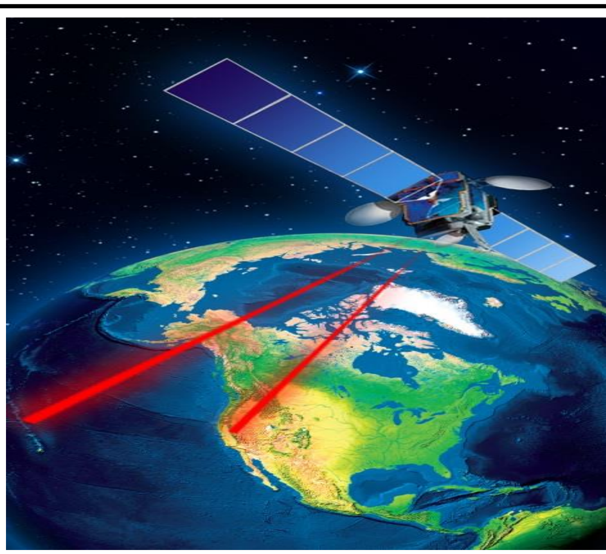
Formulation	Development	Operations

FY 2018 Budget

		Actual	Enacted	Request	Notional					
Budget Authority (in $ millions)	**Prior**	**FY 2016**	**FY 2017**	**FY 2018**	**FY 2019**	**FY 2020**	**FY 2021**	**FY 2022**	**BTC**	**Total**
Formulation	132.6	32.9	3.9	**0.0**	0.0	0.0	0.0	0.0	0.0	169.5
Development/Implementation	0.0	5.1	34.8	**31.8**	20.1	0.0	0.0	0.0	0.0	91.8
Operations/Close-out	0.0	0.0	0.0	**0.0**	1.5	0.0	0.0	0.0	0.0	1.5
2017 MPAR LCC Estimate	**132.6**	**38.0**	**38.7**	**31.8**	**21.6**	**0.0**	**0.0**	**0.0**	**0.0**	**262.7**
Total STMD Budget	**127.1**	**30.5**	**25.7**	**21.5**	**17.2**	**0.0**	**0.0**	**0.0**	**0.0**	**222.0**
Change from FY 2017				**0**						
Percentage change from FY 2017				**0**						
Total NASA Budget	**132.6**	**38.0**	**38.7**	**31.8**	**21.6**					**262.7**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



The Laser Communications Relay Demonstration seeks to prove the utility of bi-directional optical communications relay services between geosynchronous orbit and Earth.

TDM LASER COMM RELAY DEMO

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 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, other agencies, and U.S. satellite manufacturers and operators given the rising demand for bandwidth, consistent with the responses NASA received from the industry on

CSTD TDM LASER COMM RELAY DEMO (LCRD)

Formulation	Development	Operations

to STMD Request for Information. Set to fly as a hosted payload, this technology demonstration 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 (TDRS) 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 2018

No Major Changes

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 2016

Laser Communication Relay Demonstration conducted ground tests of Ground Modem 1 optical communications with Massachusetts Institute of Technology Lincoln Labs and developed an Optical Terminal testbed. In addition, the project delivered the engineering model Space Switching Unit to Lincoln Labs.

WORK IN PROGRESS IN FY 2017

With application to both commercial and NASA operations, STMD completed Critical Design Review (CDR) and Key Decision Point C (KDP-C) for the LCRD mission.

The project finalized a hosting agreement for LCRD with the spacecraft provider and will deliver flight modems, Optical Assemblies, Controller Electronics, and Space Switching Units for integration to the flight payload on the LCRD Support Assembly.

CSTD TDM LASER COMM RELAY DEMO (LCRD)

Formulation	Development	Operations

KEY ACHIEVEMENTS PLANNED FOR FY 2018

Upon completion of hardware build and delivery of last components, the project will complete integration, perform testing, and deliver the flight payload to the spacecraft integrator to support a November 2019 Launch Readiness Date.

SCHEDULE COMMITMENTS/KEY MILESTONES

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

CSTD TDM LASER COMM RELAY DEMO (LCRD)

Formulation	Development	Operations

Development Cost and Schedule

The development cost estimate includes HEOMD/SCaN ($28.6M) funding as well as STMD ($63.2M).

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	63.1 (STMD)	70	2018	63.1	0	Launch	Nov 2019	Nov 2019	0
2017	91.8 (NASA)	70	2018	91.8	0	Launch	Nov 2019	Nov 2019	0

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

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	91.8	91.8	0.0
Aircraft/Spacecraft	9.9	9.9	0.0
Payloads	20.2	20.2	0.0
Systems I&T	4.1	4.1	0.0
Launch Vehicle	0.0	0.0	0.0
Ground Systems	6.3	6.3	0.0
Science/Technology	2.6	2.6	0.0
Other Direct Project Costs	48.7	48.7	0.0

CSTD TDM LASER COMM RELAY DEMO (LCRD)

Formulation	Development	Operations

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Program Management	Project Management, LCRD Payload, LCRD Mission Operations Center (LMOC)	Goddard Space Flight Center	No change
Optical Ground Station	Optical Ground Stations, RF Ground Station and STPSat-6 Mission Control Center (SAGE).	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 LV	STPSat-6 Spacecraft (S/C) and Launch Vehicle (LV)	USAF & Orbital ATK (Spacecraft vendor)	No Change

Project Risks

Risk Statement	Mitigation
Given that the launch date slipped two months prior to the Air Force selection of a launch vehicle provider, there is risk with additional slippage beyond the 70% schedule confidence level will occur.	NASA (Project team and Space Network) is on the Senior Steering Committee for the space vehicle. This position will enable additional insight and advocacy unavailable in most hosted spacecraft arrangements. As a mission partner, NASA also has some influence on spacecraft cost increases.

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

CSTD TDM LASER COMM RELAY DEMO (LCRD)

Formulation	Development	Operations

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
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

HUMAN EXPLORATION AND OPERATIONS

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Exploration	3996.2	4324.0	**3934.1**	4259.7	4513.3	4437.9	4449.9
Space Operations	5032.3	4950.7	**4740.8**	4532.8	4279.2	4354.6	4342.6
Total Budget	**9028.5**	**9274.7**	**8674.9**	**8792.5**	**8792.5**	**8792.5**	**8792.5**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

The FY 2018 PBR for Exploration includes a transfer to CECR account to support modifications required to Kennedy Space Center facilities for Exploration Upper Stage and MAF repairs.

HUMAN EXPLORATION AND OPERATIONS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Exploration	3996.2	4324.0	**3934.1**	4259.7	4513.3	4437.9	4449.9
Space Operations	5032.3	4950.7	**4740.8**	4532.8	4279.2	4354.6	4342.6
Total Budget	**9028.5**	**9274.7**	**8674.9**	**8792.5**	**8792.5**	**8792.5**	**8792.5**
Change from FY 2017			**-599.8**				
Percentage change from FY 2017			**-6.5%**				

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

The FY 2018 PBR for Exploration includes a transfer to CECR account to support modifications required to Kennedy Space Center facilities for Exploration Upper Stage and MAF repairs.

NASA is committed to extending human presence into the solar system and opening the space frontier. The first steps of this great human endeavor are well underway, with research into long-duration spaceflight continuing aboard the International Space Station (ISS), the development of next generation launch systems and crew vehicles, and investments in new technologies to increase the affordability, capability, and safety of exploration activities.

To enable this effort, NASA is advancing access to low Earth orbit by engaging U.S. commercial providers. Through FY 2016, Space Exploration Technologies Company (SpaceX) and Orbital ATK have flown a combined total of 14 successful cargo delivery flights to ISS, including their two demonstration flights. Developing and operating this service using a public-private partnership was less expensive than a traditionally-procured approach. By having two commercial partners for cargo, NASA increases the resilience of its space transportation capabilities, as evidenced by the minimal impact from the Orb-3 and SpX-7 losses. ISS was able to absorb both losses without immediate impacts to operations and utilization due to excellent logistics planning and management. Building upon this paradigm shift to procure services from privately held companies, NASA also has entered into contracts with two industry partners to develop a U.S. commercial capability to transport crew to and from ISS. SpaceX is scheduled to begin certified crew transportation services in September 2018, followed by Boeing in December 2018. In addition, NASA recently awarded Commercial Resupply Services-2 to SpaceX, Orbital ATK, and Sierra Nevada to provide cargo transportation services to ISS beginning in 2019.

Exploring deep space requires the capability to transport crew and large masses of cargo beyond low Earth orbit. To accomplish this, NASA is developing deep space exploration capabilities, including the Orion crew capsule, the heavy-lift Space Launch System launch vehicle, and supporting ground facilities and systems as the foundational components. The Orion crew exploration vehicle will carry up to four humans to orbit with an emergency abort capability, provide transit to cislunar space, sustain the crew while in space for up to 22 days, and provide safe reentry from deep space. While not part of the existing development plans, Orion's systems could operate in space for up to 1,000 days with additional habitation volume and systems. Future versions of the Space Launch System (SLS) could provide unprecedented volume to deep space, leveraging NASA heritage systems to reduce risk. Upgraded ground operations capabilities at Kennedy Space Center will process flight hardware, assemble and launch the vehicles, and recover crew after the mission.

Before these systems can safely send humans into deep space for extended missions, NASA must continue vital human health research already underway, develop key technologies, and enhance the supporting capabilities required for mission success. The Human Exploration and Operations Mission Directorate (HEOMD) budget funds a portfolio of research, development, and operational programs to extend the boundaries of human space exploration and generate new scientific and technical knowledge. The advancement of new technologies and capabilities are essential for an ambitious and achievable exploration program, including new capabilities for in-situ resource utilization, deep-space habitation and mobility, in-space power and propulsion, and entry, decent, and landing. HEOMD utilizes a mix of NASA civil service expertise, conventional industrial contracts, milestone-based private sector capability developments and services, and international and U.S. commercial partnerships.

EXTENDING HUMAN PRESENCE INTO THE SOLAR SYSTEM: ENABLING MULTIPLE DESTINATIONS

NASA envisions a future where people will be able to live and work in deep space for years and return safely home to Earth. In this new era, NASA is implementing an exploration strategy using a capability-driven approach. This strategy leverages near-term mission opportunities that enable an incremental buildup of infrastructure for more complex missions in the future, such as exploring Mars and its moons as part of the agency’s goal of opening the space frontier.

The cornerstone of our current efforts is ISS, which has provided opportunities to investigate the challenges of future human spaceflight. What capabilities do we need for long-duration missions? What effect does the harsh environment of space have on the crew? How can we maximize the crew’s health and performance on future deep-space missions? What habitation system will provide the reliability needed for a deep space mission? Research continues on ISS to answer these questions and to validate space exploration capabilities in an operational environment, while maintaining close proximity to Earth.

To advance our ability to conduct a sustainable campaign of progressively more complex exploration missions, NASA intends to explore various locations in cislunar space. In the volume of space around the Earth-Moon system, NASA and its partners can identify and pioneer new solutions to technical and human challenges that could only have been discovered or engineered in deep space. In this region of space, crews would conduct test operations of SLS and Orion, demonstrate new space systems, and build up and validate the capability to travel beyond the Earth-Moon system.

As NASA incrementally lessens human reliance on Earth, cislunar space will provide a location from which we can mount missions to the more distant reaches of space, including expeditions to Mars. The distance and duration of these future missions requires that crew and transportation systems be largely independent of Earth. Logistics, power and propulsion systems, human factors, habitat, and operations all must be capable of supporting the autonomous operations necessary to travel millions of miles and spend many months in space. NASA’s strategy is to move in phases from Earth-reliant research and technology development through cislunar space to eventually achieve an Earth-independent exploration capability for human mission durations that enable us to reach Mars and other destinations in the solar system.

HUMAN EXPLORATION AND OPERATIONS

PHASE 0: EXPLORATION SYSTEMS TESTING ON ISS AND IN LOW EARTH ORBIT

ISS 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.

Not only is ISS capable of supporting a broad range of research and technology development, it is also serving as a test bed for new business relationships that will enable the commercialization of low Earth orbit. NASA has partnered with the Center for the Advancement of Science in Space (CASIS) to exploit the National Lab portion of ISS for commercial and other government agency research, allowing researchers and entrepreneurs representing a wide range of disciplines to develop groundbreaking technologies and products in a microgravity environment. While CASIS is broadening the non-traditional demand-side use of ISS, NASA is assisting commercial service providers in increasing research capabilities and offering services on the supply-side. For example, NASA launched the Bigelow Expandable Activity Module (BEAM) and attached it to ISS. Technology development and demonstrations on ISS are critical to exploration beyond low Earth orbit and BEAM provides data on how expandable habitats work in the conditions of space.

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 2018, 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 and its partners are working together to create concepts and technologies that can generate revenue in low Earth orbit, to develop commercial platforms and services in this region of space, and to enable the private sector to transport cargo and people from the ground, into space and back. These public-private partnerships will foster innovation and help prepare the private sector to take a leading role in low Earth orbit during and after the transition off the ISS platform.

PHASE 1: CISLUNAR DEMONSTRATION OF EXPLORATION SYSTEMS

NASA's deep space missions require advanced capabilities for space travel and life support allowing both the spacecraft and humans to live away from the safety of Earth for years. These technologies require innovation, modernization, knowledge, and advancements in nearly every field, from propulsion to thermal protection to advanced avionics; from fundamental biology to botany, physiology and, psychology.

NASA is now in the fabrication and assembly phase of developing its new Space Launch System, Orion crew exploration vehicle, and launch site ground systems. NASA is focused on bringing these capabilities together to conduct the first Exploration Mission. Exploration Mission-1 (EM-1) is the first milestone test of America's new deep space exploration system. Launching atop SLS, the uncrewed Orion spacecraft will travel into space for up to a 21-day journey beyond the Moon and back to Earth. Preparing new systems for first flight is always a challenge. NASA continues to evaluate the impact the following events will have on the EM-1 launch readiness date: 1) the integrated manufacturing, test, and processing schedules based on projection of the ESA service module delivery; 2) the impact of tornado damage recovery at Michoud Assembly Facility and 3) first time production issues for the SLS stages element. NASA will be providing updates to the launch readiness date in the near future.

EM-1 is not only a test flight, but will include a payload of several CubeSats that will be deployed to analyze the presence of water and ice on the Moon, set up an observation post to track near-Earth asteroids, and detect and measure radiation levels. The data that we gather from these CubeSats will be used to better understand cislunar space.

NASA is also working toward the first crewed mission (EM-2), scheduled to launch in FY 2021, with a commitment to launch no later than 2023.

Building on the success of NASA's partnerships with commercial industry to date, in early 2015 NASA selected 12 Next Space Technologies for Exploration Partnerships (NextSTEP) to advance concept studies and technology development projects in the areas of advanced propulsion, habitation and small satellites. NASA selected three companies to advance electric propulsion capabilities, two to develop CubeSats to launch as secondary payloads on EM-1 to explore volatiles on the moon, four to provide advanced habitat concept studies, and three to advance the state of the art toward the regenerative Environmental Control and Life Support Systems (ECLSS).

The advanced electric propulsion contracts have achieved significant success in maturing new high-powered in-space propulsion technologies required for deep space exploration. Each partner completed development of most of their subsystems and all their one-year milestones including culmination of operational testing time moving closer to developing 100 kW electric thrusters. By the end of FY 2017 this progress includes completing 10 cumulative hours leading to 100 continuous hours of thermal steady state operations. Similarly, the two CubeSat efforts have made steady progress meeting their milestones to launch as secondary payloads on EM-1. In the follow-on effort, NextSTEP-2, NASA selected the same four companies previously chosen for habitation concept studies (Bigelow Aerospace, Boeing, Lockheed Martin, and Orbital ATK) in the summer of 2016, plus Sierra Nevada Corporation, to develop full-sized ground prototypes of their habitat concepts by 2018. NanoRacks also was selected in the second phase to conduct a feasibility study on the concept of converting spent rocket upper stages into habitats while in space. After ground-testing the five full-scale prototypes in 2018, NASA will determine the agency's acquisition approach for flight units to be deployed in cislunar space. Through NextSTEP-2, NASA also continued the three ECLSS contracts that will advance the state of the art toward the regenerative systems required for deep space habitats.

PHASE 2: CISLUNAR VALIDATION OF EXPLORATION SYSTEMS

To travel beyond low Earth orbit, NASA requires enhanced habitation and related capabilities. Researchers are studying the effects of long-duration space exploration on humans in an effort to safeguard crews and assure mission success. New technologies are being infused into systems and capabilities geared toward supporting eventual missions to Mars including solar electric propulsion systems, deep space habitation systems, in-situ resource utilization, and operations with reduced logistics dependence. The demands of deep space require assuring robust communications and data download, and increasingly complex navigation systems. These efforts continue to be critical priorities within HEOMD's

Space Operations and Explorations budgets, and will enable NASA to extend our progress along the capability driven framework while maintaining reliable and affordable access to space. One example is the NextStep BAA program, where NASA is working through public-private partnerships to develop new capabilities, like deep-space habitation, that leverage commercial interests in low-earth orbit and deep-space to advance new technologies and increase affordability.

EARTH-INDEPENDENT ACTIVITY

To enable space travel that is Earth independent, NASA will continue to incrementally and progressively expand capabilities and distance from Earth. We will likely need to complete development of whole new types of entry and landing systems, partial-gravity countermeasures, and long-duration surface systems such as in-situ resource utilization (ISRU) and in-space manufacturing. Activities are underway in these areas in collaboration with the Science Mission Directorate (SMD) and the Space Technology Mission (STMD) Directorate. For example, the HEOMD and the STMD are jointly funding the Mars Oxygen ISRU Experiment (MOXIE) on the SMD's Mars 2020 rover mission, which will demonstrate the capability to produce and store oxygen from Martian atmospheric carbon dioxide. Oxygen generated at Mars will be essential for production of both breathable atmosphere and fuel for ascending from the Martian surface. NASA is also collaborating with SpaceX on the company's Red Dragon mission to Mars in 2020. The mission offers NASA a flight technology demonstration of critical entry, descent, and landing technologies for human exploration, particularly supersonic retro-propulsion, in the Mars atmosphere about a decade sooner and at a fraction of the cost to NASA for a future data campaign.

SPACEFLIGHT SERVICES

The HEOMD portfolio also includes core capabilities needed to conduct the Agency's human and robotic exploration, which include Space Communications and Navigation (SCaN), Launch Services, astronaut selection and training, crew health and safety, Rocket Propulsion Test (RPT), and related activities.

Human space exploration inspires us, advances our understanding of our world and beyond, fuels new industries, and demands a highly-skilled workforce. As we explore and expand human presence into the solar system, we open the space frontier and advance American leadership, helping to create opportunities for diplomacy and global cooperation. Space exploration is not limited to economic, scientific or political benefit; ultimately, space exploration is about inspiration.

EXPLORATION

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Exploration Systems Development	3640.8	3929.0	**3584.1**	3739.7	3898.2	3771.5	3762.3
Exploration Research and Development	355.4	395.0	**350.0**	520.0	615.1	666.4	687.6
Total Budget	**3996.2**	**4324.0**	**3934.1**	**4259.7**	**4513.3**	**4437.9**	**4449.9**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

The FY 2018 PBR includes a transfer to CECR account to support modifications required to Kennedy Space Center facilities for Exploration Upper Stage and MAF repairs.

EXPLORATION

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Exploration Systems Development	3640.8	3929.0	**3584.1**	3739.7	3898.2	3771.5	3762.3
Exploration Research and Development	355.4	395.0	**350.0**	520.0	615.1	666.4	687.6
Total Budget	**3996.2**	**4324.0**	**3934.1**	**4259.7**	**4513.3**	**4437.9**	**4449.9**
Change from FY 2017			**-389.9**				
Percentage change from FY 2017			**-9.0%**				

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

The FY 2018 PBR includes a transfer to CECR account to support modifications required to Kennedy Space Center facilities for Exploration Upper Stage and MAF repairs.

On March 8, 2017, NASA's Orion Spacecraft Parachutes Tested at U.S. Army Yuma Proving Ground in Arizona.

NASA is shaping the future architecture of human space exploration. With the objective of extending human presence deeper into the solar system through a sustainable human and robotic spaceflight program, the Agency has developed an approach to expand the distance and duration of human space exploration building off the exploration happening today on the International Space Station. Human Exploration and Operations Mission Directorate (HEOMD) programs continue to develop capabilities within the Exploration budget, intended to provide flexibility in destination for the Nation’s human spaceflight program. NASA will evolve these core capabilities through continued technical advancements. The agency has developed a phased approach for this activity, starting with ISS and progressing to deep space and beyond.

HEOMD’s Exploration Systems Development programs are creating components of this architecture for human exploration beyond low Earth orbit. The Orion, crew capsule, Space Launch System (SLS) rocket, and Exploration Ground Systems (EGS) that support their integration and launch, will take us to cislunar space. It is here where NASA will conduct deep-space missions to test systems and concepts, paving the way for long-duration human space exploration while conducting a variety of science missions, some of which may require access to the lunar environment and surface.

Extending human presence deeper into the solar system also requires the expansion of technical and scientific knowledge to tackle complex problems, develop creative new solutions, and increase the affordability of space exploration. Through Exploration Research and Development programs, the Human Research Program (HRP) is working to understand and mitigate the effects of long-term human exposure to space. NASA's Advanced Exploration Systems (AES) is developing technologies and maturing systems required for deep-space missions by identifying and pioneering new solutions to technical and human challenges.

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

EXPLORATION SYSTEMS DEVELOPMENT

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Orion Program	1270.0	1350.0	**1186.0**	1170.2	1123.4	1124.5	1124.5
Crew Vehicle Development	1251.5	1338.7	**1175.5**	1159.7	1112.9	1114.0	1114.0
Orion Program Integration and Support	18.5	11.3	**10.5**	10.5	10.5	10.5	10.5
Space Launch System	1971.9	2150.0	**1937.8**	2083.6	2265.6	2177.6	2177.4
Launch Vehicle Development	1921.9	2094.9	**1881.7**	2032.7	2189.9	2101.1	2101.1
SLS Program Integration and Support	50.0	55.1	**56.1**	50.8	75.7	76.5	76.3
Exploration Ground Systems	398.9	429.0	**460.4**	486.0	509.1	469.5	460.5
Exploration Ground Systems Development	398.9	415.7	**460.4**	470.7	493.7	453.8	444.8
EGS Program Integration and Support	0.0	13.3	**0.0**	15.3	15.4	15.7	15.7
Construction & Envrmtl Compl Restoration	28.3	8.8	**95.9**	0.0	0.0	0.0	0.0
Exploration CoF	28.3	8.8	**95.9**	0.0	0.0	0.0	0.0
Total Budget	**3669.1**	**3937.8**	**3680.1**	**3739.7**	**3898.2**	**3771.5**	**3762.3**
Change from FY 2017			**-1.7**				
Percentage change from FY 2017			**-0.05%**				

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

Total budget in FY 2017 exceeds appropriated amount because it is a combination of the CECR account and the ESD account.

EXPLORATION SYSTEMS DEVELOPMENT

The team at the Neil Armstrong Operations and Checkout building at NASA's Kennedy Space Center in Florida pose in front of the Exploration Mission-1 crew module (center), the crew module structural test article (far left) and the Exploration Flight Test-1 crew module (far right) that flew in Dec. 2014.

NASA's Exploration Systems Development programs are working together to build the foundational infrastructure of the deep space exploration system. The Orion crew vehicle, Space Launch System (SLS) rocket, and the Exploration Ground Systems at Kennedy Space Center will enable the Agency's bold new missions to extend human presence into the solar system.

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 carry crew to space, 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 operations 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 heavy-lift launch vehicle for a new era of exploration beyond Earth's orbit into deep space. Designed to be the world's most powerful rocket, SLS will launch astronauts in the Orion spacecraft on missions to cislunar space, and eventually support missions to Mars, while opening new possibilities for other payloads including robotic scientific missions to places like Mars, Saturn and Jupiter. With the highest-ever payload mass and volume capability and energy to speed missions through space, SLS is designed to be flexible and evolvable, to meet a variety of crew and cargo mission needs.

The objective of exploration ground systems is to prepare KSC to process and launch next-generation vehicles and spacecraft. 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 we look to the future, 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 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Crew Vehicle Development	1251.5	1257.1	**1175.5**	1159.7	1112.9	1114.0	1114.0
Orion Program Integration and Support	18.5	--	**10.5**	10.5	10.5	10.5	10.5
Total Budget	**1270.0**	**1350.0**	**1186.0**	**1170.2**	**1123.4**	**1124.5**	**1124.5**
Change from FY 2017			**-164.0**				
Percentage change from FY 2017			**-12.1%**				

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

The Orion crew module adapter was lifted out of its work stand Nov. 11 and is now undergoing secondary structure outfitting in the Neil Armstrong Operations and Checkout Building high bay at NASA's Kennedy Space Center in Florida. Photo credit: NASA/ Glen Benson

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. The first of two uncrewed flight tests planned for the Orion spacecraft, Exploration Flight Test - 1 (EFT-1), flew in December 2014, paving the way for astronauts to venture beyond low Earth orbit for the first time since the Apollo program in the early 1970s.

This capsule-shaped vehicle has a familiar look, but its crew module (CM), service module (SM), spacecraft adapter, and launch abort system (LAS) incorporate numerous technology advancements and innovations. Orion's LAS can activate within milliseconds to carry the crew from harm's way and position the module for a safe landing. The spacecraft's propulsion, thermal protection, avionics, and life support systems will enable extended duration missions beyond Earth orbit (BEO) and into deep space. Its modular design will be capable of integrating additional new technical innovations as they become available.

Orion design, development, and testing (including the flight tests) will have the spacecraft ready to carry crew no later than FY 2023. Future flights of Space Launch System (SLS) and the Orion spacecraft into cislunar space will extend our capability for human deep space exploration operations, reducing the overall risk as mission durations extend. Orion missions will use the proving ground of cislunar space to develop the systems and procedures necessary for Mars-class missions.

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

ORION PROGRAM

EXPLANATION OF MAJOR CHANGES IN FY 2018

NASA continues to evaluate the impact the following events will have on the EM-1 launch readiness date: 1) the integrated manufacturing, test, and processing schedules based on projection of the ESA service module delivery; 2) the impact of tornado damage recovery at Michoud Assembly Facility; and 3) first time production issues for the SLS stages element. NASA will be providing updates to the launch readiness date in the near future.

Program Elements

ORION PROGRAM INTEGRATION AND SUPPORT

Orion program integration and support activities manage the SLS and Exploration Ground System (EGS) program interfaces. 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 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

Formulation	Development	Operations

FY 2018 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022	BTC	Total
Formulation	4666.8	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	4666.8
Development/Implementation	297.0	1251.4	1100.5	**1107.4**	1110.4	826.0	558.0	254.4	111.1	6616.2
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2017 MPAR LCC Estimate	**4963.8**	**1251.4**	**1100.5**	**1107.4**	**1110.4**	**826.0**	**558.0**	**254.4**	**111.1**	**11283.0**
Total Budget	**4958.8**	**1251.5**	**1257.1**	**1175.5**	**1159.7**	**1112.9**	**1114.0**	**1114.0**	**0.0**	**13143.4**
Change from FY 2017				**-81.6**						
Percentage change from FY 2017				**-6.5%**						

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

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The difference between the total budget and the MPAR LCC estimate, is the total budget represents content outside of EM-2.

The total budget prior line represents FY 2011 pre-formulation and FY2012 - FY2015 budgets, excluding CoF and additional expenditures from 2005-2011 under the Constellation program.

CREW VEHICLE

Formulation	Development	Operations

Engineers at NASA's Michoud Assembly Facility (MAF) in New Orleans, LA, perform the first weld on the Orion spacecraft pressure vessel for EM-1 on Sept. 5, 2015. This is the third Orion pressure vessel built. Engineers continue to refine the design, reducing the number of welds from 33, on the first pressure vessel, to seven on the current one, saving 700 pounds of mass.

PROJECT PURPOSE

Orion will be capable of transporting humans to multiple destinations beyond our Moon and into deep space, sustaining them longer than ever before, and returning them safely to Earth. Drawing from more than 50 years of human spaceflight Research and Development (R&D) and stimulating new and innovative manufacturing and production capabilities, Orion's design will meet the evolving needs of our Nation's space program, and push the envelope of human exploration for decades to come. For further programmatic information, go to http://www.nasa.gov/orion.

EXPLANATION OF MAJOR CHANGES IN FY 2018

NASA continues to evaluate the impact the following events will have on the EM-1 launch readiness date: 1) the integrated manufacturing, test, and processing schedules based on projection of the ESA service module delivery; 2) the impact of tornado damage recovery at Michoud Assembly Facility; and 3) first time production issues for the Space Launch System stages element. NASA will be providing updates to the launch readiness date in the near future.

PROJECT PARAMETERS

Orion will be able to carry a crew of four astronauts beyond Earth orbit and provide habitation and life support for up to 21 days. The spacecraft's three components are the Crew Module (CM), the Service Module (SM), and the Launch Abort System (LAS), with a separate adapter to connect the spacecraft and launch vehicles. While the CM 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 within which to live and work for long durations far from Earth. Orion's advanced heat shield will protect the crew from reentry heating during a high-speed return from beyond Earth orbit – heating that will exceed that experienced by any human spacecraft in over four decades. The SM is comprised of a crew module adapter and the European Space Agency (ESA)-designed and developed service module (ESM). Together they provide in-space power, propulsion, and other life support systems. On a tower atop the crew module sits the LAS, which in the event of an emergency during launch or climb to orbit will activate within milliseconds to propel the crew module away from the launch vehicle to safety. The abort system also provides a protective shell that shields the crew module from dangerous atmospheric loads

Formulation	Development	Operations

and heating during ascent. Once Orion is out of the atmosphere and safely on its way to orbit, the spacecraft will jettison the LAS.

ACHIEVEMENTS IN FY 2016

Engineers at NASA's Kennedy Space Center (KSC) completed a series of pressure tests on the Orion crew module. The tests confirmed the weld points of the underlying structure, called the pressure vessel, will protect astronauts during the launch, in-space, re-entry and landing phases of spaceflight. NASA and ESA conducted a Critical Design Review (CDR) for Orion's European-built service module. The service module is an essential part of the spacecraft that will power, propel, and cool Orion in deep space as well as provide air and water for crewmembers. During the review process, technical experts examined the module designs and numerous technical items were processed and closed out, giving engineers confidence the module design is mature enough to continue with fabrication, assembly, integration and testing.

The Orion team completed the heat shield structure for NASA's EM-1. The completed structure underwent static loads testing, proving it can endure the 350,000-pound load the spacecraft will experience during its next flight beyond the Moon and back. The performance of the third and final LAS abort motor igniter qualification static test was a success. This test is a significant milestone for Orion and an important step forward on the path to full qualification of the abort motor for the LAS.

Engineers completed pyroshock testing with a full-scale test version of the Orion service module at the Space Power Facility at Glenn Research Center's (GRC) Plum Brook Station (PBS). During the tests, engineers fired powerful pyrotechnics to simulate the shocks the service module will experience as Orion separates from the Space Launch System (SLS). Additionally, ESA, Airbus Defence and Space, and the NASA service module team successfully completed the second solar panel deployment test at PBS. The deployment test was conducted after a series of acoustic and vibration tests to ensure the arrays will successfully deploy on orbit after being launched on the powerful SLS. NASA successfully kicked off a series of tests September 30th, to qualify Orion's parachute system for flights with astronauts, a milestone that will help the Agency safely return crew to Earth from deep -space missions.

WORK IN PROGRESS IN FY 2017

NASA and the U.S. Navy conducted testing in October off the coast of California using the USS San Diego and various watercraft and equipment to practice for recovery of Orion on its return from deep - space missions. The testing, called Underway Recovery Test (URT-5) is the first major integrated test in a series of tests to prepare the recovery team, hardware and operations to support recovery of the Orion spacecraft using a U.S. Navy ship. The term "underway" refers to recovery tests done when a ship is at sea.

Tile blocks have been pre-fitted around the Orion EM-1 crew module heat shield inside the Neil Armstrong Operations and Checkout Building high bay at KSC in Florida. The heat shield is one of the most critical elements of Orion and protects it and the astronauts inside from searing temperatures experienced during re-entry through Earth's atmosphere on the return home. For Orion's next spaceflight, the top layer of Orion's heat shield that is primarily responsible for helping the crew module endure

Formulation	Development	Operations

reentry heat will be composed of approximately 180 blocks, which will be made of an ablative material called Avcoat designed to shed away as it heats up.

Engineers at PBS finished a series of tests on a full-size test version of Orion's service module to verify it can withstand the vibrations it will experience when it launches and travels into space atop SLS. In a lab at Johnson Space Center (JSC) in Houston, engineers simulated conditions astronauts in space suits would experience when the Orion spacecraft is vibrating during launch atop the SLS. A series of tests occurring at JSC will help human factors engineers assess how well the crew can interact with the displays and controls they will use to monitor Orion's systems and operate the spacecraft. Engineers and technicians with NASA and Orion manufacturer, Lockheed Martin, are preparing the EM-1 crew module for a series of proof pressure and leak tests to confirm the welded joints of the propulsion and Environmental Control and Life Support Systems (ECLSS) tubing are solid and capable of withstanding launch, re-entry and landing. The work test series will take place at the Neil Armstrong Operations and Checkout Building at KSC in Florida. The Orion propulsion system includes the propellant and thrusters that support deorbit and re-entry of the spacecraft from deep space while the ECLSS provides cooling for interior and exterior components on the crew module throughout a long-duration mission.

Orion completed a functional test of its crew module recovery mechanism (CMRM) in the Panel Test Facility at Ames Research Center (ARC) in California in February. After Orion missions, recovery personnel will use the CMRM to capture and handle the crew module after it splashes down in the ocean. Since the mechanism must function shortly after splashdown, it can be hot during this operation. The Panel Test Facility functional test ensured the CMRM will operate correctly even when still very hot from the heat of re-entry. The test was successful, demonstrating end-to-end CMRM operation at temperatures near 400 degrees Fahrenheit – a level higher than those expected during an actual mission.

NASA is continuing a series of tests throughout FY 2017 to qualify Orion's parachute system for flights with astronauts.

The first set of the ESM avionics equipment shipped to the Lockheed Martin Integrated Test Lab (ITL) after completing their development and integrated testing at the Airbus Defence & Space facility in Les Mureaux, France. After installation in the ITL, post-ship checkouts and passing an Acceptance Review, Lockheed Martin will begin integration and testing with U.S. equipment. Once all components are fully integrated, the ITL will be able to emulate ESM spacecraft functionality, and enable integrated Command-Service Module subsystem and mission testing. The ESM Propulsion Qualification Module (PQM) underwent final assembly at OHB Sweden prior to shipment to JSC's White Sands Test Facility (WSTF) in New Mexico for propulsion testing. ESA, Airbus Defence and Space, NASA and Lockheed Martin have successfully completed the formal handover of the European Service Module Structural Test Article (E-STA), transferring ownership of the Airbus built hardware from ESA to NASA.

The CM will power up for Operations and Checkout integrated tests. The ESM will be delivered to KSC third quarter of FY 2017. The CM/SM mate will occur in the fourth quarter of FY 2017. Before mating to the integrated SM, the program will complete CM assembly and integration. This includes installing the thermal protection system, including the heat shield backshell and Forward Bay Cover; the recovery systems including the Command Module Up-righting System (CMUS), parachute system with associated pyrotechnics; avionics, software, and harnessing; structural support; fluids handling; and other required flight systems. The combined spacecraft will ship to PBS for thermal and vacuum testing. The plan is to

CREW VEHICLE

Formulation	Development	Operations

release the final three flight software loads by mid FY 2017. The inert LAS for EM-1 will deliver in the fourth quarter of FY 2017. Manufacturing for the EM-2 pressure vessel structure will start, as NASA, in parallel to EM-1, prepares for the first crewed mission of Orion's EM-2.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

FY 2018 begins with the mating of LAS to the Orion CM and SM. The next step will be the delivery of the Orion Crew and SM to Ground Operations for final preparation and stacking in the Vehicle Assembly Building (VAB) at KSC. The Orion spacecraft will be mated to the SLS in the third quarter of FY 2018 and will undergo full integration prior to rollout of the stacked vehicle to LC- 39B. After completing tests and final checkouts at the launch pad, Orion and SLS will be ready for the EM-1 launch.

In parallel to EM-1 launch preparation in FY 2018, Orion will continue building the spacecraft for the first crewed mission, EM-2. The EM-2 pressure shell and the EM-2 LAS will be in the early manufacturing stages for the EM-2 mission, which will carry humans further from Earth than any previous human spaceflight mission.

In late FY 2017, the mated CM and SM will ship to PBS for thermal vacuum, acoustics, and electromagnetic interference testing, which will continue into the second quarter of FY 2018.

SCHEDULE COMMITMENTS/KEY MILESTONES

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

** The FY 2018 President's Budget fully supports EM-1 mission requirements. However, NASA continues to evaluate the impact the following events will have on the EM-1 launch readiness date: 1) the integrated manufacturing, test, and processing schedules based on projection of the ESA service module delivery; 2) the impact of tornado damage recovery at Michoud Assembly Facility; and 3) first time production issues for the SLS stages element. NASA will be providing updates to the launch readiness date in the near future.*

CREW VEHICLE

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	2017	6,616.6	-2.2	EM-2	Apr 2023	Apr 2023	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost. This amount reflects a transfer of funding to formulation costs and does not represent a reduction in the lifecycle cost estimates.

CREW VEHICLE

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**6,768.4**	**6,616.6**	**-151.8**
Mission Operation	281.6	273.3	-8.3
Program Management	671.5	634.4	-37.1
Safety and Mission Assurance	191.4	182.4	-9.0
Spacecraft	3205.1	3,200.5	-4.6
Systems Engineering and Integration	539.3	501.7	-37.6
Test and Verification	460.6	426.9	-33.7
Other	1418.9	1,397.4	-21.5

** NASA continues to evaluate the impact the following events will have on the EM-1 launch readiness date: 1) the integrated manufacturing, test, and processing schedules based on projection of the ESA service module delivery; 2) the impact of tornado damage recovery at Michoud Assembly Facility; and 3) first time production issues for the SLS stages element. NASA will be providing updates to the launch readiness date in the near future.*

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 supports the crew module from launch through separation before reentry.	Provider: JSC Lead Center: JSC Performing Center(s): ARC, JSC, LaRC, and GRC Cost Share Partner(s): ESA	None

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Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
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

CREW VEHICLE

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: The Orion test and verification plan increases the reliance on spacecraft component and subsystem testing, Then: There is a potential increased risk of technical issues in higher-level systems.	Orion will continue to develop guidelines to implement the component qualification approach, validate the proposed test campaign to meet flight test objectives to identify gaps and risks, and assess and reduce risk to flight hardware.
If: Integrated software and avionics testing requires more work than planned, Then: ITL (where this testing is performed) may not have sufficient capacity at peak testing times.	Orion manages the timing of the tests to reduce the peak workloads and to seek other testing capacity using other existing avionics labs.

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.

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 SM with the Lockheed Martin portion of the spacecraft.

MAJOR CONTRACTS/AWARDS

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

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Formulation	Development	Operations

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
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

CREW VEHICLE

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
PDR	SRB	Sep 2009	To evaluate completeness and consistency of the program's preliminary design, including its projects, is meeting all requirements with appropriate margins, acceptable risk, and within cost and schedule constraints; determine the program's readiness to proceed with the detailed design phase.	Program cleared to proceed to next phase.	N/A
Resynchronization Review	SRB	Jul 2012	The purpose of the review is to realign the program's preliminary design to the current Exploration system development requirements. NASA policies allow changes to a program's management agreement in response to internal and external events. An amendment to the decision memorandum signed at the KDP-B review held before PDR if a significant divergence occurs.	Program cleared to proceed to next phase.	N/A

CREW VEHICLE

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
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
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

CREW VEHICLE

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
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
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

CREW VEHICLE

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
System Acceptance Review/Design Certification Review	N/A	Jul 2018	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 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Launch Vehicle Development	1921.9	**2094.9**	1881.7	2032.7	2189.9	2101.1	2101.1
SLS Program Integration and Support	50.0	**55.1**	56.1	50.8	75.7	76.5	76.3
Total in FY17 Budget Structure	**1971.9**	**2150.0**	**1937.8**	**2083.5**	**2265.6**	**2177.6**	**2177.4**
Programmatic CoF in CECR Account	28.3	8.8	95.9	0	0	0	
Exploration Ground Systems	398.9	**429.4**	460.4	486	509.1	469.5	460.5
Total in FY12 Budget Structure	**2399.1**	**2588.2**	**2494.1**	**2569.5**	**2774.7**	**2647.1**	**2637.9**
Change from FY 2017			-94.1				
Percentage change from FY 2017			-3.64%				

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

This aerial picture shows the successful RS-25 hot-fire test conducted February 22, 2017 at Stennis Space Center's A1 test stand. Four RS-25 engines along with two, five-segment solid rocket boosters, will power the SLS on missions to deep space. The on-going testing of the RS-25 engine provides critical data on the newly designed Engine Controller Unit.

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

SLS is a critical national capability for exploring the solar system and continuing U.S. leadership in science, technology, and exploration for decades to come. The vehicle's capabilities will evolve using a block upgrade approach, driven by near and long-term exploration mission requirements. Initially, SLS has the capability to carry over 70 metric tons (now estimated to be nearly 90 metric tons) to low Earth orbit and nearly 30 metric tons to the exploration proving ground near the Moon. The next evolution of the SLS incorporates the advanced Exploration Upper Stage (EUS) now under development and will improve vehicle lift performance to more than 105 metric tons to low Earth orbit and 40 metric tons to cislunar space, significantly increasing mission capability. Ultimately, SLS can evolve to carry over 130 metric tons to low Earth orbit and 45 metric tons to the cislunar space.

SPACE LAUNCH SYSTEM

SLS leverages over a half-century of experience with launch vehicles including Saturn and Space Shuttle, along with advancements in technology and manufacturing to lower the cost of previously more expensive components. For example, advances are allowing NASA to produce the first SLS boosters at about two-thirds the cost of the less-powerful Space Shuttle boosters. Additionally,with additional investment, new and less labor-intensive methods are under development to manufacture replacement RS-25 engines at lower costs than the original RS-25's used as the Space Shuttle Main engines. The Agency will continue to identify and implement affordability strategies to ensure that 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.

EXPLANATION OF MAJOR CHANGES IN FY 2018

NASA continues to evaluate the impact the following events will have on the EM-1 launch readiness date: 1) the integrated manufacturing, test, and processing schedules based on projection of the ESA service module delivery; 2) the impact of tornado damage recovery at Michoud Assembly Facility; and 3) first time production issues for the SLS stages element. NASA will be providing updates to the launch readiness date in the near future.

Pursuant to P.L. 114-133, NASA is continuing Block 1B upgrades to the SLS including Exploration Upper Stage (EUS) engineering design, development and procurement activities leading to the EM-2 launch. This includes the completion of the Critical Design Review and the start of manufacturing activities in FY 2018.

Program Elements

SLS PROGRAM INTEGRATION AND SUPPORT

SLS program integration and support activities manage the Orion and EGS program interfaces. This effort is critical to ensure that SLS systems' performance meets technical and safety specifications, and supports the programmatic assessments that are key to achieve integrated technical, cost, and schedule management. In addition, the SLS integration effort is vital to manage interfaces with other NASA activities, including strategic studies, feasibility studies, and small-scale research tasks that feed into future human exploration efforts. To align upcoming NASA exploration and technology activities, some associated crosscutting studies and initiatives conducted in other programs are now being worked in Advanced Exploration Systems, enabling effective coordination between research and technology capabilities required to support robotic, extravehicular activities, and future exploration missions. Coordination and timely integration across the three programs enable 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 2018 Budget

		Actual	Enacted	Request	Notional					
Budget Authority (in $ millions)	Prior	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	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	3119.2	1577.6	1155.3	**989.1**	180.3	0.0	0.0	0.0	0.0	7021.4
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2017 MPAR LCC Estimate	**5793.2**	**1577.6**	**1155.3**	**989.1**	**180.3**	**0.0**	**0.0**	**0.0**	**0.0**	**9695.4**
Total Budget	**6060.6**	**1921.9**	**1940.0**	**1881.7**	**2032.7**	**2189.9**	**2101.1**	**2101.1**	**0.0**	**20229.0**
Change from FY 2017				**-58.3**						
Percentage change from FY 2017				**-3.0%**						

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

The difference between the total budget and the MPAR LCC estimate, is the total budget represents content outside of EM-1.

The Total budget prior line represents FY2012 - FY2015 budgets, excluding CoF and additional expenditures prior to 2012.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

At the Promontory, Utah test facility of Orbital ATK, the booster for NASA's SLS rocket fired for a two-minute test on June 28, 2016 completing the second critical full-scale ground test qualification motor firing.

PROJECT PURPOSE

As NASA expands its focus for human spaceflight to destinations 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, American astronauts will be able to explore space beyond low Earth orbit.

EXPLANATION OF MAJOR CHANGES IN FY 2018

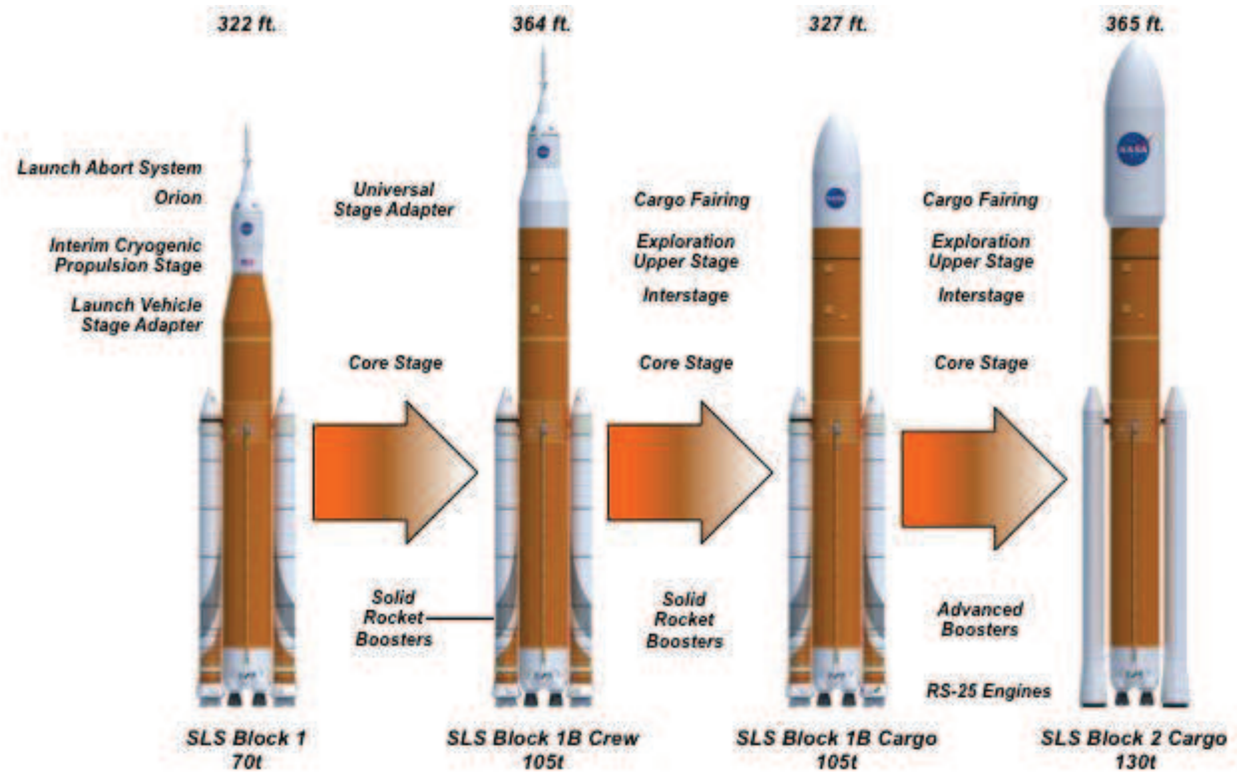
NASA continues to evaluate the impact the following events will have on the EM-1 launch readiness date: 1) the integrated manufacturing, test, and processing schedules based on projection of the ESA service module delivery; 2) the impact of tornado damage recovery at Michoud Assembly Facility; and 3) first time production issues for the SLS stages element. NASA will be providing updates to the launch readiness date in the near future.

Project Parameters Launch Vehicle Development will work to achieve cost, schedule, and performance goals by leveraging hardware designed for previous programs, including Space Shuttle main engines, five-segment solid rocket boosters, and an interim cryogenic propulsion stage (ICPS) using a derivative from the Delta cryogenic second stage. Additionally, development has started for an advanced Exploration Upper Stage (EUS), which will add significantly to the vehicle's lift capability. The program benefits from NASA's half-century of experience with liquid oxygen and hydrogen heavy-lift vehicles, large solid rocket motors, and advances in technology and manufacturing practices.

SLS vehicle design will be flexible and evolvable based on mission requirements. In an effort to achieve schedule and cost efficiencies, each evolution shares the same basic core stage with modifications to accommodate both crew and cargo requirements as needed. Initially, SLS will achieve a 70 metric ton lift capability to low Earth orbit, and nearly 30 metric tons to cislunar space. Upgrades, including the EUS, will improve vehicle lift performance to 105 metric tons to low Earth orbit and 40 metric tons to cislunar space, where NASA will demonstrate deep-space technologies and hardware needed for future missions independent of Earth. Ultimately, with the addition of advanced boosters, SLS could evolve to carry over 130 metric tons to low Earth orbit and 45 metric tons to cislunar space.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations



ACHIEVEMENTS IN FY 2016

In FY 2016, SLS completed significant activities, such as welding in the Vertical Assembly Center at Michoud Assembly Facility (MAF) of the first core stage flight engine section, forward skirt, and the 130+ foot tall liquid hydrogen tank that will fuel the four RS-25 rocket engines during SLS ascent. Additionally, SLS successfully conducted multiple development engine tests on the A-1 Test Stand at SSC. The newly designed Engine Controller Unit (ECU) made significant progress through development and testing cycles, engine hotfire tests, lab testing, and the assembly of the first flight model. In June 2016, the SLS Booster Qualification Motor-2 test at Orbital ATK was a success. This is the second of two full-scale ground qualification motor tests qualifying the design for use on SLS.

SLS continued to develop, test, and integrate flight avionics in the software integration test facility, allowing development and testing of avionics in an accurate flight-like configured system. SLS also made significant progress on the manufacturing and assembly of the ICPS, Launch Vehicle Stage Adapter (LVSA), and the Orion Stage Adapter.

Construction of test stands for new structural test article (STA) facilities neared completion. STA testing, using the new test stands, will ensure adequate structural capability prior to launch. Significant achievements in fabrication and assembly progressed on many of the STAs including, Core Stage Engine Section, and Core Stage Liquid Hydrogen tank, Interim Cryogenic Propulsion Stage, Launch Vehicle Stage Adapter, and the Orion Stage Adapter. In addition to making considerable progress towards fabrication, qualification, and assembly of flight elements, SLS is making strides in preparing for element delivery to KSC for processing and integration. Progress is being made towards the launch of Exploration

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Mission – 1 (EM-1), the next evolution of the vehicle moved forward with the content and planning for the EUS Preliminary Design Review (PDR), and the procurement of RL10 rocket engines to power the EUS on deep-space exploration missions.

WORK IN PROGRESS IN FY 2017

During FY 2017, SLS will continue to progress towards EM-1 and concurrently, develop the next vehicle evolution. ICPS, Launch Vehicle Stage Adapter, and the Orion Stage Adapter, flight software, RS-25 engines, and motor segments will be complete and ready for assembly. SLS will complete production and component integration of the EM-1 ICPS and fabricate the EM-1 Orion Stage Adapter. Qualification of the new ECU design will complete and flight model units will deliver to support EM-1. The full scale Core Stage mock up, named Pathfinder, will be completed and delivered to SSC for B2 test stand confirmation of Core Stage test fit. The renovations and refurbishment of the B2 test stand at SSC will be completed and ready for the flight hardware Core Stage hot fire test. Flight software and related avionic components will continue testing in the software integration test facility at Marshall Space Flight Center (MSFC). The EUS will complete its PDR validating progress to critical design and fabrication.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

The flight model ECUs will install and the RS-25 flight engines will be ready for integration into the core stage. During FY 2018, component delivery and preparation for the EM-1 launch begins with delivery of the ICPS and LVSA to KSC for system integration. The EM-1 Booster segments will arrive at KSC beginning final assembly with the aft and forward skirts. SLS will prepare for the EM-1 Design Certification Review planned for early 2019, conduct the EM-2 Critical Design Review (CDR), and begin fabrication of components for EM-3, and beyond.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2018 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	TBD

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Milestone	Confirmation Baseline Date	FY 2018 PB Request
EM-1 Launch Readiness	Nov 2018	TBD*

** NASA continues to evaluate the impact the following events will have on the EM-1 launch readiness date: 1) the integrated manufacturing, test, and processing schedules based on projection of the ESA service module delivery; 2) the impact of tornado damage recovery at Michoud Assembly Facility; and 3) first time production issues for the SLS stages element. NASA will be providing updates to the launch readiness date in the near future.*

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	2017	TBD*	0	EM-1 Launch Readiness	Nov 2018	TBD*	0

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

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LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**7,021.4**	TBD	TBD
Stages Element	3,138.7	TBD	TBD
Liquid Engines Office	1,198.3	TBD	TBD
Booster Element	1,090.3	TBD	TBD
Other	1,594.2	TBD	TBD

** NASA continues to evaluate the impact the following events will have on the EM-1 launch readiness date: 1) the integrated manufacturing, test, and processing schedules based on projection of the ESA service module delivery; 2) the impact of tornado damage recovery at Michoud Assembly Facility; and 3) first time production issues for the SLS stages element. NASA will be providing updates to the launch readiness date in the near future.*

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 and avionics integration	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC, SSC, and KSC 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 interim cryogenic propulsion stage, Orion stage adapter, launch vehicle stage adapter, 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	Mitigation
Given new Propellant, Liner, and Insulation (PLI) materials, especially new 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 certification for flight rationale cannot be obtained.	Orbital ATK work is continuing on testing and analyses, supporting Design Certification Review efforts. A significant portion deals with the effect of barrier coating on mechanical properties, and structural margins allowable for flight after long-term storage. Recent discussions have looked at the use of analogs supporting validation and verification of analytical methodologies.
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. Additionally schedule margin versus time curves are plotted and reported on a monthly 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	Orbital ATK	Magna, UT
Core Stage Engine	Aerojet Rocketdyne	Desoto Park, CA
ICPS	Boeing Aerospace	Huntsville, AL
Stages	Boeing Aerospace	Huntsville, AL
Upper Stage Engines	Aerojet Rocketdyne	West Palm Beach, FL

INDEPENDENT REVIEWS

NASA established an SRB to perform the independent reviews of the Space Launch Vehicle project as required by NPR 7120.5.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

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	TBD	To certify the implemented design complies with applicable requirements and necessary verification activities are satisfactorily completed.	Certification of the SLS Block 1 design is completed.	N/A

EXPLORATION GROUND SYSTEMS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	**398.9**	**429.0**	**460.4**	**486.0**	**509.1**	**469.5**	**460.5**
Change from FY 2017			**31.4**				
Percentage change from FY 2017			**7.3%**				

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

A view of the VAB at NASA's KSC in Florida. To the left is the mobile launcher that will be used to carry NASA's SLS rocket and Orion spacecraft to Launch Pad 39B for EM-1.

The Exploration Ground System (EGS) program enables integration, processing, and launch of the Space Launch System (SLS) and Orion spacecraft. EGS is making 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 beneficiaries are current and future NASA programs including Orion, SLS, and additional customers such as U.S. Government agencies and commercial industry.

EXPLANATION OF MAJOR CHANGES IN FY 2018

NASA continues to evaluate the impact the following events will have on the EM-1 launch readiness date: 1) the integrated manufacturing, test, and processing schedules based on projection of the ESA service module delivery; 2) the impact of tornado damage recovery at Michoud Assembly Facility; and 3) first time production issues for the SLS stages element. NASA will be providing updates to the launch readiness date in the near future.

EXPLORATION GROUND SYSTEMS

Program Elements

EGS PROGRAM INTEGRATION AND SUPPORT

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

EXPLORATION GROUND SYSTEMS DEVELOPMENT

See the Exploration Ground Systems Development.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

FY 2018 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022	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	531.1	403.3	417.1	**425.9**	69.7	0.0	0.0	0.0	0.0	1847.1
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2017 MPAR LCC Estimate	**1496.9**	**403.3**	**417.1**	**425.9**	**69.7**	**0.0**	**0.0**	**0.0**	**0.0**	**2812.9**
Total Budget	**1273.0**	**398.9**	**395.9**	**460.4**	**470.7**	**493.7**	**453.8**	**444.8**	**0.0**	**4391.2**
Change from FY 2017				**64.5**						
Percentage change from FY 2017				**16.3%**						

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

The difference between the total budget and the MPAR LCC estimate, is the total budget represents content outside of EM-1.

The Total budget prior line represents FY2012 - FY2015 budgets, excluding CoF and additional expenditures prior to 2012.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

A technician monitors the progress as NASA's Crawler-Transporter 2 moves slowly along the crawlerway back to the crawler park site after a test run to LC- 39B at NASA's KSC in Florida. Upgrades to the crawler include 88 new roller bearings, 22 on each "truck" section, and a new jacking, equalizing and leveling system. (In the background is the new mobile launcher.)

PROJECT PURPOSE

Exploration Ground Systems (EGS) is preparing Kennedy Space Center (KSC) to accommodate NASA's next-generation human space exploration vehicles for space exploration. EGS is developing the necessary ground systems' while refurbishing and upgrading infrastructure and facilities required for assemble, test, and launch Space Launch System (SLS) and Orion, along with the landing and recovery activities of Orion. This includes Pad 39B, the Vehicle Assembly Building, Mobile Launcher and other smaller facilities to move from a Space Shuttle focused to support exploration missions. The modernization efforts keeps flexibility in order to accommodate a multitude of government, commercial and other customers.

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

EXPLANATION OF MAJOR CHANGES IN FY 2018

NASA continues to evaluate the impact the following events will have on the EM-1 launch readiness date: 1) the integrated manufacturing, test, and processing schedules based on projection of the ESA service module delivery; 2) the impact of tornado damage recovery at Michoud Assembly Facility and 3) first time production issues for the SLS stages element. NASA will be providing updates to the launch readiness date in the near future.

Pursuant to P.L. 114-133, NASA is continuing Block 1B upgrades to the SLS including Exploration Upper Stage (EUS) engineering design, development and procurement activities leading to the EM-2 launch. This includes work required for EGS to modify the ground systems at KSC to support the use of the EUS, including modifications the Vehicle Assembly Building and a major re-build of the Mobile Launcher post EM-1.

PROJECT PARAMETERS

EGS is modernizing and upgrading (KSC's) ground systems and facilities required to integrate SLS and Orion, move the integrated vehicle to the launch pad, and launch it successfully into space. For the Exploration Missions (EMs), 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

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

crawler-transporters; preparing Launch Complex (LC)-39B, rocket launch site at KSC, modernizing computers, tracking systems, and other networks.

ACHIEVEMENTS IN FY 2016

In December 2015, the program completed Critical Design Review, which demonstrated the program readiness to proceed to fabrication, installation and testing of KSC ground systems. Upgrades at the LC-39B were 80 percent completed and included a new communication system; new heating, ventilation and cooling systems; replacement of water system piping and installing new ignition overpressure/sound suppression bypass valves. The program completed structural and facility modifications on the Mobile Launcher, and will finish installing ground support equipment in FY 2017.

The pressure vessel for the Orion crew module arrived at KSC and processing began February 2016 to prepare it for launch atop the SLS rocket. The Orion heat shield which will protect the Orion crew module during re-entry after the spacecraft's first uncrewed flight test arrived at KSC in August 2016. The program began testing of several of the umbilical connectors that will attach to SLS rocket from the tower on the Mobile Launcher. The umbilicals tested included: the tail service mast, Orion Service Module, two Aft Skirt Purges, three of the eight Vehicle Support Posts and Core Stage Forward Skirt Umbilical (CSFSU). The tests will ensure each launch accessory is functioning properly and is ready for installation on the mobile launcher tower. The Crawler Transporter completed an intensive overhaul to include, 16 new jacking, equalization and leveling (JEL) cylinders that lifts the Mobile Launcher and keeps them level during transport to the launch pad. Crawler-Transporter 2 completed a test trek to LC-39B, moving along the crawlerway to verify the operation of the completed upgrades necessary to transport the Mobile Launcher, with Orion atop the SLS rocket to Pad 39B for EM-1.

Upgrades and modifications to the Multi-Payload Processing Facility (MPPF) were completed, and the program began verification and validation (V&V) testing to make sure the facility is ready when Orion's crew module and its service module arrive for launch of EM-1. Upgrades included installing new pneumatics systems for gaseous helium, gaseous oxygen, gaseous nitrogen, and breathing air and a ground cooling system. All of this equipment is necessary to process a human-rated spacecraft. MPPF validation began on July 2016 and will continue through July 2017. Command, control, and communications systems software and displays that support end-to-end spaceport applications are undergoing validation to support facility activation and launch operations. In the Vehicle Assembly Building (VAB), EGS has installed all elevator platforms and completed construction of 15 out of 20 adjustable high-bay platform halves, which will support SLS stacking and integration for EM-1. At LC-39B, the program started the application of new heat-resistant bricks to the concrete walls on the north side of the flame trench-deflector system, as well as, modifications for infrastructure and propellant and gas systems in preparation for launch.

WORK IN PROGRESS IN FY 2017

During the first and second quarter of FY 2017, EGS completed lifting, installing, and securing Platform A in High Bay 3 inside the VAB. EGS also completed assembly of the VAB platforms with the necessary piping and electrical wiring to support integration and stacking of EM-1 in first quarter FY 2017. In the

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

summer of 2017, EGS will begin moving the Mobile Launcher to the VAB. This will be a multi-element operation, confirming systems on the Mobile Launcher work together with systems in the VAB.

EGS will complete the flame trench modifications at Pad LC-39B to support the launch of the SLS rocket. In addition, EGS will complete the software and hardware development and validation used to control and monitor the SLS rocket at the time of its launch. In September 2017, the program will complete Mobile Launcher ground support equipment (GSE) installation. SLS aft booster skirt is undergoing refurbishment and painting and it is ready for assembly process in the Booster Fabrication Facility. Construction of a 1.4 Million gallon liquid hydrogen tank began at Launch Pad 39B to support the SLS rocket and all future launches from Launch Pad 39B. The CSFSU underwent testing for four months at LETF to confirm load limits, ability to disconnect before liftoff and readiness before installation on the Mobile Launcher. The main purpose of the CSFSU is to provide conditioned air and gaseous nitrogen to the SLS Core Stage Forward Skirt. The assembly of the Orion heat shield to the Orion crew module will take place fourth quarter of 2017.

More than 100,000 components associated with EM-1 will arrive at the center during FY 2017. A team of engineers and technicians will integrate them with the spacecraft. EGS will begin assembly of Orion with its systems and subsystems necessary for flight. The module will receive its avionics; electrical power storage and distributions systems; thermal controls; cabin pressure control; command and data handling; communications and tracking; guidance, navigation and control; reaction control system propulsion; and flight software and computers.

In late October, EGS, the U.S. Navy, U.S. Air Force and contractor employees wrapped up Underway Recovery Test-5 (URT), a successful rehearsal of Orion recovery, aboard the USS San Diego in the Pacific Ocean off the coast of California. These tests have helped contribute to the team's understanding of how to adjust for various water conditions and contingency scenarios, as they get ready for launch. GSDO program will complete the EGS System Integration Review in August 2017, which will evaluate readiness for Multi-Element V&V. EGS is conducting studies on the requirements to support SLS upgrades for EM-2 on the communication systems, the Mobile Launcher, and requiring additional liquid hydrogen capacity at the pad.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

Once the program has completed the system verification and validation phase, the program will begin the operations and integration phase in preparation for Multi-Element V&V for the Mobile Launcher, Pad, and VAB. Spacecraft offline processing will begin in the third quarter of 2018. During this process, EGS will validate all systems software and hardware in order to determine the system readiness for a safe and successful launch.

During the fourth quarter of 2018, the Mobile Launcher will roll into the VAB High Bay 3 for the start of multi-element verification and validation testing with the platforms. Integration operation will begin after the required 24-hour cool-down period on the Mobile Launcher.

SLS Core Stage and Orion Crew Service Module will arrive at KSC to begin integrated operations approximately nine months prior to its launch readiness window. Completion of Booster stacking and

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Core Stage mate will take place. Crew Service Module delivered to the Launch Abort System Facility for stacking and integration. Upon completion of vehicle stacking and integration, a model test will occur prior to connection of the umbilicals and stabilizer. Power provision to the Orion crew module and the vehicle is prepared for tests to confirm the spacecraft flight readiness in fourth quarter 2018. Verification will begin of all ground system and vehicle interfaces required for launch except the Mobile Launcher to launch pad interface.

There are three additional URTs planned in support of EM-1 beginning in first quarter. The tests will allow NASA and the U.S. Navy to continue to demonstrate and evaluate the recovery processes, procedures, and hardware before committing to conducting actual recovery operations for EMs.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2018 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
KDP-D	Aug 2016	Aug 2016
SIR	Aug 2017	Aug 2017
EM-1 Launch Readiness	Nov 2018	TBD*

*** NASA continues to evaluate the impact the following events will have on the EM-1 launch readiness date: 1) the integrated manufacturing, test, and processing schedules based on projection of the ESA service module delivery; 2) the impact of tornado damage recovery at Michoud Assembly Facility; and 3) first time production issues for the SLS stages element. NASA will be providing updates to the launch readiness date in the near future.*

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milesto ne Data	Current Year Milestone Data	Milestone Change (mths)
2015	1,843.5	70	2017	TBD*	TBD	EM-1 Readiness	Nov 2018	TBD	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 (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

*** NASA continues to evaluate the impact the following events will have on the EM-1 launch readiness date: 1) the integrated manufacturing, test, and processing schedules based on projection of the ESA service module delivery; 2) the impact of tornado damage recovery at Michoud Assembly Facility; and 3) first time production issues for the SLS stages element. NASA will be providing updates to the launch readiness date in the near future.*

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**	TBD	TBD
Mobile Launcher	213.1	TBD	TBD
LC-39B Pad	77.5	TBD	TBD
VAB	92.7	TBD	TBD
Command, Control, and Communications	198.0	TBD	TBD
Offline Processing and Infrastructure	110.2	TBD	TBD
Other	1,152.0	TBD	TBD

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

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

*** NASA continues to evaluate the impact the following events will have on the EM-1 launch readiness date: 1) the integrated manufacturing, test, and processing schedules based on projection of the ESA service module delivery; 2) the impact of tornado damage recovery at Michoud Assembly Facility; and 3) first time production issues for the SLS stages element. NASA will be providing updates to the launch readiness date in the near future.*

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. In FY 2016, EGS transitioned the program to a new Mission Management Model to develop ground system and processes, and launch flight hardware by aligning roles and responsibilities, synergizing functions, and simplifying interfaces.

Element	Description	Provider Details	Change from Baseline
Ground Systems Implementation (GSI)	GSI is responsible for design, development, build, hardware/software integration, verification and facility systems, and 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
Mission Management Team (MMT)	MMT includes project management, safety and mission assurance, logistics, systems engineering, utilities and facility operations, and maintenance.	Provider: KSC Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: There is insufficient time to perform all V&V activities, Then: There is a possibility of a schedule delay to the GSDO Operations Readiness Date.	Mobile Launcher team started overlaying updated construction schedule with the V&V schedule. Rescheduling a significant portion of the park site V&V to the VAB, which would affect the overall V&V schedule completion.
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.	EGS will continue face-2-face quarterly meeting with SLS and Orion and began reporting Launch Criteria status weekly. EGS will receive SCCS 4.0 verified and validated system S/W H/W (including Orion, SLS and ICPS Gateways).
If: The programmatic baseline schedule has insufficient time and funding allotted to perform all Launch Accessory testing at the LETF including rework, redesign, regression testing and problem resolution, Then: There is a possibility of not meeting the scheduled program delivery to Mobile Launcher milestone.	Through schedule analysis, LETF has incorporated a work schedule for CSFSU, CSITU, and ICPSU with contractor support to mitigate this risk. Monitoring of the risk will continue.
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.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Acquisition Strategy

To retain flexibility and maximize affordability, GSDO serves as its own prime contractor for EGS 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 the Mobile Launcher structural and facility systems construction contract, 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.

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

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

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
CDR	SRB	Mar 2016	To demonstrate that program design is mature; support full-scale fabrication, assembly, integration, and test; and meet overall performance requirements within cost and schedule constraints.	Program cleared to proceed to next phase	N/A
SIR	SRB	Jun 2017	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

HUMAN RESEARCH PROGRAM

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	**145.0**	**--**	**140.0**	**140.0**	**140.0**	**140.0**	**140.0**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

The ISS Twins Study, performed by NASA's Human Research Program, on identical twin astronauts (Scott Kelly in space for a year and Mark Kelly on the ground) opened a new era of genomic investigations in space that may transform our ability to provide precision medical treatments and countermeasures to astronauts aboard future exploration missions.

Sending astronauts into space involves a multitude of complicated systems, but perhaps the most complex is the human system. 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 that 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, and eventually at other locations, including Mars, HRP is developing the scientific and technological expertise to send humans into deep space for longer durations. 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 ISS, as well as in ground-based analog environments and laboratories, are expanding our capabilities to 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 during all phases of future spaceflight missions.

Space radiation poses significant health risks for crewmembers, including the possibility of developing cancer later in life, radiation sickness during the mission, and post-mission effects on the nervous and cardiovascular systems. HRP is working with Advanced Exploration Systems (AES), Crew Health and Safety and Orion teams on both in-mission and post-mission radiation countermeasures to minimize exposures and provide radiation protection. The collaborative effort involves developing advanced radiation shielding technologies, defining permissible exposure limits, defining requirements for real-time radiation alert systems, optimizing mission architectures, radiation exposure biomedical monitoring, as well as incorporating post-mission health surveillance to ensure that crewmembers can safely live and work in space without exceeding acceptable radiation 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) 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 2018

None.

ACHIEVEMENTS IN FY 2016

HRP concluded the on-orbit data collection from the joint U.S./Russian ISS One-Year Mission. This data provided NASA a first look into the effects of longer mission durations on ocular health, immune and cardiovascular systems, cognitive performance testing, and countermeasure effectiveness against bone and muscle loss. Additionally, on-orbit data collection from the ISS Twins Study concluded this year, where former astronaut Scott Kelly spent a year in orbit while his twin, retired astronaut Mark Kelly, remained on Earth. Findings from the study will provide unprecedented information regarding the effects of spaceflight on the entire complement of biomolecules, such as proteins (proteomics) and genes (genomics). Such data potentially provides novel approaches to protecting the health and performance of astronauts during Mars missions and other exploration missions beyond low Earth orbit.

HRP conducted approximately 23 ISS biomedical research investigations and 10 flight investigations on ISS. Some of the research completed included the flight portion of the Ocular Health study to collect evidence characterizing the risks of and defining the visual, vascular, and central nervous system changes observed during exposure to spaceflight, as well as the effect on vision alterations and intracranial pressure. Ongoing studies included work to mitigate the sleep disturbances risk of long-duration spaceflight through incorporating a multi-spectrum lighting countermeasure to help ISS crewmembers improve sleep and enhance performance.

HRP implemented multiple studies on teamwork in spaceflight analog environments, with efforts heavily devoted to NASA's Human Exploration Research Analog (HERA). The HERA facility provides an environment in which spaceflight mission simulations can be conducted with high levels of flight operations fidelity and experimental control. HRP implemented four 30-day missions in the HERA that included testing monitoring technologies; examining the effects of communication delay on performance; investigating team cohesion, cooperation, and resilience over time; and evaluating the effectiveness of team training countermeasures on mitigating potential behavioral or performance decrements. HRP and the National Space Biomedical Research Institute (NSBRI) selected 52 proposals, out of 234 received, to investigate questions about astronaut health and performance on future deep-space exploration missions. The proposals are from 35 institutions in 16 states for a total of approximately $33 million. Researchers will be investigating the impact of the space environment on various aspects of astronaut health, including visual impairment, behavioral health, bone and muscle loss, cardiovascular alterations, human factors and performance, neurobehavioral and psychosocial factors, sensorimotor adaptation and the development and application of smart medical systems and technologies. All of the selected research will contribute towards NASA's future human exploration missions beyond low Earth orbit. For example, NSBRI recently funded a U.S. small business, Equinox, whose Balance Goggles™ may help patients on Earth manage glaucoma as well as enable astronauts to retain visual acuity while in space.

WORK IN PROGRESS IN FY 2017

Initial findings from both ISS One-Year Mission and Twins Study were presented at the annual HRP Investigator's Workshop in January. Whole genome sequencing showed each twin has hundreds of unique mutations in their genome, which are normal variants. Transcriptome, or Ribonucleic acid (RNA) sequencing, showed more than 200,000 RNA molecules were expressed differently between the twins. Since RNA is one of four major macromolecules essential for all known forms of life, this research shows how sensitive genes are to the changing environments, in space or on Earth. Additionally, shifts in microbial species in space included a change in ratio of two dominant bacterial groups (i.e., Firmicutes and Bacteroidetes) present in the gastrointestinal tract. The ratio of one group to the other increased during flight and returned to pre-flight levels upon return to Earth. Differences in the viral, bacterial, and fungal microbiome between the twins were pronounced at all test time points due to their differing diet and environment. Both of these observations indicate a systematic adjustment of the astronaut's genetic and microbiome during spaceflight missions. Scott Kelly and his one-year mission Russian cosmonaut counterpart, Mikhail Kornienko, both experienced a decrease in fine motor skills over time which could have operational implications on a mission to Mars. Additionally, sensorimotor dysfunction tests found vastly different performance and recovery, despite spending equal time in space. Differences suggest that a focus on preflight training and experience is beneficial. These initial observations may provide understanding of novel pathways to protect the health and performance of crews during Mars missions and other exploration missions beyond low Earth orbit.

HRP researchers plan to conduct approximately 18 ISS biomedical research investigations during each ISS mission increment, complete seven flight investigations, and initiate three new research investigations. Studies to mitigate the risk of long-duration spaceflight include a light countermeasure to help ISS crewmembers improve sleep and enhance performance; functional immune alterations; and a study that will compare the absorption, metabolism and effects of certain medication use on the ground and in the space environment.

HRP has initiated a new public-private partnership, the Translational Research Institute (TRI) that will lead a national effort in translating cutting-edge emerging terrestrial biomedical research and technology development into applied spaceflight human risk mitigation strategies for exploration missions. The institute will solicit and select innovative multidisciplinary teams whose products have potential to significantly reduce NASA human health and performance risks during space exploration missions by "translating" research into application and by increasing the exchange of information between the biomedical research community and the human spaceflight medical community. The first TRI national solicitation is scheduled for release in the spring timeframe.

HRP will start joint NASA/NSF Antarctic analog studies to support behavioral health and performance research. Working with the NSF Polar Program, HRP will integrate 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. The first study will be undertaken during the 2017 winter-over and will include approximately 110 U.S. Antarctic program volunteers located at the McMurdo and South Pole stations. Volunteers will complete periodic computer-based questionnaires, provide saliva samples, and wear a monitor that records sleep and wake cycles. Researchers will use 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 will begin joint NASA/German Aerospace Center (DLR) analog studies to support human health countermeasures, exploration medical and behavioral health and performance research. Working with the DLR Space Agency and the DLR Institute for Aerospace Medicine, NASA will integrate these studies into HERA missions, and DLR will integrate NASA studies into its Envihab medical research facility bed rest campaigns.

HRP plans to deliver a real-time crew performance assessment tool, which should prove very useful in gathering near real-time human factors and habitability data during spaceflight missions that can be applied to the designs of next generation spacecraft and habitats. Currently, no established methods exist to collect real-time human factors and habitability data. Instead, these memory-contingent data are acquired at the end of missions during post-flight crew debriefs, which typically occur weeks after the events have occurred.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

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; and leverage resources and expertise through collaborative research with other NASA programs, international partners and other U.S. agencies such as DoD, DOE, NSF, and NIH.

HRP will undertake risk mitigation activities associated with long-duration human spaceflight that address medical consumables tracking technology to better understand pharmaceutical countermeasure effectiveness; develop improved injury assessment models to better protect crew during dynamic phases of flight; protect team function and performance during the isolation and confinement of long-duration missions; improve the physiological medical standards to better protect muscle and aerobic capacity; and deliver an improved cancer risk projection model for operational use to protect crew from space radiation risks. Finally, HRP will help improve the health of our nation's children by continuing the annual *Train Like an Astronaut Fitness Challenge* which will be in its eighth year and was developed in cooperation with NASA scientists and fitness professionals working directly with astronauts.

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, high radiation, 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 determine standards for health and habitability, and define 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 Department of Energy 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 National Science Foundation Antarctic facilities, other national isolation analogs, and international partner facilities in Germany and Russia.

Program Schedule

Date	Significant Event
Oct 2017	NASA Cancer Risk Projection Model V2.0 Delivery
Dec 2017	Medical Consumables Tracking Final Report
Jan 2018	Team Performance Protocol Recommendations for Long Duration Missions
Feb 2018	2018 HRP Investigators' Workshop
Mar 2018	Muscle and Aerobic Medical Standard Recommendations Update
Mar 2018	Injury Assessment Model to Mitigate Injury During Dynamic Flight Phases
May 2018	Human Exploration Research Opportunity 2017 NASA research announcement (NRA) Selections
Jun 2018	Release 2018 Human Exploration Research Opportunity NRA
Aug 2018	Complete Mission X: Train Like an Astronaut Fitness Challenge

HUMAN RESEARCH PROGRAM

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): N/A
Human Health Countermeasures	Provider: JSC Lead Center: JSC Performing Center(s): ARC and GRC Cost Share Partner(s): N/A
Human Factors and Behavioral Performance	Provider: JSC Lead Center: JSC Performing Center(s): ARC, GRC, and KSC Cost Share Partner(s): N/A
Space Radiation	Provider: JSC Lead Center: JSC Performing Center(s): LaRC Cost Share Partner(s): N/A
ISS Medical Project	Provider: JSC Lead Center: JSC Performing Center(s): ARC and KSC Cost Share Partner(s): N/A

Acquisition Strategy

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

HRP plans to release the Human Exploration Research Opportunities umbrella NRA that will request research proposals across all of its research elements throughout the year, including Space Radiation and Crew Health and Performance. This NRA provides opportunities for researchers and universities from across the nation to develop flight experiments and contribute to NASA's exploration mission.

MAJOR CONTRACTS/AWARDS

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

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	National Academies	Jun 2016	Review of NASA research on human health risks	Informs program research prioritization	Jun 2017
Quality	National Council on Radiation Protection (NCRP)	Jul 2016	Review of space radiation health risks	Establish research priorities for space radiation research	Jul 2017
Quality	Peer Review Panel	Jul 2016	Peer review of NRA	Selected grantees	Jul 2017
Quality	Independent Program Assessment	Sep 2015	Review of program management policies and practices	Verifies adherence to NASA program management policies	Sep 2017
Quality	SRB/External Independent Review	Dec 2016	Review of research projects, gaps, and tasks	Verifies project prioritization/ reprioritization	Dec 2017

ADVANCED EXPLORATION SYSTEMS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	210.4	--	210.0	380.0	475.1	526.4	547.6

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

The Bigelow Expandable Activity Module (BEAM) is the first expandable habitat to be installed on the space station. It was expanded on May 28, 2016. Expandable habitats are designed to take up less room on a spacecraft, but provide greater volume for living and working in space once expanded. Astronaut Kate Rubins conducted several evaluations inside BEAM, including air and surface sampling.

The Advanced Exploration Systems (AES) division develops foundational technologies and 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 human spaceflight missions. Public-private partnerships can be agreements and contracts that enable NASA and private sector industry and academia to share in the risk and gain of government investments. These shared risks and gains include incentivizing technical performance, the building of future commercial markets and a shared financial interest in the development of capabilities.

AES activities focus on human spaceflight systems for deep space, and robotic precursor missions that identify and address knowledge gaps related to potential destinations prior to human exploration missions. Major areas of work include systems development for advanced in-space propulsion; landing capabilities; *in-situ* resource prospecting and processing; reliable life support; deep space habitation systems; and capabilities to reduce future logistics requirements during exploration. NASA is working to create future accommodations for astronauts to live, work, and thrive throughout the solar system and AES provides innovative tools that drive these efforts to journey beyond low Earth orbit.

AES provides activities focused on advanced design, development, and demonstration of exploration capabilities to reduce risk, lower life cycle cost and validate operational concepts for future human missions. AES leads the development of new approaches to project and engineering management, such as rapid systems development or alternative management concepts, open innovation, and collaboration.

The Agency identifies and addresses potential risks of new technologies by performing early validation and ground/flight testing of prototype systems prior to their integration into operational systems. Early risk reduction can minimize cost growth and improve the affordability of future space exploration. For example, NASA is advancing a phased approach to habitation and habitation systems development that includes initial ground testing of systems and components, and subsequent demonstration and operations on International Space Station (ISS), followed by incremental deployment leading to an integrated habitation capability in cislunar space.

NASA also continues to leverage core capabilities, technology developments, and innovative approaches among agency organizations including Human Exploration and Operations Mission Directorate (HEOMD), Space Technology Mission Directorate (STMD), Office of the Chief Technologist (OCT), Science Mission Directorate (SMD), and implementing field centers nationwide, to maximize combined capabilities and future outcomes. AES performs an integrating function with cross-cutting technology development activities that support various Agency programs and organizations.

AES serves as a key technology and risk reduction provider for NASA that delivers a considerable amount of flight hardware development in vital support of the agency's largest exploration and operations programs as well as associated strategic planning, innovative solutions, novel initiatives, and leadership of complete small flight missions. The technologies, capabilities and processes pioneered by AES 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 2018

The Asteroid Redirect Mission (ARM) will not be pursued; instead efforts will be redirected toward an initial solar-electric power/propulsion bus. HEOMD will perform low-level studies of requirements, acquisition planning, and partnership approaches to support NASA and commercial application. In FY2017, AES suspended work related to Advanced Space Suits. Prior work continues to be incorporated into an integrated Extra-Vehicular Activity (EVA) development plan to be implemented by the International Space Station program.

ACHIEVEMENTS IN FY 2016

In FY 2016, AES continued a crucial set of activities to leverage past achievements from development work performed from FY 2012 – FY 2015. Key activities included habitation and habitation systems gaining a fundamental understanding of novel habitation structures, integrated advanced life support systems, fire safety, and radiation protection; foundational systems including autonomous systems and operations, as well as avionics, autonomy, and software; synthetic biology applications; robotic precursors including *in-situ* Resource Utilization (ISRU) prospecting missions and instruments for Mars exploration, and vehicle systems including modular power systems, advanced propulsion, and lander technologies. Highlights include the following:

In May, the Bigelow Expandable Activity Module (BEAM) was successfully launched aboard a SpaceX rocket to the ISS to demonstrate inflatable structures technology for deep space habitats. BEAM is the first expandable habitat to be installed on the ISS. Expandable habitats are designed to be packaged into a small volume for launch, but provide greater volume for living and working in space once expanded. BEAM was berthed to the ISS for a two-year demonstration and analysis of inflatable habitats. The primary goals include characterizing the deployment process and the module's structural integrity, and measuring the internal thermal and radiation environments during this test period.

ADVANCED EXPLORATION SYSTEMS

AES completed Saffire-I, the first in a series of six spacecraft fire safety flight experiments on a Cygnus vehicle. The Saffire payloads will help us understand how large-scale fires spread in microgravity and test fire detection and suppression techniques. NASA will use the knowledge obtained from these experiments in detailed analysis and optimization for future fire protection systems.

Four companies were selected via a Next Space Technologies for Exploration Partnerships (NextSTEP) Phase 1 Broad Agency Announcement (BAA) in March 2015 to define system concepts for a modular habitation capability to enable extended missions in deep space. Those companies completed their concept study deliverables for NextSTEP Phase 1. Additional NextSTEP Phase 1 activities include development of life support systems, advanced electric propulsion, and small satellites called CubeSats to fly on Exploration Mission 1 (EM-1), which is the first planned flight of the Space Launch System (SLS) and the Orion spacecraft.

In April 2016, NASA issued an omnibus NextSTEP-2 BAA to solicit proposals for Phase 2 development of prototype deep space habitats. As a result of the BAA, five companies were selected to develop habitation prototypes and one was selected to conduct a feasibility study on an alternate architecture concept. Habitats provide space for the astronauts to live and accommodate all of the equipment and consumables to support human life (i.e., a breathable atmosphere, clean water, food, a place to sleep, workstations to support crew tasks, exercise equipment, etc.). These ground prototypes will allow NASA and the NextSTEP-2 industry partners to evaluate configurations of the habitat; 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.

AES continued to integrate advanced autonomy software, sensors, and feedback controls with advanced life support hardware to demonstrate improved overall efficiency and increased autonomy. Increased autonomy and reliability are essential for missions beyond low Earth orbit in the context of both crew time and limited communications back to Earth. In addition, AES avionics and software provided direct benefits to: Orion Program, Ascent Abort 2 Project, AES Autonomous Systems and Operations, AES Modular Power Systems, Resource Prospector, Delay/Disruption Tolerant Networking, Logistics Reduction (Radio Frequency Identification (RFID) sensing applications for ISS), and Lander Technologies including Lunar CATALYST.

AES completed the Instrument Accommodation Reviews for Mars 2020 mission payloads to demonstrate oxygen production from the atmosphere and measure surface weather conditions. The Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE) instrument completed its Preliminary Design Review (PDR).

AES made substantial progress towards the completion of the Cubesats on the EM-1 mission. The three AES funded payloads (BioSentinel, NEA Scout and Lunar Flashlight) and the two payloads co-funded by AES through the NextSTEP BAA (Lunar Ice Cube and Skyfire). These missions 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.

AES is continuing to do pre-formulation work in support of characterizing the distribution and abundance of resources found naturally in the soil of the Moon. NASA is looking at approaches to locate and obtain subsurface samples of ice and other volatiles in the shadowed regions near the lunar poles. During 2016, AES conducted thermal vacuum testing to simulate the environment that a lunar rover would experience on the Moon. AES continues to explore options for a lunar lander element of the mission including international and domestic partnership options.

More efficient air and water systems are under development and are planned for demonstration on ISS over the next five years. AES accelerated work on three planned ISS flight demonstrations including an aerosol sampler, a spacecraft atmospheric monitor (S.A.M), and a brine processor. These systems will increase efficiency and reduce dependence on resupply from Earth. An Aerosol Sampler was launched to ISS for detecting small airborne particles that cause allergies and irritate crew members' eyes and noses. The S.A.M will detect hazardous contaminants in the ISS air. For future missions, additional water must be reclaimed due to the significant resupply penalty for missions beyond low Earth orbit. NASA has pursued various technology development programs for a Brine Processor in the past several years. Beginning in 2016 the selected technology will be transitioned to a flight hardware program for demonstration on ISS.

In FY 2016, a series 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. The SPHERES-Slosh investigation is examining the way liquids move inside containers in a microgravity environment. The phenomena and mechanics associated with such liquid movement are still not well understood and are very different than our common experiences with the behavior of liquid on Earth. Rockets deliver satellites to space using liquid fuels for propulsion, and this investigation plans to improve our understanding of how propellants within rockets behave in order to increase the safety and efficiency of future vehicle designs.

During FY 2016, ARM continued technology development for SEP within STMD and selected Aerojet Rocketdyne as the vendor for Advanced Electric Propulsion (EP) system engineering and flight units. STMD is also developing dexterous robotic systems and proximity operations sensors and algorithms for interaction with non-cooperative bodies.

ARM also competitively selected four companies to provide studies on leveraging commercially available spacecraft capabilities to provide an advanced SEP based spacecraft bus design. A broadly solicited and competitively selected Formulation Assessment and Support Team comprised of 100 members across academia, industry and the government provided critical applied scientific input to reduce uncertainty and risk during ARRM requirements development.

In September 2016, ARM released the Umbrella for Partnerships (ARM-UP) BAA to request partner-provided payloads and systems on the ARRM spacecraft to meet partner goals and reduce mission risk. The BAA also sought partnerships for a mission investigation team to support ARM.

As NASA transitions away from the Asteroid Redirect Mission, all relevant work previously conducted on power and propulsion will continue to advance toward a demonstration of that capability in deep space. Activities conducted under ARM, including thruster risk reduction, SEP spacecraft bus industry studies and human/robotic mission integration, provides important ground work for the power and propulsion bus and other future deep space exploration objectives.

ADVANCED EXPLORATION SYSTEMS

WORK IN PROGRESS IN FY 2017

As NASA works to extend human space exploration beyond low Earth orbit, AES will continue to develop reliable life support systems, deep space habitats, advanced in-space propulsion, landing capabilities, in situ resource prospecting and processing and overall capabilities to reduce logistics requirements to support future human spaceflight missions.

One of the key aspects of habitation is to understand and manage the risk related to fire in space. In FY 2017, AES launched the Saffire-II experiment on an Orbital-ATK cargo flight to the ISS to investigate the flammability of various material samples in space. After the initial three tests are completed, the sequence of Saffire experiments will continue, with each test building upon data from the previous one, to investigate fire detection and post-fire clean up. This will help scientists understand how microgravity and limited oxygen affect flame size for the safety of current and future space missions. Saffire-III has been integrated on Orbital-ATK cargo flight (OA-7) and will assess flame spread of large-scale microgravity fire (spread rate, mass consumption, heat release) at higher air-flow rates.

AES will maintain investments in efforts that reduce logistics requirements, including in-space manufacturing technology development and demonstration on ISS. The in-space manufacturing effort will demonstrate a Refabricator that will recycle plastic parts to produce feedstock for an integrated 3D printer. In-space manufacturing can greatly reduce the inventory of spare parts and tools that are needed on long missions. A BAA will also be released to solicit proposals for a multi- material fabrication laboratory (FabLab) which is a small-scale workshop offering advanced in-space fabrication.

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 in FY 2020 will demonstrate the ability of the launch abort system to function as the spacecraft breaks through the speed of sound while using the AES approach to lean project management, and testing AES-developed avionics and core flight software that are planned as systems for future capabilities.

AES entered into a partnership with the Korean Aerospace Research Institute (KARI) via the Korea Pathfinder Lunar Orbiter (KPLO) mission. NASA will sponsor instrument(s) to fly on the lunar orbiter designed by KARI. KPLO is scheduled to launch in December 2018, and is the first mission of KARI's Lunar Exploration Program, which aims to robotically explore the Moon through a series of orbiter and lander missions. Through an Announcement of Opportunity, AES will select and develop a set of contributed instruments that will map the distribution of lunar resources.

In FY 2017, ARM completed the competitively selected studies on industry capability-leveraged spacecraft and plans to provide an advanced SEP based spacecraft bus design. Mission formulation included design of an asteroid deflection demonstration through enhanced gravity tractor concept, mission design for low thrust trajectory trades and options.

ARM will complete evaluations of the ARM-UP BAA proposals for partner-provided payloads and investigation team membership.

These accomplishments continue forward progress toward realization of a deep space operational power and propulsion capability that is directly applicable to wide range of robotic and human spaceflight missions.

ADVANCED EXPLORATION SYSTEMS

KEY ACHIEVEMENTS PLANNED FOR FY 2018

In August 2016, NASA selected five proposals under the NextSTEP-2 BAA to develop prototype cislunar habitats. The estimated period of performance begins in FY 2017 and extends until FY 2018. NASA intends to integrate functional habitation systems into ground prototype habitats for testing in 2018. Throughout the NextSTEP-2 performance phase, NASA will provide Government Furnished Equipment (GFE) and systems as well as NASA personnel expertise to each industry partner. During this phase, NASA will lead the effort to develop standards and common interfaces, and will develop an internal reference architecture to support the next acquisition phase. The intended outcome of activities is a diverse set of complete, long duration deep space architecture designs (including standards, common interfaces, and testing approaches) from the awarded contractors, and development and test of full-size ground prototypes. The acquisition phase will begin after all milestones have been met under the NextSTEP-2 contracts, and will be informed by ongoing discussions with international partners.

As part of ongoing work under the NextSTEP-1 awards, AES plans to conduct ground tests of high-power electric propulsion systems.

AES will also continue the development of Saffire-IV, V, and VI flight experiments to demonstrate combustion products monitoring and post fire cleanup.

AES will develop and test highly reliable life support systems to deploy on ISS and Orion, including a brine processor to recycle water from urine, a miniaturized spacecraft atmospheric monitor to detect hazardous chemicals in the air, and a universal waste management system (toilet).

The Lunar Cargo Transportation and Landing by Soft Touchdown (Lunar CATALYST) initiative will continue to support commercial partners while they complete assembly of at least one flight-ready commercial lunar lander.

In addition to the two NextSTEP Phase 1 CubeSats, AES will deliver three additional secondary CubeSat payloads to fly on SLS in 2018. The Lunar Flashlight CubeSat will look for lunar volatiles in shadowed craters, the BioSentinel CubeSat will study the effects of the deep space radiation environment on yeast DNA, and the Near Earth Asteroid Scout CubeSat will visit a candidate asteroid for future human exploration using a solar sail.

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.

HABITAT SYSTEMS

Habitation and Habitation Systems provide the fundamental capability to provide a safe place for astronauts to carry out NASA’s mission in space and on other worlds, with integrated life support systems, radiation protection, fire safety, and systems to manage food, waste, clothing, and tools. NASA’s AES division 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 stakeholder, including STMD, the ISS, Orion and SLS Programs, the Human Research, and the Space Communications and Navigation programs.

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 development efforts, reliable 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.

Through the NextSTEP effort, NASA and industry will 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 towards meeting NASA long duration, deep-space habitation needs while promoting 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. In parallel with NextSTEP-2, NASA will define a reference habitat deep space architecture based on contractor concepts and identified overall government contributions, including GFE, in preparation for the acquisition strategy for an initial exploration habitation capability with extensibility to Mars class systems. The Agency will work with industry to define common interfaces and standards to ensure that components provided by different companies can be integrated and function together. A one-year test of the technology referred to as a "shakedown" cruise, will be conducted in cislunar space with a deep space habitat and in-space propulsion system to demonstrate the ability to live and work beyond low Earth orbit and validate the key operational capabilities required for Mars missions in the 2030s.

CREW MOBILITY SYSTEMS

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 advanced in-space propulsion, multiple destination extensible lander technology, modular power systems, and automated propellant loading on the ground and on planetary surfaces. These activities which will benefit future robotic and human missions by improving autonomous precision landing on planetary surfaces, as well as potential new propellants and/or propulsion systems. NASA shares these landing capabilities through public-private partnerships with industry under the Lunar CATALYST initiative. Other ongoing initiatives include work on advanced propulsion under the NextSTEP BAA awards, crew module systems AA-2 and modular power for multiple exploration vehicles and systems such as fuel cells.

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, in-situ resource utilization, in-space manufacturing, communication and networking technologies, synthetic biology applications, and near-Earth object monitoring.

ROBOTIC PRECURSOR ACTIVITIES

AES leads robotic investigations that are paving the way for humans to continue the journey. 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, characterizing the Mars surface radiation environment, radar imaging of near-Earth asteroids, instrument development, and research and analysis. Current activities include the Radiation Assessment Detector operations on the Curiosity rover to measure the radiation environment on Mars, deep space CubeSat missions, and instruments planned for the Mars 2020 rover mission.

STRATEGIC OPERATIONS, INTEGRATION, AND STUDIES

AES coordinates with the Agency's deep-space human spaceflight architecture and strategic planning (Mars Study Team), including mission and systems analysis and international coordination. It conducts studies and analysis to translate strategy into developmental (technology and capability) priorities and operational efficiencies.

Program Schedule

Date	Significant Event
Nov 2016	Saffire-II fire safety experiment launch
Jan 2017	Ascent Abort-2 PDR
Jan 2017	MOXIE CDR
Feb 2017	Select NASA contributed instruments for KPLO
Apr 2017	Terrestrial flight test of precision landing system for robotic landers
Jun 2017	Brine Processor Assembly CDR
Sep 2017	Resource Prospector Mission Design Review (MDR)
Q2 2017	Saffire-III fire safety experiment launch
Q3 2018	Complete integration of EM-1 CubeSats for delivery to SLS
Q3 2018	NextSTEP-2 prototype habitats delivered for ground testing
Q4 2018	100 hour test of high-power electric thrusters

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. The AES Division establishes overall direction and scope, budget, and resource allocation for activities implemented by the NASA centers.

AES, STMD, and the Planetary Science Division within SMD jointly fund robotic precursor activities, developing instruments to include on NASA's science and international missions. AES coordinates with the STMD and SMD on Robotic Precursors planning and execution.

AES is leading the selection of sponsored payloads on KPLO. Through this partnership opportunity with KARI, AES intends to sponsor payloads to address gaps in knowledge or information required to reduce risk, increase effectiveness, and improve the design of robotic and human space exploration missions and complement KARI's primary mission objectives and instruments.

Program Element	Provider
Habitat Systems	Provider: NASA Centers Lead Center: HQ Performing Center(s): JSC, MSFC and JPL Cost Share Partner(s): Bigelow Aerospace, Boeing, Lockheed Martin, Orbital ATK, Sierra Nevada, and NanoRacks (NextSTEP)
Vehicle Systems	Provider: NASA Centers Lead Center: HQ Performing Center(s): GRC, JSC, MSFC, and JPL Cost Share Partner(s): Ad Astra, Aerojet Rocketdyne, MSNW (NextSTEP)
Foundational Systems	Provider: NASA Centers Lead Center: HQ Performing Center(s): ARC, JSC, KSC, and MSFC Cost Share Partner(s): Department of Defense
Robotic Precursor Activities	Provider: NASA Centers Lead Center: HQ Performing Center(s): ARC, JPL, MSFC, and KSC Cost Share Partner(s): SMD, STMD, Morehead State University, Lockheed Martin (NextSTEP)
Strategic Operations, Integration, and Studies	Provider: NASA Centers Lead Center: HQ Performing Center(s): ARC, JPL, JSC, MSFC, and KSC Cost Share Partner(s): Launch Services Program, SMD, ISS

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, which are represented through the AES domains. 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. Teams are provided limited procurement funding to purchase materials, equipment, and 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 continues to increase the use of competitively selected external awards and public-private partnerships. For example, in FY 2015 AES awarded 12 NextSTEP BAAs, allowing NASA to pursue public-private partnerships for advanced habitation and life support, high-power electric propulsion systems testing, and small satellites for launch on SLS. AES plans continued with additional Phase-2 awards in 2016 for development of prototype habitats. Phase 3 acquisition of flight habitat systems is planned to begin in FY 2019.

In FY 2017, AES plans to release several BAAs including one for the advancement of a multi-material FabLab for in-space manufacturing and one for the advancement of lunar landed instrument payloads.

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
Vehicle Systems: Lander Capabilities	Moon Express, Astrobotic Technologies, and Masten Space Systems	MSFC, JSC, and KSC
NextSTEP BAA Awards	Boeing, Bigelow Aerospace, Lockheed Martin, Orbital ATK, Dynetics, UTC Aerospace Systems, Orbitec, Ad Astra, Aerojet Rocketdyne, MSNW, Morehead State University	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, Innovation, and Engineering Committee.

SPACE OPERATIONS

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Space Shuttle	5.4	--	**0.0**	0.0	0.0	0.0	0.0
International Space Station	1436.4	--	**1490.6**	1561.3	1611.4	1616.5	1635.2
Space Transportation	2667.8	--	**2415.1**	2118.7	1811.4	1868.6	1808.9
Space and Flight Support (SFS)	922.7	--	**835.0**	852.7	856.4	869.4	898.5
Total Budget	**5032.3**	**4950.7**	**4740.8**	**4532.8**	**4279.2**	**4354.6**	**4342.6**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

SPACE OPERATIONS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Space Shuttle	5.4	--	**0.0**	0.0	0.0	0.0	0.0
International Space Station	1436.4	--	**1490.6**	1561.3	1611.4	1616.5	1635.2
Space Transportation	2667.8	--	**2415.1**	2118.7	1811.4	1868.6	1808.9
Space and Flight Support (SFS)	922.7	--	**835.0**	852.7	856.4	869.4	898.5
Total Budget	**5032.3**	**4950.7**	**4740.8**	**4532.8**	**4279.2**	**4354.6**	**4342.6**
Change from FY 2017			**-209.9**				
Percentage change from FY 2017			**-4.2%**				

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

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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.

Space Operations capabilities enable rocket propulsion testing; assure safe, reliable, and affordable access to space; and maintain secure and dependable communications with crewed and robotic missions across the solar system and beyond.

NASA promotes the full utilization of the International Space Station (ISS) for conducting research and technology development. The ISS serves as a platform for advanced human systems research and technology, enabling safe and reliable exploration beyond low Earth orbit. As a national research laboratory, ISS leverages global collaboration and commercial partnerships to advance our Nation's and world's capabilities in space and help open the space frontier. The ISS provides opportunities for U.S. commercial companies to further enhance their experience and business base in low Earth orbit. Programs in the Space Operations portfolio also support and expand commercialization as the foundation of future U.S. civilian space efforts including promoting new opportunities for collaboration with industry on space station operations and supporting public-private partnerships for deep-space habitation and exploration systems.

The Crew and Cargo Program manages transportation services provided by both international partners and domestic commercial providers. NASA continues to advance commercial spaceflight and the American jobs it creates.

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 capabilities, bolster American leadership, reduce our current reliance on foreign providers for this service, and help stimulate the American aerospace industry.

The Space and Flight Support programs continue providing mission critical space communications, launch and test services as well as astronaut training to support its customer missions. The Space Communications and Networks program provides communication with missions in low Earth orbit and the 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 most distant missions. The Launch Services Program provides expertise and active launch mission management for over 40 NASA and other civil sector government scientific 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.

The 21st Century Space Launch Complex (21CSLC) initiative will conclude at the end of fiscal year (FY) 2017. Transfers to end users for remaining facility operations and maintenance items have been completed. Kennedy Space Center (KSC) will complete a number of infrastructure modernization projects, including refurbishing the wharf at the Turn Basin at KSC, Lightning System Upgrade, additional conditioning of the Launch Complex 39 crawler way and roof replacement of the KSC Logistics facility. Key projects at Wallops Flight Facility (WFF) will also be completed in FY 2017, such as the Range Control Center upgrades that will improve the capabilities in the control center used to support Orbital ATK commercial resupply services launches, and modernization of the Bermuda tracking facility.

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

INTERNATIONAL SPACE STATION PROGRAM

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
ISS Systems Operations and Maintenance	1092.5	--	**1173.1**	1219.7	1214.7	1213.9	1232.5
ISS Research	343.9	--	**317.5**	341.7	396.7	402.6	402.6
Total Budget	**1436.4**	**--**	**1490.6**	**1561.3**	**1611.4**	**1616.5**	**1635.2**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

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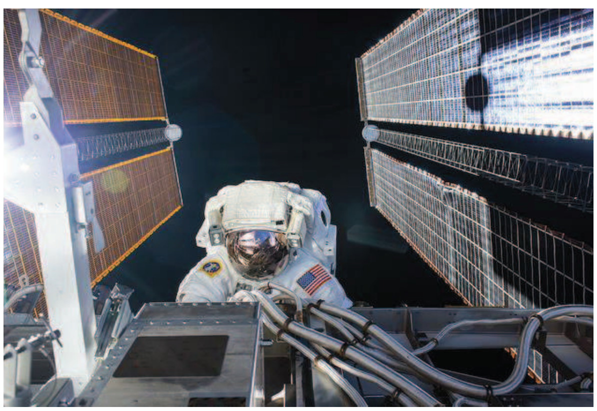

NASA astronauts Jeff Williams and Kate Rubins (pictured) conducted a six-hour and 48-minute spacewalk on September 1, 2016, where they successfully retracted a thermal radiator, installed two enhanced high definition cameras, and tightened bolts on a joint that enables one of the ISS solar arrays to rotate.

The International Space Station (ISS) is the largest and most complex habitable space-based research facility ever constructed by humanity. This highly complex facility provides a unique platform, enabling distinct research opportunities. 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 860,000 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).

The ISS will be in full operations and utilization through at least 2024. 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 human spaceflight 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.

INTERNATIONAL SPACE STATION PROGRAM

The ISS will facilitate moving human exploration of space from an Earth-reliant to an Earth-independent capability, a shift necessary for deep space exploration. The ISS is the only microgravity platform enabling long-term testing of new life support and crew health systems, advanced habitat modules, and other technologies needed to decrease reliance on Earth. Over the next several years, the program will continue to focus on capabilities needed to maintain a healthy and productive crew in deep space. Most recently, in March 2016, astronaut Scott Kelly returned from a year-long mission in space. Ongoing studies related to his time on the ISS and return home will be of incredible value for analysis of long-duration missions and their effects on the human body. Other manifested or planned experiments and demonstrations include tests of improved long-duration life support for Mars missions, advanced fire safety equipment, high-data-rate communications, techniques to improve logistics efficiency, large deployable solar arrays, 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 also provides a rich environment for endless research possibilities in the areas of fundamental biological and physical sciences.

The ISS program aims to provide direct research benefits to the public through its operations, research, and technology development activities. As a National Laboratory, the 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 2018

None.

ISS SYSTEMS OPERATIONS AND MAINTENANCE

Formulation	Development	Operations

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	**1092.5**	**--**	**1173.1**	**1219.7**	**1214.7**	**1213.9**	**1232.5**

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NASA flight engineer Peggy Whitson performs investigative troubleshooting on the Combustion Integrated Rack aboard ISS (Dec 2016).

The International Space Station (ISS) is a complex research facility and human outpost in low Earth orbit developed in a collaborative, multinational effort led by the U.S. with partners in Canada, Europe, Japan, and Russia. 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 extreme 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.

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, requires precise planning and logistics. The 463-ton vehicle requires routine maintenance and is subject to unexpected mechanical failures, given its highly complicated systems. 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 solely on the materials available to them onboard. This requires the support team on Earth to monitor and painstakingly plan for replacement parts and consumables, such as filters and gas, as well as spares like the sequential shunt unit (SSU), which is a key component of the ISS's power channel. 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.

ISS SYSTEMS OPERATIONS AND MAINTENANCE

Formulation	Development	Operations

The ISS program considers all aspects of the mission when developing operations plans to meet program objectives. These include scheduling crew activities, choreographing the docking and undocking of visiting crew and supply ships, evaluating consumables supply, flight plan variability, and managing 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.

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 the ISS is prepared to respond to failure of any item 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.

FY 2015 was one of the ISS program's most logistically challenged years. The program faced the loss of two commercial cargo resupply vehicles carrying critical research, consumables and spares. Both providers returned to flight in 2016. However, on September 1, 2016, SpaceX's Falcon 9 rocket exploded during a routine prelaunch fueling operation on a non-NASA mission. This prompted an investigation to understand the root cause of the anomaly resulting in additional cargo flight delays for the ISS. This is an example of the critical nature of the program's contingency planning.

Finally, as part of the Administration's commitment to increase cooperation with industry through the use of public-private partnerships, the ISS program is conducting a study of which operations, maintenance, and research activities could be commercialized. The implementation of such public-private partnerships will foster innovation and help prepare the private sector to take a leading role in low Earth orbit during and after the transition off the ISS platform.

EXPLANATION OF MAJOR CHANGES IN FY 2018

None.

ACHIEVEMENTS IN FY 2016

The ISS Systems O&M project continues to maintain resources both on-orbit and on the ground to operate and utilize the ISS. NASA expects continued 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 flights to the ISS approximately every three weeks. Each flight required extensive planning and

ISS SYSTEMS OPERATIONS AND MAINTENANCE

Formulation	Development	Operations

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 tracking, crew health care, environmental control and life support, electrical power, extravehicular activities (EVAs), extravehicular robotics, flight crew equipment, propulsion, structures and mechanisms, thermal control, guidance, navigation, and control. This past year a solar array voltage regulator shorted, causing one of the ISS's eight power sources to be lost. Flight controllers continued operations with no major issues by quickly re-routing the systems normally tied to this source to other power channels. The anomaly resolution team was able to quickly assess the issue and employ a repair plan to replace the malfunctioning unit. ISS crew members were able to execute EVA-35 to replace the unit and restore the lost power channel. Maintaining optimal power on the ISS is vital to research operations and crew safety.

The team supported one Russian EVA and six U.S. EVAs in FY 2016. Many of the U.S. EVAs continued the major reconfiguration onboard the ISS which began in FY 2015. NASA is continuing modifications to docking ports to enable traffic flexibility and port redundancy for the U.S. operating segment crew and cargo vehicle missions. This culminated in the installation of the first International Docking Adapter in August 2016. EVAs also supported maintenance and repairs, including installing a thermal cover on the Alpha Magnetic Spectrometer (AMS) to provide thermal shielding to pumps inside the experiment which were showing some signs of degradation, reconfiguration of the ISS's cooling system, restoring use of the Crew Equipment Translation Aid (CETA) cart which helps carry hardware during spacewalks, and retracting and stowing an unused thermal radiator.

WORK IN PROGRESS IN FY 2017

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. 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 one Russian EVA and at least five U.S. EVAs in FY 2017. The current nickel-hydrogen batteries on the ISS are nearing their end of life and require replacement for the ISS life extension. The O&M project will be 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. EVAs will also continue the major reconfiguration activities previously mentioned with the relocation of Pressurized Mating Adapter (PMA)-3.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

The ISS O&M project is planning to support U.S. astronauts aboard Commercial Crew flights. The ISS program will continue to work closely with the commercial partners to ensure that any challenges are addressed and the operations and research conducted aboard the ISS continues to be accomplished with minimal issues. NASA plans to work with international partners to maintain a continuous ISS crew

ISS SYSTEMS OPERATIONS AND MAINTENANCE

Formulation	Development	Operations

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 several Russian EVAs and at least three U.S. EVAs in FY 2018. The major reconfiguration activity begun in FY 2015 will be completed with the installation of the second International Docking Adapter. Once completed, the ISS will have two visiting vehicle docking ports and two visiting vehicle berthing ports. While current Commercial Resupply Service vehicles use berthing ports, the new commercial crew vehicles will require docking ports. When a visiting vehicle docks to the ISS, that arriving vehicle is in control of attaching itself to the ISS. When a vehicle berths to the ISS, the ISS is in control of capturing and attaching the arriving vehicle to the ISS via the Space Station Remote Manipulator System (SSRMS). The process of un-berthing requires the use of the SSRMS which does not support rapid crew evacuations in the event of an emergency. However, berthing ports are bigger and therefore allow for the transfer of larger equipment. EVAs will also continue to replace aging batteries with new more efficient lithium-ion batteries.

ISS SYSTEMS OPERATIONS AND MAINTENANCE

Formulation	Development	Operations

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 2016	Two U.S. EVAs
Jan 2017	Four contingency U.S. EVAs
Mar 2017	Three U.S. EVAs
Jul 2017	Russian EVA
Nov 2017	Russian EVA
Dec 2017	Contingency Russian EVA
Jan 2018	U.S. EVA
Feb 2018	Two Russian EVAs
Mar 2018	Two U.S. EVAs
Apr 2018	Four contingency U.S. EVAs; Two Russian EVAs
Aug 2018	Two Russian EVAs

Project Management & Commitments

While NASA maintains the integrator role for the entire ISS, each partner has primary authority for managing and operating the hardware and elements they provide. Within NASA, Johnson Space Center (JSC) in Houston, Texas leads project management of the ISS Systems O&M.

Acquisition Strategy

NASA extended the current Boeing vehicle sustaining engineering contract on a sole source basis to The Boeing Company 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

Formulation	Development	Operations

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	Nov 2016	Provides independent guidance for the NASA Administrator	No new formal recommendations or findings	Mar 2017
Other	NASA Aerospace Safety Advisory Panel	Feb 2017	Provides independent assessments of safety to the NASA Administrator	No new formal recommendations or findings	2017

ISS RESEARCH

Formulation	Development	Operations

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	343.9	--	317.5	341.7	396.7	402.6	402.6

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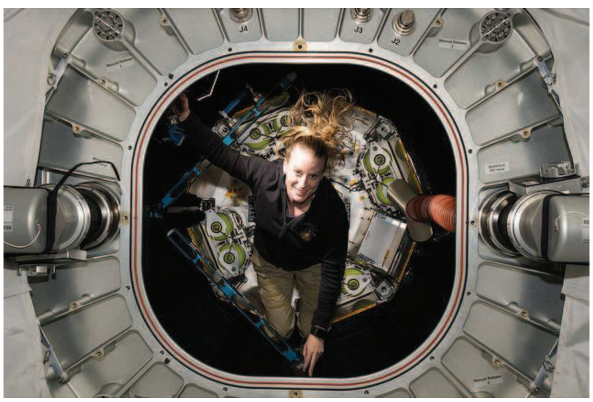

NASA astronaut Kate Rubins inspected the Bigelow Aerospace Expandable Activity Module (BEAM) attached to ISS. Expandable habitats are designed to take up less room on a spacecraft while providing greater volume for living and working in space once expanded. BEAM is the result of a public-private partnership that allowed Bigelow to deploy and test this capability at a fraction of the cost.

The International Space Station (ISS) is an orbiting platform that provides an unparalleled capability for space-based research and a unique venue for developing technologies for future human space flight exploration. The ISS enables scientific investigation of physical, chemical, and biological processes in an environment very different from Earth. As a research and development facility, the ISS supports a variety of science laboratories, external testbeds, and observatory sites, allowing astronauts to conduct a wide range of experiments in low Earth orbit. The ISS is managed as a U.S. National Laboratory enabling the use of its research facilities by the private sector and other government agencies to benefit the U.S. economy. The ISS supports research across a diverse array of disciplines, from fundamental physics and biophysics to human physiology and biotechnology. Research is also conducted on space biology, materials science and enabling technologies, among many others. The ISS is the primary science platform for the new Open Science Initiatives GeneLab and MaterialsLab, which enable next generation research by creating publicly available open access data resources and platform development. In addition, ISS is a platform for educational activities that enable the public to engage in the national and global endeavor of human spaceflight, and inspire students to excel in science, technology, engineering, and mathematics.

As the name implies, ISS is not strictly a NASA endeavor, but a collaborative venture with our international partners, including the Canadian, European, Japanese, and Russian space agencies. Although each partner has distinct national goals for ISS research, all participating agencies share a unified goal to extend the resulting knowledge for future exploration and to benefit humanity. Within NASA, mission directorates prioritize their research investments based on Exploration roadmaps for technologies needed

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to support future exploration and studies from the National Academies, such as the Decadal Survey on Biological and Physical Sciences in Space.

The ISS Research program funds fundamental and applied research in biological and physical sciences to enable future human exploration and add to our existing body of knowledge. It also funds a multi-user systems support (MUSS) capability, which provides 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 on-orbit research facilities. ISS Research also supports the Center for the Advancement of Science in Space (CASIS), a non-profit organization that manages the ISS National Laboratory.

Research and development conducted aboard ISS, sponsored by both NASA and the Agency's commercial partners, holds the promise of next-generation technologies in health and medicine; robotics, manufacturing, and propulsion; and development of applications that will benefit life on Earth. As NASA's only long-duration flight testbed, researchers aboard ISS study the effects of long-duration exposure to the space environment on the crew and devise and test countermeasures to offset health risks. Additionally, researchers evaluate extended performance of equipment critical to long-duration flight 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.

At the conclusion of Expedition 48 in September 2016, more than 1,900 investigators from 95 countries around the world have performed over 2,164 research investigations utilizing the ISS and over 1,300 R&D results have been published in scientific journals and magazines (Note: these are early estimates with final numbers expected to be published in early 2017).

COMMERCIALIZATION ACTIVITIES ON ISS

NASA and the ISS program, in partnership with CASIS, are leveraging ISS to enable the commercialization of low Earth orbit. Low Earth orbit is already partially commercialized – private sector companies operate numerous robotic spacecraft in this region of space, and the NASA Crew and Cargo program purchases commercial transportation services to and from low Earth orbit. However, the ISS program is playing a unique role in advancing the frontiers of economic activity in space. NASA is creating public-private partnerships which will allow entrepreneurs to explore potential revenue-generating activities which are enabled by the unique microgravity environment. By generating concepts and technologies that can generate revenue in low Earth orbit, these public-private partnerships will foster innovation and help prepare the private sector to take a leading role in low Earth orbit during and after the transition off the ISS platform. In addition, NASA is advancing the research capabilities and analytical tools onboard the ISS by purchasing services from the commercial entities that own and operate these capabilities, rather than follow the traditional government-contractor relationship to acquire NASA-owned facilities that has been used in the past.

NASA and its partners have different responsibilities within the broader commercialization effort. CASIS is reaching broad sectors of traditional and non-traditional commercial companies, as well as other government agencies to utilize the ISS National Laboratory and stimulate demand for ongoing commercial activity in low Earth orbit. NASA is actively implementing new, streamlined processes for

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researchers through its Revolutionize ISS for Science and Exploration (RISE), which enables users to fly research more quickly and cost effectively. NASA has recently released a request for proposal for payload integration services, entitled Research, Engineering, Mission and Integration Services (REMIS). These awards, planned for FY 2017, will transition these once NASA-only functions to a variety of commercial vendors, thus increasing the opportunity for the commercialization of low Earth orbit. Finally, NASA has requested feedback in the form of a request for information (RFI) for Advancing Economic Development in low Earth orbit via Commercial Use of Limited Availability, and Unique International Space Station Capabilities. Through this RFI, NASA hopes to learn more about commercial company interest in using available external ports and other unique ISS capabilities for their own business endeavors in low Earth orbit. ISS is also conducting a study to evaluate whether there are additional operations, maintenance, and research activities which have the potential for commercialization.

New external and internal commercial research platforms will be launching in the next two years. The Materials on ISS Experiment-Flight Facility (MISSE-FF), developed by Alpha Space, and the Multi-User System for Earth Sensing (MUSES), developed by Teledyne Brown Engineering, will augment ISS accommodations for external research significantly. The BioChip SpaceLab, developed by Hnu Photonics, and the BioBox, developed by Science, Technology and Advanced Research Systems (STaARS), will bring new commercially-operated internal capabilities for space biology research. The BioChip SpaceLab facility provides an ultra-portable, remote-controlled, automated microfluidics platform for general biological investigations and planned stem cell research. Ownership of all of these platforms is retained by their respective developers. Each developer is actively marketing the platform and seeking to increase the commercial user base of the ISS.

EXPLANATION OF MAJOR CHANGES IN FY 2018

None.

ACHIEVEMENTS IN FY 2016

On March 2, 2016, the study of identical twins Scott and Mark Kelly entered a new phase as Scott Kelly returned to Earth from his yearlong mission. Scott and Mark are nearly genetically identical, and studying them provides scientists a unique opportunity to examine how environment, diet, and other outside factors affect human health and performance. While one astronaut was in space for a year, the other twin remained on Earth allowing researchers to study the effects of space travel, including genetics, psychology, physiology, microbiology, and immunology.

The GeneLab Open Science Initiative moved into phase two, allowing researchers to search and access omics data such as genomics, transcriptomics, proteomics, epigenomics, metabolomics and microbiomics, from various data centers around the world including other government bioinformatics systems supported by the National Institutes of Health and Department of Energy. GeneLab is based on open source software to bring cutting edge and evolving capability to research without needing to purchase new data systems. GeneLab now contains more than 80 datasets and is averaging over 1,000 file downloads per month.

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Vegetable plant research enables the development of sustainable food supplies for long duration exploration missions. As part of the “Veggie” project series of experiments, astronauts successfully grew cabbage and red lettuce on board ISS and then enjoyed eating the first ever space-grown salad.

The Packed Bed Reactor Experiment arrived to ISS in December 2015. This investigation focuses on the role and effects of gravity on gas-liquid flow through porous media. These are critical components often found in life support systems, thermal control devices, fuel cells, and biological and chemical reactors. The results will influence future environmental control systems design.

NASA launched the Bigelow Expandable Activity Module (BEAM) and attached it to the ISS. Technology development and demonstrations on the ISS are critical to exploration beyond low Earth orbit and BEAM will provide research on how expandable habitats work in the conditions of space.

The Advanced Colloids Experiment-Temperature control-1 (ACE-T-1) research focuses on tiny suspended particles which assemble into structures while microscopically suspended in another fluid. The microgravity environment provides researchers insight into the fundamental physics of micro particle self-assembly and the kinds of structures that are possible to create novel high-tech materials.

The Burning and Suppression of Solids – Milliken investigation tested flame-retardant cotton fabrics to determine how well they resist burning in microgravity. Results benefit research on flame-retardant textiles that can be used on Earth and in space. Sponsored by Milliken & Company, this is a commercial investigation using the ISS National Laboratory.

Rodent Research-3, sponsored by pharmaceutical company Eli Lilly and Co., studied changes in the musculoskeletal system that happen in space. Spaceflight causes a rapid loss of bone and muscle mass especially in the legs and spine, with symptoms similar to those experienced by people with muscle degenerative diseases or with limited mobility on Earth. Results expand scientists’ understanding of muscle atrophy and bone loss in space, while testing an antibody that has been known to prevent muscle wasting in mice on Earth.

Commercial service provider NanoRacks deployed their NanoRacks External Platform (NREP), which is capable of hosting a number of individual investigations at one time. This is the first commercial platform mounted on the exterior of ISS for the testing of commercial research payloads, sensors, and electronic components in space.

The Biomolecule Sequencer demonstrated, for the first time, that DNA sequencing is feasible in microgravity using a crew-operated, miniaturized device to identify microbes, diagnose diseases, monitor crew health, and possibly detect DNA-based life off Earth. Over 211,000 sequences containing 2.35 billion bases were measured, with performance slightly better than a comparable measurement taken on Earth.

CASIS continued to attract and enable non-traditional space customers to the ISS National Laboratory. Of 34 new projects selected during FY 2016, almost half were new-to-space customers and more than half involved commercial users. The National Science Foundation selected five projects for the ISS National Laboratory in FY 2016, providing $1.5 million in grant funding for these projects. This will become an annual sponsored program involving up to $1.8 million per year toward a variety of physical

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sciences R&D topics. The National Institutes of Health National Center for Advancing Translational Sciences also committed grant funding focused on human physiology and disease onboard ISS, part of a four-year collaboration involving up to $12 million in funding using tissue chip technology for translational research onboard ISS for the benefit of human health on Earth. Total external sponsorship of ISS National Laboratory CASIS research solicitations grew by 800% in FY 2016 alone. CASIS also exceeded its $3 million grant target for research portfolio funding for the fourth year in a row, allocating more than $5.3 million in CASIS seed funding toward ISS National Laboratory projects. This seed funding generated more than $15 million in matching funding from non-NASA/non-CASIS sources. Finally, CASIS continues to attract leading venture capital and angel investors, growing its network to 33 investors. To date, CASIS has facilitated more than 70 introductions between start-up companies and its investor network, resulting in growth, diversity of funding, and types of users of the ISS National Laboratory. In FY 2016, 58 ISS National Laboratory payloads were delivered to ISS.

For a more comprehensive list of research achievements on ISS, go to http://www.nasa.gov/mission_pages/station/research/index.html

WORK IN PROGRESS IN FY 2017

NanoRacks' NextGen research platform called Black Box is designed to provide near-launch payload turnover of autonomous payloads while providing advanced science capabilities for customers. This accommodation will be operated on a commercial basis. The LEMUR-2 Cubesats are part of a remote sensing satellite constellation that provides global ship tracking and weather monitoring. These satellites were deployed from both ISS and from a Nanoracks External Deployer installed on the exterior of the OA-5 Cygnus service module, enabling satellite deployments after departing from the ISS.

The Cool Flames experiment uses the Combustion Integrated Rack to help scientists develop more efficient advanced engines and new fuels for use in space and on Earth. The Lighting Effects investigation tests a new lighting system aboard the station designed to enhance crew health and keep their body clocks in proper sync with a more regular working and resting schedule. The system uses adjustable light-emitting diodes (LEDs) and a Dynamic Lighting Schedule that varies intensity and spectrum of the LEDs in tune with sleep and wake schedules. Lighting manipulation has potential as a safe, non-pharmacological way to optimize sleep and circadian regulation on space missions. People on Earth, especially those who work night shifts, could also improve alertness and sleep by adjusting lighting for intensity and wavelength.

Outside the Earth's magnetic field, astronauts are exposed to space radiation that can reduce immune response, increase cancer risk, and interfere with electronics. The Fast Neutron Spectrometer investigation will help scientists understand high-energy neutrons, part of the radiation exposure experienced by crews during spaceflight, by studying a new technique to measure electrically neutral neutron particles. Because it experiences radiation from a variety of sources, ISS provides an excellent environment for evaluating this instrument. This improved measurement will help protect crews on future exploration missions.

Only a few animals, such as tadpoles and salamanders, can regrow a lost limb, but the onset of this process exists in all vertebrates. Rodent Research-4, sponsored by the U.S. Department of Defense (DoD)

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and CASIS, studies what prevents other vertebrates such as rodents and humans from re-growing lost bone and tissue, and how microgravity conditions impact the process. Results will provide a new understanding of the biological reasons behind a human's inability to grow a lost limb at the wound site, and could lead to new treatment options for the more than 30 percent of the patient population who do not respond to current options for treating chronic non-healing wounds.

The Space Test Program Houston-5 platform is host to a wide variety of experiments. These include the Lightning Imaging System which will measure the amount, rate and energy of lightning as it strikes around the world. Understanding the processes that cause lightning and the connections between lightning and subsequent severe weather events is a key to improving weather predictions and saving life and property. From the vantage of the station, the LIS instrument will sample lightning over a wider geographical area than any previous sensor. The platform will also host Raven, a real-time spacecraft navigation system that provides the eyes and intelligence to see a target and steer toward it safely. Future robotic spacecraft will need advanced autopilot systems to help them safely navigate and rendezvous with other objects, as they will be operating thousands of miles from Earth.

Monoclonal antibodies are important for fighting off a wide range of human diseases, including cancers. An investigation by Merck Research Labs will crystallize a human monoclonal antibody that is currently undergoing clinical trials for the treatment of immunological disease. Preserving these antibodies in crystals allows researchers a glimpse into how the biological molecules are arranged, which can provide new information about how they work in the body. Thus far, Earth-grown crystalline suspensions of monoclonal antibodies have proven to be too low-quality to fully model. With the absence of gravity and convection aboard ISS, larger crystals with more pure compositions and structures can grow. Results have the potential to improve drug delivery and manufacturing on Earth.

A proof-of-concept investigation on the Gene-RADAR® device developed by Nanobiosym will test the ability of this device to accurately detect, in real time and at the point of care, any disease that leaves a genetic fingerprint. A Nanobiosym Genes study sponsored by CASIS will analyze two strains of bacterial mutations aboard ISS, providing data that may be helpful in refining models of drug resistance and support the development of better medicines to counteract the resistant strains.

During the Microgravity Expanded Stem Cells investigation, also sponsored by CASIS, crew members will observe cell growth and morphological characteristics in microgravity and analyze gene expression profiles of cells grown on the ISS. This information will provide insight into how human cancers start and spread, which aids in the development of prevention and treatment plans.

The NASA Science Mission Directorate (SMD)-sponsored SAGE III Earth observation instrument, launched to the ISS on February 19, 2017, will record changes to the Earth's ozone layer, such as fluctuations in concentrations of greenhouse gases and thinning of the ozone layer. Scientists do not yet understand how these changes affect climate, and accurate long-term measurements such as those provided by SAGE III are crucial for understanding the processes that impact climate change

The Zero Boil-Off Tank investigation will provide experimental data to validate updated computer models for potential application to cryogen tank designs that could reduce propellant launch mass, and improve existing models for developing cryogen storage systems.

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The Advanced Plant Habitat (APH) is the largest enclosed environmentally controlled chamber designed to support commercial and fundamental plant research onboard ISS. The APH facility is required testing methods for food crop production for exploration missions. The research will enable NASA to understand how to build exploration bio-regenerative life support systems with closed system ecology, mass, power, shelf life, and storage volume. This research will also enable NASA to produce healthy food, waste management, biological stability of the habitat, and material reuse, which is critical knowledge for long-term operations of future exploration systems.

The MUSES platform will simultaneously host up to four Earth observation instruments that can be changed, upgraded, and robotically serviced. Teledyne Brown Engineering is developing the Earth-imaging platform as part of its commercial space-based digital imaging business. Teledyne will operate, maintain, and sustain MUSES on a commercial basis, and provide services to hosted instruments for ISS.

TangoLabs 1 and 2, developed by Space Tango, are next-generation facilities capable of hosting 21 one unit CubeLab form factor investigations at a time, continue to expand the research capabilities on the ISS targeted at making access affordable to a number of non-traditional users, including educational institutions and small companies, while meeting the needs of more traditional users.

A set of follow-on fruit fly experiments, Fruit Fly Lab 2, will build upon the previous research by studying multiple generations of fruit flies (drosophila). The drosophila heart develops and functions in a fashion remarkably similar to that of the human heart. These experiments will identify which aspects of heart function are affected by microgravity, whether these effects are made worse by pre-existing genetic abnormalities, and whether gender plays a role in these responses. Three independent studies of Macromolecular Biophysics (MMB) protein crystallization will be also be flown. This work will help in the creation of drugs used in protein therapeutics.

Astronauts will conduct the Advanced Combustion via Microgravity Experiments (ACME) which consists of five independent studies of gaseous flames in the Combustion Integrated Rack (CIR). ACME's primary and secondary goals are to help improve fuel efficiency and reduce pollutant production in practical combustion on Earth, and inform spacecraft fire prevention through innovative research focused on materials flammability.

Satellites are powered by solar arrays, which convert sunlight into energy. The Roll-Out Solar Array flight experiment will test an entirely new deployable solar array design that is stronger, lighter, and packages more compactly for launch. It has higher power density than existing technology and can be easily adapted to different sizes, making it a promising material for use on all future NASA, military and commercial solar-powered spacecraft.

The Neutron star Interior Composition Explorer (NICER) payload, jointly sponsored by SMD and the Space Technology Mission Directorate (STMD), will study neutron stars by performing soft X-ray timing and spectroscopy analyses. Neutron stars are unique environments: They squeeze more than 1.4 solar masses into a city-size volume, giving rise to the highest stable densities known in the universe. By answering a long-standing astrophysics question— "How dense is a neutron star?"—NICER will provide unprecedented constraints to models describing the state of matter in extreme environments. Through the embedded Station Explorer for X-ray Timing and Navigation Technology, it will also demonstrate, for the

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first time, real-time, on-board X-ray pulsar navigation, which is a significant milestone in the quest to establish a GPS-like navigation capability throughout the Solar System and beyond.

Rodent Research-5 will continue bone loss experimentation and will test a new drug that can both rebuild and block bone loss on mice experiencing spaceflight-induced skeletal damage. Because osteoporosis affects more than 200 million people worldwide, this research has the potential to result in new innovative treatments that promote bone formation to improve health for crew members in orbit and people on Earth.

Sponsored by SMD, ISS Cosmic-Ray Energetics and Mass (ISS-CREAM) payload will work on solving a fundamental astrophysics mystery: what gives cosmic rays such incredible energies, and how does that affect the composition of the universe? Scientists hope to discover whether cosmic rays are accelerated by a single cause, which is believed to be supernovae. On the ISS, this payload can gather ten times more data than prior balloon-borne CREAM measurements due to increased data collection time on the ISS. It will also complement the ongoing ISS cosmic ray particle science being performed by the Alpha Magnetic Spectrometer and the Calorimetric Electron Telescope.

The Cold Atom Laboratory will take advantage of the microgravity environment to create the coldest known matter in the universe—just a trillionth of a degree above absolute zero. The laboratory could enable significant discoveries in atomic physics, which would be applicable to next generation communications, navigation, timekeeping, and computing systems.

The CASIS-sponsored Optical Fiber Production in Microgravity investigation by Made In Space demonstrates the merits of manufacturing fiber optic filaments in microgravity. The optical fiber chosen for production aboard the ISS is a high value optical fiber, which is known as ZBLAN. While ZBLAN has potential to far exceed the performance of other fibers in common use, the terrestrially produced fiber suffers from glass impurities and microcrystal formation which reduce performance. Microgravity has been shown to significantly reduce these imperfections, and production of fibers in space may enable not only improved materials but also a new frontier in manufacturing and space utilization.

In the technology demonstration area, Silicon Graphics International will fly its commercially-funded Spaceborne Computer. This is a high performance computer with novel methods of mitigating radiation induced interruptions. The investigation will validate these methods and inform the company of the best answers for computing challenges beyond low Earth orbit where crews might rely more heavily upon a high performance computer and the radiation environment can be extreme.

Overall, CASIS will continue to increase the throughput of high-value ISS National Laboratory projects focused on disruptive strategies to solve big cross-cutting challenges, such as optimization of tissue-on-a-chip technologies for biomedical testing. It will continue to develop multi-year and multi-institutional projects that benefit the economy, promote collaboration and innovation, and provide valuable R&D information through partnerships with non-NASA government agencies. CASIS will continue to expand the ISS National Laboratory R&D portfolio through targeted business development efforts to attract strategically selected organizations (commercial companies, commercial and public-private consortia, or philanthropic research funding organizations) that are projected to generate significant positive value and impact through multiple flight projects.

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As momentum gains in research and technology investments from prior years, CASIS expects to see an increase in tangible products, services, and research publications, especially in areas of physical and materials sciences, drug delivery/development, and disease modeling. CASIS will continue to evaluate results from ISS National Laboratory projects using quantifiable assessments of economic and societal potential, using these findings to inform selection and prioritization of new projects. The center also seeks to reach 250,000 students with ISS National Laboratory-related STEM education content and secure agreements with three new STEM partners.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

The original MISSE experiments investigated the long-term exposure of materials to the harsh environment of space as a partnership between NASA and DoD. In FY 2018 a new version will launch to ISS, making materials exposure tests available commercially to NASA, DoD and private aerospace companies. MISSE-FF includes new enhancements such as near real-time experiment monitoring, regular photographing of samples in flight and expanded accommodations to house more complex experiments, all while being executed robotically rather than by astronauts during EVAs. MISSE experiments help to reduce spacecraft development costs while increasing reliability.

Other new accommodations aboard ISS will continue to provide valuable opportunities for the commercial sector from both a research and technology development perspective but also as a commercial service provider. A Zero-G Mass Measurement Device, developed by Orbitec; the Advanced Space Experiment Processor (ADSEP) and Multi-specimen, Variable-gravity Platform (MVP), developed by Techshot; and the DLR Earth Sensing Instrument Spectrometer (DESIS-30), a hyperspectral instrument jointly developed by DLR and Teledyne Brown Engineering, will continue to augment research capabilities as well as commercial participation. Next generation laboratory capabilities will also launch, including an advanced microscopy suite and a new rapid freeze capability for biological specimens.

The Space Debris Sensor is a calibrated impact sensor designed to directly measure the ISS orbital debris environment for two to three years. This Commercial Off-The-Shelf-based instrument will provide excellent semi-real-time impact detection and recording capability.

Sponsored by SMD, the Total and Spectral Solar Irradiance Sensor will provide absolute measurements of the total solar irradiance and spectral solar irradiance, which is important for accurate scientific models of climate change and solar variability. Another SMD-sponsored payload, Ecosystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS), will measure the temperature of plants and look to understand how much water plants need and how they respond to stress. The ISS orbit will allow ECOSTRESS to take observations at different times of day across the seasons, which will help detect the timing, location, and predictive factors leading to plant water uptake, decline, and/or cessation over the diurnal cycle. The measurements will also help calculate agricultural water consumptive use over the contiguous United States. One of the core products that will be produced by ECOSTRESS team is a leading drought indicator that can identify that plants are stressed and that a drought is likely to occur providing the option for decision-makers to take action.

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Robotic Refueling Mission 3 is a technology demonstration to test in-space rocket propellant transfer technology. It will demonstrate the ability to transfer and freeze a cryogenic fluid and transfer Xenon gas, both in zero-gravity. 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.

Astronauts will conduct materials research in the Materials Science Research Rack making use of the first U.S.-built Sample Cartridge Assembly (SCA). Understanding and modeling material properties, in the absence of gravity, allows development methods for creating new and improved materials on Earth.

In the field of biology, the Advanced Plant Experiments 5 (APEX-05) will utilize the Veggie facility on ISS and a set of follow-on fruit fly experiments, Fruit Fly Lab 3, will build upon the previous research by studying multiple generations of fruit flies and provide further insight into immune system and cardiovascular research. Cellular biology studies planned during FY 2018 include the Tissue Regeneration – Evaluation of Inductive Agents investigation, which will study the mechanisms that restore tissues post-injury and the impact of microgravity on the process. The deliverables from this research may help evaluate the practicality of growing complex tissues in spaceflight. Finally, the CASIS-sponsored Rodent Research-6 will test an implantable drug delivery system that circumvents the need for daily injections. If successful, this system could serve as a universal technology for drug delivery and animal testing. In collaboration with Novartis and NanoMedical Systems, this validated system may rapidly translate into a commercial product.

NASA will continue to enhance the existing open science pipeline to study gravity as a continuum by utilizing ground based and on-orbit ISS research. The GeneLab Phase 2 Data System will go live in 2018 increasing the ability of scientists to conduct data analysis and create next generation hypotheses about the effects of microgravity on living organisms. The Life Beyond low Earth orbit science initiative will seek to investigate biological systems in habitats beyond low Earth orbit. In conjunction with other ISS flight experiments, researchers will be able to explore the differences between biological adaptation and response in low Earth orbit on ISS to those changes observed in the deep space environment.

Management of the National Laboratory by CASIS will continue to leverage external funding (commercial, non-NASA government, investment capital, etc.) with a minimum goal of $10 million annually. In support of future payloads and enabling a sustainable system for ongoing R&D in low Earth orbit, CASIS will prioritize selection of flight projects that contribute matching funding toward direct project costs. CASIS will also continue development of R&D programs to further support low Earth orbit commercialization, some of which may be classed as “high risk, high reward”—including pilot programs to enable specific markets. Finally, the National Laboratory portfolio will continue to include a subset of projects selected to inspire future scientists, engineers, and technology leaders of tomorrow. CASIS will continue to partner with other successful educational and outreach organizations using ISS National Laboratory-related content, with a goal of reaching 400,000 United States students in FY 2018.

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

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activities performed on-board, including the research performed. The table below outlines start dates of the upcoming increments to ISS.

Date	Significant Event
Nov 2016	Increment 50
Apr 2017	Increment 51
June 2017	Increment 52
Sep 2017	Increment 53
Dec 2017	Increment 54
Feb 2018	Increment 55
Apr 2018	Increment 56
Sep 2018	Increment 57

Project Management & Commitments

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. The ISS program office is the interface with CASIS and manages other ISS Research activities such as MUSS and National Laboratory enabling activities.

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
MUSS (includes National Laboratory 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

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Acquisition Strategy

NASA awards contracts and grants for conducting research on ISS. 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 Laboratory.

NASA prioritizes ISS research based on recommendations from the National Academies and the Decadal Survey on BPS in Space. The National Academies has a committee on its Space Studies Board to provide independent advice on strategy and priorities in the physical and life sciences at NASA. In addition, there is a HEO Research Subcommittee within the NASA Advisory Council to advise NASA on the direction of basic research within HEO. Major technology demonstrations require significant cooperative funding and NASA is developing an approach for cross-agency prioritization of ISS technology initiatives.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Vehicle Sustaining Engineering Contract	The Boeing Company	Houston, TX
Huntsville Operations Support Center	COLSA Corporation	Huntsville, AL
Mission Operations and Integration (MO&I) Contract	Teledyne Brown Engineering	Huntsville, AL
ISS National Laboratory Management Entity	CASIS	Melbourne, FL

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	NASA Advisory Council	Nov 2016	Provides independent guidance for NASA Administrator	No new formal recommendations or findings for ISS	Mar 2016

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Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	NASA Aerospace Safety Advisory Panel	Feb 2017	Provides independent assessments of safety to the NASA Administrator	No new formal recommendations or findings for ISS	2017

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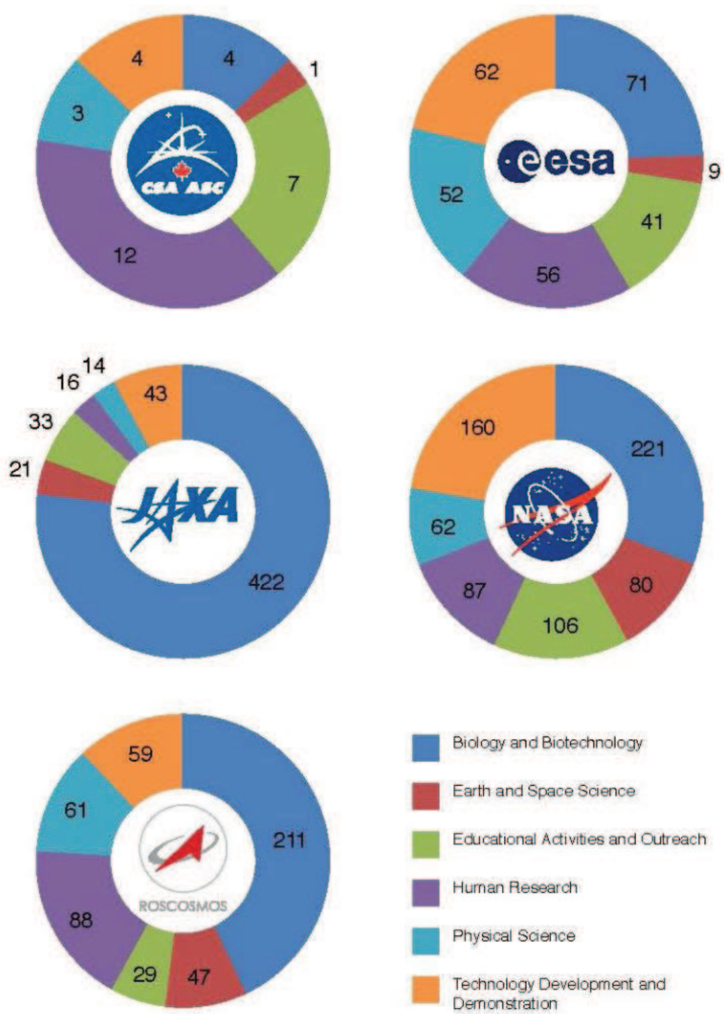
Historical Performance

In FY 2016, NASA estimates ISS partners performed 386 research and technology investigations, including 107 new investigations. During this period, NASA estimates that NASA performed 152 investigations, including 77 new investigations. The charts below display historical data, by partner agency, for research investigations performed on ISS since 1998, and a comparison of FY 2016 NASA-sponsored and National Lab-sponsored investigations.



NASA utilization includes investigations by the Italian Space Agency (ASI), an ISS Participant Agency.

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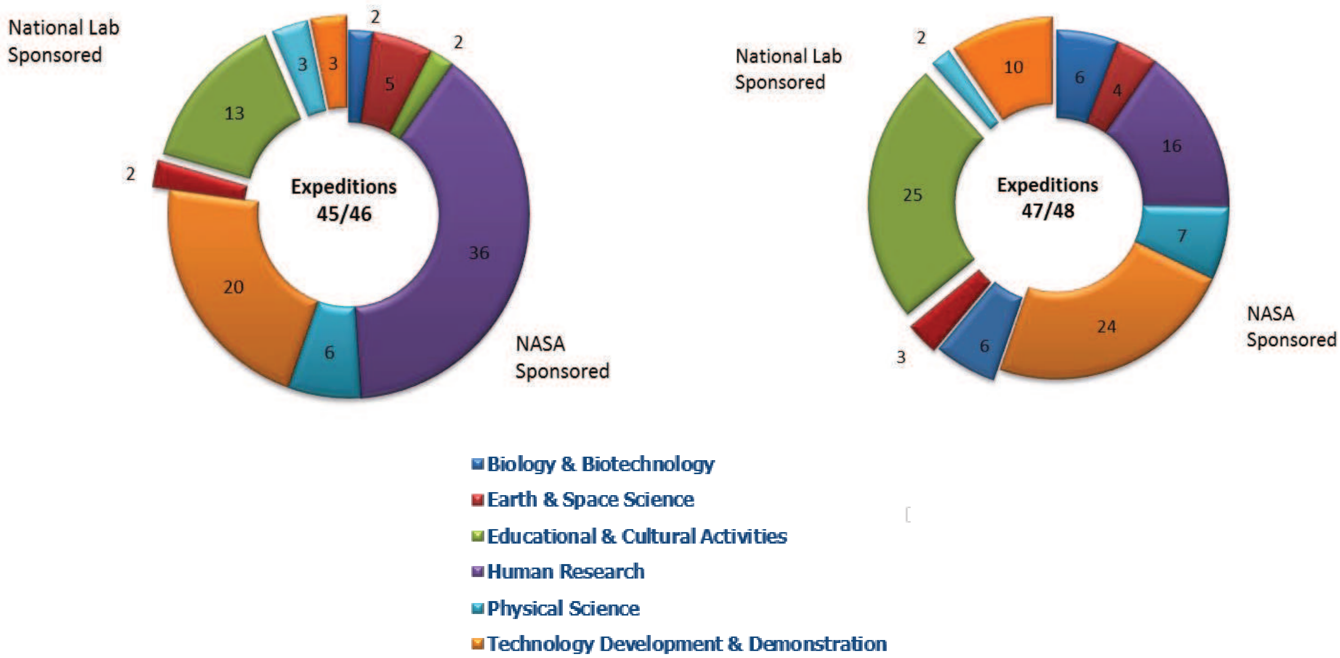


SPACE TRANSPORTATION

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Crew and Cargo Program	1424.0	--	**1683.2**	1945.6	1775.5	1832.3	1772.6
Commercial Crew Program	1243.8	--	**731.9**	173.1	35.8	36.3	36.3
Total Budget	**2667.8**	**--**	**2415.1**	**2118.7**	**1811.4**	**1868.6**	**1808.9**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

Orbital ATK's Cygnus spacecraft on its way to the launch site at the Wallops Flight Facility (October 2016).

The Space Transportation theme's objective is to transport U.S. astronauts and cargo safely back and forth to America's national laboratory in low Earth orbit, International Space Station (ISS). This theme includes the Commercial Crew Program (CCP) and the Crew and Cargo Program. Maintaining ISS requires a fleet of vehicles and launch locations to transport astronauts, science experiments, critical supplies, and maintenance hardware; replenish propellant; and dispose of waste.

CCP partners with the U.S. commercial sector to develop and operate safe, reliable, and affordable crew transportation to low Earth orbit. NASA awarded Commercial Crew Transportation Capability (CCtCap) contracts to Boeing and 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 Orbital ATK, Sierra Nevada, and SpaceX. NASA purchases crew transportation to ISS from the Russian Roscosmos State Corporation, known as Roscosmos, and 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.

EXPLANATION OF MAJOR CHANGES IN FY 2018

None.

CREW AND CARGO PROGRAM

Formulation	Development	Operations

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	1424.0	--	1683.2	1945.6	1775.5	1832.3	1772.6

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

The SpX-10 Dragon commercial cargo spacecraft arrives at ISS on February 23, 2017, with about 5,500 pounds of experiments and supplies. Crew members used the Canadarm2 robotic arm to capture the spacecraft, then handed command over to ground controllers to attach Dragon to the ISS.

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 the ISS operations and research. Deliveries not only provide science experiments, critical supplies and maintenance hardware, but also rotate crewmembers, replenish propellant, and dispose of waste.

The Crew and Cargo program manages transportation services provided by both international partners and domestic commercial providers. NASA’s commercial service contracts to resupply the ISS have changed the way the Agency does business in low Earth orbit (LEO). With these contracts, NASA continues to advance commercial spaceflight and support the American jobs created by this industry.

NASA purchases cargo delivery to the ISS under the original Commercial Resupply Services (CRS) contracts with Orbital ATK and SpaceX. Orbital ATK, SpaceX, and Sierra Nevada have also begun work under the follow-on CRS-2 contracts for missions beginning in 2019. For CRS flights to ISS, SpaceX currently and Sierra Nevada will in the future launch CRS missions from Cape Canaveral, Florida. SpaceX uses their Falcon 9 rocket to launch their Dragon cargo vehicle, while Sierra Nevada will be using the Atlas V rocket to launch their Dream Chaser cargo vehicle. Orbital ATK 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, Orbital ATK also launches CRS missions on Atlas V rockets from Cape Canaveral, Florida. The FY 2018 Budget supports 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 contracts to support the development of several companies' efforts

Formulation	Development	Operations

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. The results of this arrangement have been a reinvigorated 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 both in this program to improve the CRS-2 contract vehicle and in other programs to expand the successful use of public-private partnerships.

Roscosmos currently provides the ISS crew transportation. NASA plans to continue purchasing crew transportation services from Roscosmos until a domestic capability is available. 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 (PCMs) (i.e., crew missions) to the ISS; subsequent missions are funded by the Crew and Cargo Program.

The Crew and Cargo Program also funds activities supporting visiting vehicles that provide transportation for the ISS, including integration activities and the NASA docking system which will be used by commercial crew providers.

EXPLANATION OF MAJOR CHANGES IN FY 2018

None.

ACHIEVEMENTS IN FY 2016

Shortly after the third Orbital Sciences CRS launch (Orb-3) on October 28, 2014, the Antares rocket carrying a Cygnus spacecraft exploded, causing the destruction of the spacecraft and cargo. Orbital ATK returned to flight on December 6, 2015 with OA-4 using an Atlas V launch vehicle. Subsequently, they also successfully launched OA-6 with an Atlas V launch vehicle on March 22, 2016. Their first CRS Antares flight since the launch vehicle mishap was OA-5 on October 17, 2016.

Later in FY 2015, the seventh SpaceX CRS mission (SpX-7) was lost when the Falcon 9 rocket carrying the Dragon spacecraft exploded after launch on June 28, 2015. SpaceX's next CRS mission took place on April 8, 2016, with the successful launch of the SpX-8 mission. They also successfully launched the SpX-9 mission on July 18, 2016. However, on September 1, 2016, SpaceX’s Falcon 9 rocket exploded during a routine prelaunch fueling operation on a non-NASA mission which has resulted in additional cargo flight delays for ISS. However, cargo flights resumed in FY 2017 with SpX-10. Because of the fixed-price, milestone-based structure of the CRS contract vehicle, these delays did not result in cost increases to NASA and NASA received increased vehicle research capability as a result of the launch delays.

Orbital ATK completed seven CRS milestones in support of seven commercial resupply flights, including milestones for successful completion of two flights in FY 2016. SpaceX completed 13 CRS milestones in support of 12 commercial resupply flights, including milestones for successful completion of two flights in FY 2016.

CREW AND CARGO PROGRAM

Formulation	Development	Operations

On January 14, 2016, NASA awarded CRS-2 contracts for cargo resupply of the ISS to Orbital ATK, Sierra Nevada and SpaceX. Each mission requires complex preparation and several years of lead time. CRS-2 integration milestones began in FY 2016 to support flights beginning in 2019 which will expand the science and research capability of the ISS. This is Sierra Nevada's first commercial cargo contract with NASA.

In FY 2016, the Crew and Cargo Program began funding CCtCap contract milestones for crew missions with Boeing and SpaceX. More information on CCtCap progress can be found under the CCP portion of this document. The program also supported three Soyuz launches and four Progress launches (Russian cargo vehicle). Progress launches are not funded by NASA.

WORK IN PROGRESS IN FY 2017

NASA expects Orbital ATK to launch three CRS flights and complete six milestones in support of seven CRS/CRS-2 commercial resupply flights. Their OA-5 flight was the first flight of the upgraded Antares rocket, which provides an increase in cargo upmass capability. NASA also expects SpaceX to launch three CRS flights and complete 15 performance milestones in support of 10 CRS/CRS-2 commercial resupply flights. The SpX-11 mission is planning for the first re-use of a Dragon spacecraft capsule. Orbital ATK, Sierra Nevada, and SpaceX have successfully completed milestones through their Preliminary Design Reviews and will continue to perform CRS-2 integration milestones through 2018. The program will also continue funding CCtCap contract milestones for crew missions with Boeing and SpaceX.

Russian Roscosmos State Corporation, known as Roscosmos, informed NASA that starting in March of 2017, they will be reducing their crew size on the Russian segment from three to two cosmonauts until sometime in FY 2018. Roscosmos' decision to temporarily reduce their crew complement in the summer of 2017 to two cosmonauts until the new Russian science module is ready would have reduced the science accomplishments planned for the ISS. NASA has extended Astronaut Peggy Whitson's return to ensure EVA capability until her return in September and which provides valuable U.S. crew time for experiments on board the station. Peggy's skill and experience makes her an incredible asset aboard the space station that will benefit both our commercial and international partner communities with research and technology development. This has also provided NASA the opportunity to purchase additional crew transportation in order to increase research capability on the ISS. In September of 2017, Soyuz 52S will carry an additional U.S. operating segment (USOS) astronaut increasing the USOS crewmembers on ISS from three to four. The program will also support three Progress launches and one HTV (Japanese cargo vehicle) launch that are not funded by NASA.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

The Crew and Cargo program will enable continued research and technology development by providing a stable crew and cargo flight plan. These flight plans include Soyuz launches carrying USOS crewmembers to the ISS. NASA will purchase additional crew transportation in March 2018 on Soyuz 54S to continue providing four USOS crew members on the ISS until September, when domestic crew capability is scheduled to become available through the Commercial Crew Program. Once commercial crew launch services become available, NASA will be able to permanently increase the crew size on the

Formulation	Development	Operations

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.

The increase in the number of crew on board the ISS and the resulting increase in hours devoted to research will result in increased NASA demand for cargo transportation. To meet this increase in demand, four commercial resupply flights are planned to deliver research and logistics hardware in FY 2018. NASA expects Orbital ATK to launch one CRS flight and complete seven performance milestones in support of six CRS/CRS-2 flights. SpaceX plans to launch three commercial resupply flights and complete 18 performance milestones in support of ten CRS/CRS-2 flights. NASA expects Sierra Nevada to complete one performance milestone in support of one CRS-2 flight. These resupply flights will be vital for delivering not only the critical "day to day" supplies needed, but also the experiments and investigations that will enable the astronauts to continue important research on ISS. They will also support the additional research enabled by the additional astronaut. Orbital ATK, Sierra Nevada, and SpaceX will continue to perform CRS-2 integration milestones. The flight schedule also includes 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 that the ISS can sustain nominal operations and maintenance, while allowing the program to respond to any anomalies that might occur. The table below shows the scheduled ISS flight plans for FY 2017 and FY 2018. NASA funds the SpaceX and Orbital ATK missions, as well as Soyuz seats related to USOS crew requirements. The planned spacing of the Soyuz crew rotation flights ensures a continuous crew presence on the ISS, and smooth transitions between crews.

Date	Significant Event
Oct 2016	OA-5
Oct 2016	Soyuz 48S
Nov 2016	Soyuz 49S
Dec 2016	Progress 65P (anomaly)
Dec 2016	HTV-6
Feb 2017	SpX-10
Feb 2017	Progress 66P
Apr 2017	OA-7
Apr 2017	Soyuz 50S
Jun 2017	SpX-11

CREW AND CARGO PROGRAM

Formulation	Development	Operations

Date	Significant Event
Jun 2017	Progress 67P
Jul 2017	Soyuz 51S
Aug 2017	SpX-12
Sep 2017	Soyuz 52S
Sep 2017	OA-8
Oct 2017	Progress 68P
Nov 2017	SpX-13
Dec 2017	3R (Russian Proton launch of Multipurpose Laboratory Module)
Dec 2017	Soyuz 53S
Jan 2018	SpX-14
Feb 2018	HTV-7
Feb 2018	Progress 69P
Mar 2018	OA-9
Mar 2018	Soyuz 54S
Apr 2018	Progress 70P
May 2018	Soyuz 55S
Jun 2018	SpX-15
Jun 2018	6R (Soyuz launch of Russian Node Module)
Sep 2018	Soyuz 56S
Sep 2018	U.S. Crew Vehicle (USCV)-1

Formulation	Development	Operations

Project Management & Commitments

JSC is responsible for management of the Crew and Cargo Program.

Element	Description	Provider Details	Change from Formulation Agreement
Crew transportation	Roscosmos will provide crew transportation to the ISS via the major contract described below until a domestic capability is available.	Provider: Roscosmos Lead Center: JSC Performing Center(s): N/A Cost Share Partner(s): Canadian Space Agency (CSA), European Space Agency (ESA), and JAXA	N/A
Cargo transportation	Orbital ATK, 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: Orbital, 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. NASA competitively awarded the original CRS contracts to SpaceX and Orbital on December 23, 2008, and services began in 2012. These are milestone-based, fixed-price, indefinite delivery/indefinite quantity (IDIQ) contracts. On January 14, 2016, NASA competitively awarded CRS-2 contracts to Orbital ATK, Sierra Nevada, and SpaceX with cargo transportation services planned to begin in 2019. The Agency applied knowledge gained from the original CRS contracts and required a number of key enhancements for the CRS-2 contracts. Adjustments to the CRS-2 contract structure, as compared to the structure of CRS, include focusing requirements on the execution of a minimum of six missions as opposed to the delivery of a specified quantity of metric tons of cargo; the inclusion of a variety of delivery, return and disposal options for both pressurized and unpressurized cargo, as well as an optional accelerated return to increase operational flexibility and responsiveness to research requirements; and the addition of an insurance requirement to cover damage to government property during launch services, reentry services or transportation to, from, in proximity of, or docking with the ISS. Like the current CRS contracts, CRS-2 contracts are milestone-based, fixed-price IDIQ contracts. While the maximum potential value of all

CREW AND CARGO PROGRAM

Formulation	Development	Operations

CRS-2 contracts is $14 billion from 2016 through 2024, NASA will order missions as needed and the total prices paid under the contracts will depend on which mission types and quantities are ordered.

The original contract with Roscosmos expanded cooperation between the United States and Russia on human spaceflight, including the Shuttle-MIR program and construction of the ISS. In 2006, NASA modified the Roscosmos contract to include crew transportation, rescue, and related services. The agreement is a sole source contract under Federal Acquisition Regulation (FAR) 6.302-1, which is applicable when there is only one responsible source and no other supplies or services will satisfy Agency requirements. 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 NASA the option to purchase Soyuz crew transportation services for three USOS crew members in 2019 in the event that domestic commercial crew services are delayed. A decision to exercise this option must be made by early FY 2018. NASA will begin using domestic crew transportation services once available.

In September 2014, NASA's CCP awarded CCtCap contracts to Boeing and SpaceX. Those awards include at least two service missions per provider, with a maximum of up to six service missions per provider. CCP is funding milestones on the initial service missions, called Post Certification Missions. The Crew and Cargo program will fund the subsequent service missions. These crewed vehicles will provide a minimum of 220 pounds of cargo as specified by the ISS program.

CREW AND CARGO PROGRAM

Formulation	Development	Operations

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	Orbital ATK	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	Nov 2016	Provides independent guidance for the NASA Administrator	No new formal recommendations or findings for the ISS	Mar 2017
Other	NASA Aerospace Safety Advisory Panel	Feb 2017	Provides independent assessments of safety to the NASA Administrator	No new formal recommendations or findings for the ISS	2017

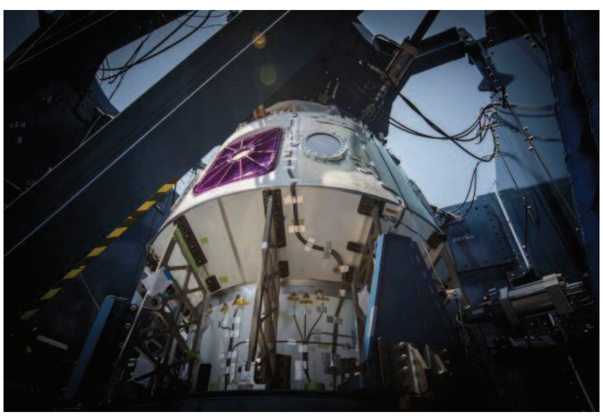
COMMERCIAL CREW PROGRAM

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	1243.8	--	731.9	173.1	35.8	36.3	36.3

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



Top Photo: The first hull of the Boeing CST-100 Starliner Structural Test Article rests in a work stand inside the company's modernized Commercial Crew and Cargo Processing Facility high bay at NASA's Kennedy Space Center in Florida (July 2016).

Bottom Photo: The first test article of a SpaceX Crew Dragon undergoes structural load testing to demonstrate the spacecraft's ability to withstand the tremendous forces it's exposed to during spaceflight (June 2016).

NASA is looking to the U.S. private sector 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 LEO space and the ISS will bolster American leadership, reduce our current reliance on foreign providers for this service, and help stimulate the American aerospace industry. By supporting the development of human spaceflight capabilities, NASA is also working to lay the foundation for more affordable and sustainable future human space transportation capabilities.

Through the Commercial Crew Program (CCP), NASA provides technical and financial support to industry partners during development of their crew transportation systems using milestone-based contracts, and certifies them to carry NASA astronauts to and from the ISS. Under this acquisition model, NASA defines requirements upfront and pays the contractor only once contract milestones are successfully completed. This approach shifts financial risk from taxpayers to the private sector, incentivizing increased cost-control, and decreasing the costs of developing the systems.

The first phase of the development effort was a series of competitively awarded Space Act Agreements (SAAs), followed by Certification Products Contracts (CPCs). The scope of the contracts included the submittal and technical disposition of specific, early development certification products. The CPC effort allowed the partners to gain insight into NASA human spaceflight requirements and gave NASA early insight into partner designs and approaches.

CCP entered the final certification phase with the award of two Commercial Crew transportation Capability (CCtCap) contracts. CCtCap requires both contractors 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. Increasing the crew of the U.S. operating segment of the ISS from three to four crew members will result in a doubling of the on-orbit research time to almost 80 hours per week. This is because the fourth crew member will be able to focus his or her time almost exclusively on conducting experiments, rather than on ISS operations and maintenance.

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. The contracts also allow the companies to retain the intellectual property associated with their spacecraft designs which facilitates the commercial sale of human space transportation services.

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. When NASA’s industry partners successfully achieve all milestones, they will own and operate their completed 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 provider's initial Post Certification Missions (PCMs). Subsequent PCMs are funded by the Crew and Cargo program.

EXPLANATION OF MAJOR CHANGES IN FY 2018

None.

COMMERCIAL CREW PROGRAM

ACHIEVEMENTS IN FY 2016

NASA's industry partners, Blue Origin, the Boeing Company (Boeing), Sierra Nevada Corporation (SNC), and SpaceX, made significant progress developing viable commercial crew transportation systems. Blue Origin completed their unfunded milestones under the Commercial Crew Development Round 2 (CCDev2) Space Act Agreement (SAA) in March 2016, and a follow-on non-reimbursable SAA was executed with Blue Origin to continue development of the company's orbital human space transportation system.

NASA's follow-on initiative, Commercial Crew integrated Capability (CCiCap), made significant progress completing planned milestones. By the end of FY 2016, SpaceX had completed 14 of 15 milestones, including their Delta Crew Vehicle Critical Design Review (CDR). SpaceX has one milestone remaining, their In-flight Abort Test, which is scheduled for FY 2018. Sierra Nevada has one funded milestone remaining, the Engineering Test Article Flight Testing #2 Review. Sierra Nevada also has one unfunded milestone remaining for the Design Analysis Cycle-6 Closeout Review. Sierra Nevada has both milestones scheduled for completion in FY 2017.

CCtCap development activities also made good progress. As of the end of FY 2016, Boeing had completed 14 of 33 development milestones. This included a key flight testing milestone, the Ground Verification Test and Environmental Qualification Test Readiness Review. NASA also granted Boeing authority to proceed on its second PCM. SpaceX had completed seven of 19 development milestones, including a major review, the Delta Critical Design Review 2. NASA also granted SpaceX authority to proceed on its first two PCMs.

WORK IN PROGRESS IN FY 2017

Sierra Nevada is scheduled to complete its last two CCiCap milestones in FY 2017. SpaceX will continue to work towards completing its final CCiCap milestone. Boeing and SpaceX will complete several CCtCap development milestones. By the end of FY 2017, NASA expects Boeing to have completed 23 of 33 milestones, including a key flight testing milestone, the Water/Land Landing Qualification Test Review. NASA expects SpaceX to have completed 12 out of 19 milestones, including a key flight testing milestone, Flight Test Without Crew Certification Review. Finally, NASA will continue to grant authority to proceed on future PCMs, as needed.

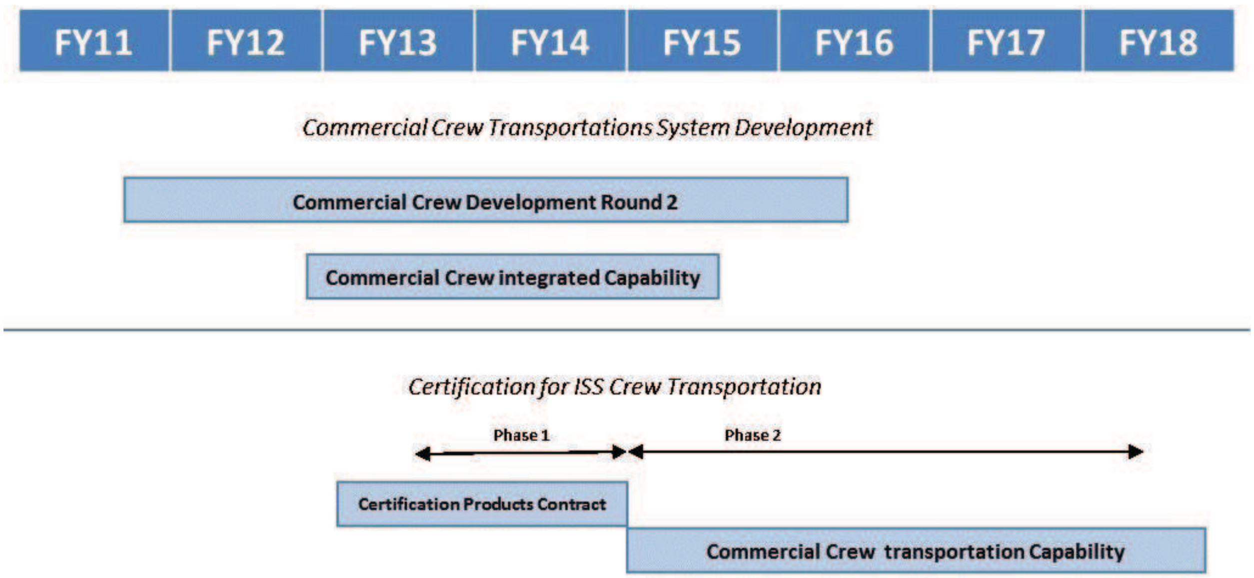
KEY ACHIEVEMENTS PLANNED FOR FY 2018

SpaceX is scheduled to complete its final CCiCap milestone, the In-flight Abort Test. Under CCtCap, SpaceX is on contract to complete certification by August 2018, completing all development milestones. By the end of FY 2018, NASA expects Boeing to complete 32 of 33 development milestones, including the Crewed Flight Test (CFT) Design Certification Review and the CFT Flight Test Readiness Review. Boeing is on contract to complete certification by October 2018. NASA will continue to grant authority to proceed on future PCMs, as needed.

COMMERCIAL CREW PROGRAM

Program Schedule

Progression of Commercial Crew development efforts.



Program Management & Commitments

The HEOMD team at NASA Headquarters performs strategic management and oversight of Commercial Spaceflight, while the Kennedy Space Center (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 to industry to begin the process of NASA certifying their crew transportation systems. 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.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
CCDev2	Blue Origin	Kent, WA
CCtCap	Boeing	Houston, TX
CCiCap	Sierra Nevada	Louisville, CO
CCiCap/CCtCap	SpaceX	Hawthorne, CA

COMMERCIAL CREW PROGRAM

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	NASA Advisory Council	Nov 2016	Provide independent guidance for the NASA Administrator	No new formal recommendations or findings	Mar 2017
Other	ASAP	Feb 2017	Provide independent assessments of safety to the NASA Administrator	ASAP recommended that NASA require providers to produce verifiable evidence of systems engineering and integration principles in support of NASA certification.	2017
Other	SRB	Oct 2016	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	Fall 2017

COMMERCIAL CREW PROGRAM

Historical Performance

Through FY 2016 (funded milestones only).

As of September 30, 2016

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	10	219.5	91%	96%	Active
Boeing	20	480.0	20	480.0	100%	100%	Completed
SpaceX	15	460.0	12	429.8	80%	93%	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	33	2,022.5	14	1174.2	42%	58%	Active
SpaceX	19	1,206.1	7	544.0	37%	45%	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 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Space Communications Networks	592.2	--	**493.0**	489.5	433.5	461.4	464.5
Space Communications Support	77.7	--	**83.3**	90.9	142.9	124.0	150.1
Total Budget	**669.8**	**--**	**576.3**	**580.4**	**576.4**	**585.5**	**614.6**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

Deep Space Station - 36 (DSS-36) in Canberra, Australia, is one of four 34 meter (111 foot) Beam Waveguide antennas to be built as part of the Deep Space Network Aperture Enhancement Project. When completed, the new set of antennas will provide the same, if not higher, sensitivity and received signal power as one of the 70 meter (230 foot) antennas that have been operating for over 50 years.

The Space Communications and Navigation (SCaN) program provides mission-critical communications and navigation services required by all NASA spaceflight missions. These missions range from high altitude balloons, to satellites in low Earth orbit, to the most distant manmade object – which is currently over 12 billion miles from Earth — Voyager 1. SCaN retrieves science, spacecraft, and crew health data for all of these missions and 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 SCaN 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. A communications or navigation failure on the spacecraft or in SCaN network systems could result in complete loss of a mission. 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 which SCaN provides services to on a reimbursable basis.

SCaN's three communications networks, the Space Network (SN), Near Earth Network (NEN), and Deep Space Network (DSN), provide these critical services to customer missions. SN communicates with missions in low Earth orbit, such as the Hubble Space Telescope (Hubble), and provides constant communication with ISS, as well as its commercial and international partner servicing vehicles. In the future, it will also support Commercial Crew providers and launches of the Space Launch System (SLS) and Orion spacecraft. The NEN communicates with suborbital missions and missions in low Earth orbit, highly elliptical Earth orbit, and some lunar orbits.

NEN supports a number of science and weather missions, including the Magnetospheric Multiscale (MMS) constellation and the Geostationary Operational Environmental Satellite-R Series (GOES-R), which is a collaborative effort between the National Oceanic and Atmospheric Administration and NASA. Future science missions dependent upon NEN services include the NASA-ISRO Synthetic Aperture Radar (NISAR) science mission as well as SLS launches. DSN communicates with the most distant missions, such as interplanetary probes. Recent examples include the JUNO satellite orbiting the planet Jupiter and the European Space Agency (ESA) ExoMars 2016 exploring Mars and serving as a data relay for science data being sent back to Earth. DSN will also provide vital communications links with the James Webb Space Telescope and the Exploration Mission 1 (EM-1) Orion vehicle during its lunar operations phase after their respective launches.

The three networks require maintenance, replenishment, modernization, and capacity expansion to ensure service for existing and planned missions. The SCaN program also includes support to ground communications links to move data between ground stations, NASA centers, and mission operation and data centers. In addition, SCaN tracks and characterizes near Earth objects within nine million miles, and determines their orbits for use by the Science Mission Directorate’s (SMD) Planetary Science Division for collision avoidance with Earth. 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.

SCaN networks make good use of public-private partnerships to support their various customers. The NEN currently 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. In addition, SCaN is currently studying options for the long-term sustainment of the SN. A broad range of technical capabilities and acquisition strategies for the future SN architecture are under consideration, including partnerships with the commercial communications satellite industry.

Space Communications Support provides functions to efficiently integrate and plan 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, and radio frequency spectrum management. Systems engineering is integral to the overall success of SCaN's architecture. The systems engineers are responsible for overseeing the formulation and execution of the future SCaN network designs. SCaN's integrated network architecture identifies mission requirements and develops the technical architecture, which responds to challenging mission and programmatic requirements, as well as the call for new, enhanced communications capabilities.

Operating in space requires significant international coordination. SCaN’s standards development and management activity maintains a portfolio of internationally agreed upon 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.

SPACE COMMUNICATIONS AND NAVIGATION

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

EXPLANATION OF MAJOR CHANGES IN FY 2018

None.

SPACE COMMUNICATIONS NETWORKS

Formulation	Development	Operations

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	592.2	--	493.0	489.5	433.5	461.4	464.5

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

The Tracking and Data Relay Satellite (TDRS-M) is undergoing final testing before its scheduled launch in August 2017 from Cape Canaveral, Florida. The geosynchronous fleet of TDRS is the space segment of the Space Network and operates 24 hours a day, 7 days a week. It provides communication and tracking services to missions in low Earth orbit.

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, U.S. Government, civil space agency and commercial missions.

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, such as Voyager 1 and Voyager 2, 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 Hubble, International Space Station (ISS), New Horizons, Magnetospheric Multiscale mission, Soil Moisture Active Passive mission, Mars Exploration Rover, Opportunity, and Voyager would not be able to deliver key science data that could help unlock mysteries of science and knowledge about our universe.

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 ISS, as well as for ground and balloon research in remote locations, such as the South Pole. The SN consists of NASA’s Tracking and Data Relay Satellite (TDRS) system of communications satellites in

SPACE COMMUNICATIONS NETWORKS

Formulation	Development	Operations

geosynchronous orbit; a set of space-to-ground link terminals at NASA's White Sands Complex, NM; and remote space-to-ground terminals in Guam, and at Blossom Point, Maryland. 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. To accomplish this, SCaN's Space Network Ground Segment Sustainment (SGSS) project will incrementally upgrade the current SN by replacing obsolete ground hardware and data systems at the ground terminals that are nearing the end of their life cycle, significantly improving reliability and cost efficiency. Due to the operational nature of the networks, NASA performs sustainment activities while communications are ongoing with no loss of service.

NASA's current TDRS fleet consists of four first-generation satellites placed into orbit 21 to 28 years ago, three second-generation satellites that have provided services for more than a decade, and two new third-generation satellites. The four original first-generation satellites are well past their expected life and are showing signs of age-related battery and electronics failures. The TDRS Replenishment project purchased three third-generation TDRS spacecraft for the Space Network, TDRS-K, -L, and -M. The TDRS spacecraft will ensure adequate services to customers into the mid-2020s. Two are currently on-orbit, and one is preparing for launch in August 2017.

The NEN provides space communications to missions in low Earth, 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, NM; U.S. McMurdo Antarctic Station; Wallops Flight Facility (WFF), Chincoteague, VA; and University of Alaska, Fairbanks, AK. 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 network provides these services for orbiting satellites with periodic passes – an average of 140 per day per satellite. The NEN also supports orbiting satellites through short duration communications services. These missions require daily and sometimes hourly contact. 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 (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 equally apart on the globe, each station will be 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.

SPACE COMMUNICATIONS NETWORKS

Formulation	Development	Operations

NASA has sent science missions to every planet in the solar system; the DSN provided communication and tracking services to all of those missions. The DSN project manages operations, maintenance and upgrades for this network.

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. It 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. Parts for the aging 70 meter antennas have become difficult to find, causing high maintenance costs and continue to increase. BWG antennas differ from conventional antennas in that the transmission and reception of multiple frequencies is facilitated by the rotation of a mirror situated beneath the antenna, in the pedestal room. The location of sensitive instrumentation and transmitters in the pedestal room, rather than in the structure of the antenna, makes BWG antennas less complicated and more flexible to maintain than conventional antennas. Therefore, these new 34 meter antennas will be easier and more cost-effective to maintain, in addition to providing the same or better 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 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 responsible for moving information between the three space communications network ground stations, NASA centers, customer mission operations and data centers. The CSO is a centralized commercial service that provides point-to-point communication services between ground sites. 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 2018

None.

ACHIEVEMENTS IN FY 2016

During the fiscal year, the space communications networks supported over 100 missions, with over 325,000 hours of tracking and more than 245,000 passes. SCaN networks provided launch to splash-down communication support for six human spaceflight missions, 12 expendable launch vehicle (ELV) missions, and one robotic mission. 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.

As part of the Guam Antenna Radome Sustainment effort, SN successfully replaced two radomes (which house the antennas) and completed System Acceptance Testing of an upgraded antenna drive system.

SPACE COMMUNICATIONS NETWORKS

Formulation	Development	Operations

Both the aging radomes and obsolescent antenna drive system were subject to failure, which would have put the antennas at risk of damage.

At White Sands, SN completed a Critical Design Review for chillers and electrical equipment, and began work on replacement of uninterruptable power supply modules, which are beyond their design life. SN has also begun upgrading its White Sands ground equipment to meet ISS requirements to provide up to 600 Mbps Ku-band data service.

Capping more than a year's effort, SGSS completed a major step in software integration and system development activities. Integrated software is a key deliverable for SGSS and drives ground system performance. The project continues building on early ground terminal functionality and successfully demonstrated TDRS Spacecraft Telemetry Tracking and Control and user service functions.

NEN completed the System Design Review for the replacement of the AS2 antenna at the Alaska Satellite Facility, which had become obsolete and inoperable. This replacement will also provide backup to the AS1 and AS3 antennas while they are being upgraded to Ka-band and also provides an opportunity to reduce commercial station provider usage. NEN also continued developing Launch Communication Stations at KSC and downrange in Bermuda. These sites are needed to support key human spaceflight missions such as EM-1 and future Exploration Missions. NEN also completed Ka-Band upgrades at the Kongsberg Satellite Services site in Antarctica. Ka-band upgrades are required at Antarctica, Alaska to meet future known high-rate Ka-band requirements for missions such as the NASA- Indian Space Research Organization - Synthetic Aperture Radar.

The DSN Follow-the-Sun Operations upgrade will be completed in two phases. Phase 1 is Follow-the-Sun remote operations and Phase 2 enables one operator to control three antennas simultaneously. Both phases are in development and Phase 1 completed its pilot successfully demonstrating remote operations for two ground stations. DSN is also upgrading its downlink tracking and telemetry to support EM-1, James Webb Space Telescope (Webb)), and Transiting Exoplanet Survey Satellite (TESS). The test readiness review was completed and deployment to ground stations began.

The DSN Aperture Enhancement Project continued to upgrade and replace existing antennas at its complexes. The project completed testing of the DSN Deployable Space System (DSS)-36 (34 meter) antenna in Canberra, Australia, in September 2016 and the antenna became operational in October 2016. Work also began on two new antennas in Madrid, Spain, DSS-56 and DSS-53. Excavation work for DSS-56 was completed and excavation work for DSS-53 began.

WORK IN PROGRESS IN FY 2017

The three space communications networks will continue to provide a level of service similar to that provided in prior years. This includes over 240,000 tracking passes, totaling more than 325,000 hours, while maintaining an extremely high level of proficiency (approximately 99.95 percent or higher), well above the 95 percent required by the SCaN Program Commitment Agreement. SCaN networks are planning to support 15 human spaceflight, 16 ELV, and five robotic mission launches.

SPACE COMMUNICATIONS NETWORKS

Formulation	Development	Operations

The SN will complete its Guam Antenna Radome Sustainment work and continue work on replacing the uninterruptable power supply module at White Sands. In addition, White Sands ground equipment upgrades will provide 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 a sufficiently large time to complete a downlink or for a data recorder to return to Earth.

With both TDRS-K and TDRS-L accepted and on-orbit, along with TDRS-M launch scheduled in 2017, SN will have adequate capacity for its expected mission set until the second-generation TDRS begin retiring in the mid-2020s. The SCaN program will also complete its study of options for the long-term sustainment of the SN, and award follow-on study contracts. A broad range of technical capabilities and acquisition strategies for the future SN architecture are under consideration, including partnerships with the commercial communications satellite industry.

The contractor has completed the last software build and is in performing the pre-integration. Once completed the contractor will start integrating the build to the system integration and testing. The SGSS project is the basis for the SN to maintain safe, reliable, and cost efficient operations for the next several decades. This is an important step towards achieving the new, modernized SN, which will enable state of the art communications capability with the ISS, SLS, Orion, and other orbiting spacecraft well into the 21st century.

The NEN will complete the Test Readiness Review for the replacement of the AS2 antenna at the Alaska Satellite Facility and begin Ka-Band upgrades at that site. The NEN will also complete development of the Launch Communication Station at Kennedy Space Center (KSC), making that site operational to support EM-1, and continue work at the Bermuda site.

The DSN Follow-the-Sun Operations upgrade will complete development of Phase 1 and begin its operational transition into remote operations for completion in FY 2018. Development of Phase 2 will continue. DSN will complete uplink subsystem upgrades to support EM-1, and complete its upgrade of downlink tracking and telemetry to support EM-1, Webb, and TESS.

The second of six new 34 meter BWG antennas under DSN Aperture Enhancement Project, DSS-36, became operational in October 2016. The project will begin construction of two antennas at Madrid Deep Space Communications Complex (MDSCC) in Spain, DSS-56 and DSS-53, which will augment the 70 meter antenna located at this site.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

The SCaN Network 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.

SPACE COMMUNICATIONS NETWORKS

Formulation	Development	Operations

As part of its sustainment activities, SGSS will continue integration, and test activities associated with completing ground station hardware and software. SN will also complete its uninterruptable power supply module replacement at White Sands. Replacement of these power modules will ensure uninterrupted power to ground equipment should there be a failure of the facility's external power supply.

NEN will complete the Operational Readiness Review for the replacement of the AS2 antenna at the Alaska Satellite Facility, significantly increasing capabilities at that facility. It will begin and complete depot level maintenance of the WG1, an 11 meter antenna at the Wallops Ground Station. 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 begin Ka-Band upgrades at the Alaska Satellite Facility scheduled for completion in FY 2020. As part of its activities to support EM-1, NEN will complete development of the Launch Communication Station in Bermuda, making that site operational.

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 2019. Construction activities for DSS-53 will also continue to support operations in FY 2020. 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. Construction for DSS-33 is scheduled to begin in FY 2019 and DSS-23 in FY 2021.

The DSN Follow-the-Sun Operations upgrade will complete Phase 1 operational transition into remote operations. Phase 2 development will continue through FY 2019 with operations completing in FY 2020.

SPACE COMMUNICATIONS NETWORKS

Formulation	Development	Operations

Project Schedule

The table below includes significant SCaN network milestones in FY 2017 and FY 2018.

Date	Significant Event
FY 2017 - Q1	DSN - DSS-36 antenna operational
FY 2017 - Q1	SN - Guam Antenna Radome Sustainment complete
FY 2017 - Q4	Launch TDRS-M Spacecraft
FY 2017 - Q4	NEN Launch Communication Station at KSC complete
FY 2018 - Q1	NEN AS2 antenna replacement complete
FY 2018 - Q1	SN - uninterruptable power supply module replacement at White Sands complete
FY 2018 - Q1	NEN Launch Communication Station at Bermuda complete
FY 2018 - Q3	DSN - Complete Phase 1 Follow-the-Sun Transition

SPACE COMMUNICATIONS NETWORKS

Formulation	Development	Operations

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

Formulation	Development	Operations

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	Harris	McLean, VA
NEN Operations	Harris	McLean, 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	October 2016	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 2018

SPACE COMMUNICATIONS SUPPORT

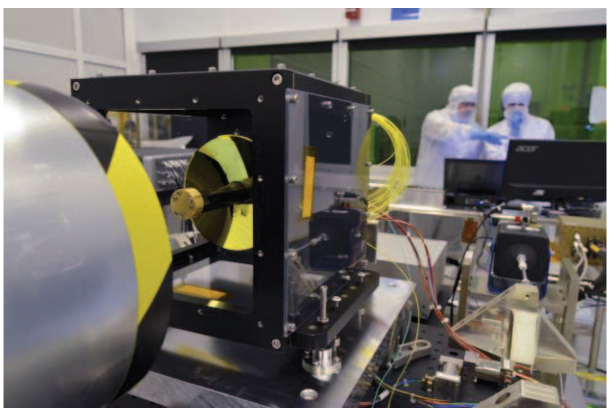
Formulation	Development	Operations

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	77.7	--	83.3	90.9	142.9	124.0	150.1

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



Scheduled to launch in 2019, the Laser Communications Relay Demonstration (LCRD) will simulate communications support, practicing for two years with a test payload on the International Space Station and two dedicated ground stations in California and Hawaii. Here in the picture, the optical module of LCRD is being assembled in the clean room at NASA Goddard Space Flight Center.

The Space Communications Support project maintains a high level of performance in NASA's SCaN program through planning, management, and technology development efforts.

Within the Space Communications Support project, SCaN's architecture planning and 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. SCaN is conducting studies to identify future space-based relay communication and navigation architectures for Earth and Mars that are infused with technologies under development to support NASA missions in the 2022 and beyond timeframe.

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. Some of the demonstrable technologies that SCaN is currently working on are optical communication and software-defined radios.

Optical communication is a form of long distance communication using light (lasers) as a means of transmitting information and has the potential to become more efficient, less expensive to operate, and

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

inherently more secure than radio communications. Optical communication terminals have a lower weight and power per terminal than comparable radio frequency (RF) terminals; they are also inherently more secure due to their narrow beams and receiver fields-of-view compared to current RF systems. SCaN is developing a plan for transitioning optical communication technology from a demonstration capability into an operational service. With NASA's Space Technology Mission Directorate (STMD), SCaN is completing the flight payload for the Laser Communications Relay Demonstration (LCRD) for flight in June 2019. STMD is funding the payload, while SCaN is funding ground operations. LCRD will be NASA's first long-period optical communications project that will demonstrate benefits for both deep space and near Earth missions. LCRD will also validate that advanced relay operations are possible and could be used for future relays, such as on Mars. To transmit a 30 cm resolution map of the entire Martian surface (at one bit/pixel) would take current RF systems two years – a laser communications system operating at projected capacity would be able to do it in nine weeks. Construction efforts, such as for LCRD ground stations, use Construction of Facilities funds appropriated in NASA's Construction and Environmental Compliance and Remediation account.

NASA is working to develop software-defined radios, a type of reconfigurable radio in which some or all of the communication layers are implemented in software and/or firmware, enabling them to be modified in space during operations. The SCaN TestBed tests various software defined radio technologies on the International Space Station (ISS). An evolution of the SCaN Testbed is the Cognitive Communications System, which will develop next generation cognitive technologies for communication to increase mission science return and improve resource efficiencies.

SCaN and STMD are also jointly working together on the Deep Space Atomic Clock (DSAC), which recently passed space-qualification testing at the Jet Propulsion Laboratory (JPL). This demonstration will revolutionize the way we conduct deep space navigation by enabling a spacecraft to calculate its own timing and navigation data in real time. Today, we can deliver a spacecraft to the top of the Martian atmosphere with a 1 to 2 km uncertainty. DSAC improves deep space navigation such that we expect this uncertainty to shrink to 100 meters, 10 to 20 times better than we can do today. This is important because it saves precious fuel that will be required to compensate for the winds on Mars and thereby allow us to get closer to the desired, targeted landing spot. DSAC also enables on-board navigation whether it is autonomous navigation for robotic missions or for crewed missions. This will speed up decision making when round trip light time becomes a detriment, really anything beyond the moon.

As one of the eleven member space agencies in the multi-national Consultative Committee for Space Data Systems (CCSDS), NASA/SCaN participates in the development of communications and data systems standards for spaceflight with its partners. 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. Eliminating the need for additional space relay satellites or a ground station results in significant cost savings to NASA without reducing services and coverage to space missions.

Electromagnetic spectrum is the valuable and finite natural resource that all NASA missions and most operations require for communications, navigation, and data services in the areas of Earth science, space science, human space exploration, and aeronautical research. Visible light and radio waves are two types of radiation that can be categorized by frequency and wavelength along the electromagnetic spectrum.

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

While NASA uses many portions of spectrum in one way or another, virtually every endeavor by the agency requires communications or data transfer via the radio spectrum. All forms of wireless communication including cellular telephones, radio and television broadcasting, GPS position locating, aeronautical and maritime radio navigation, and satellite command and control use the radio communications portion of the electromagnetic spectrum. The laws of physics dictate that at any given time and place, multiple uses of a single frequency can interfere with each other if not carefully controlled and coordinated. SCaN is responsible for ensuring access to the portions electromagnetic spectrum currently used by NASA. This includes protecting missions from interference and ensuring that sufficient bandwidth is available for future missions. SCaN provides the NASA representatives to the U.S. delegations that attend international spectrum coordination meetings. The most important of these are the World Radiocommunication Conferences, which meet every three to four years and include delegates from more than 150 nations. The purpose of these Conferences is to review and revise the International Telecommunication Union's Radio Regulations, which govern the use of electromagnetic spectrum, define frequency allocations, and refine the mechanisms by which use of electromagnetic spectrum by satellites is coordinated.

NASA spacecraft employ GPS timing signals for precision positioning, navigation, and timing for vehicles in space. This allows NASA to maximize spacecraft autonomy and enables precise spaceflight methods such as formation flying. 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. government capabilities 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 2018

None.

ACHIEVEMENTS IN FY 2016

NASA's vision for the future SCaN network architecture is to build and maintain a scalable and integrated infrastructure that provides cost-effective space communications services at order-of-magnitude higher data rates to enable NASA's science and exploration missions. For example, the operational data rate to the ISS was doubled in 2013, and current development activities will double it again in both 2017 and 2019. This infrastructure can readily evolve to accommodate new and changing technologies and will preserve current capabilities to support user mission critical events and emergencies. SCaN will use industry studies conducted in FY 2016 to include industry perspectives in our next generation architecture planning. These industry studies, combined with previous and ongoing SCaN studies, will serve as the basis for the next iteration of the SCaN network architecture, which will be capable of meeting NASA's needs for the next 25 years.

NASA is building dedicated ground terminals to support NASA's optical communications infrastructure and support LCRD. NASA is converting the JPL Optical Communications Telescope Laboratory in

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

California into Optical Ground Station (OGS)-1 and has begun making unique modifications to that existing facility. Construction has begun for OGS-2, a new facility located at the Maui Space Surveillance Complex in Hawaii. Both ground terminals passed their critical design reviews (CDRs) in April of 2016. SCaN also supported the incorporation of encryption on the LCRD mission for enhanced security. Additionally, SCaN continued to study placing an optical communication user terminal on the Japanese space agency's module on ISS in 2021. 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 commercialized, next generation design with significantly lower size, weight, power, and cost than the current state-of-the-art radio solutions. SCaN issued a Request for Information for the ILLUMA-T modem in FY 2016 and expects to execute a procurement in mid-FY 2017.

The SCaN TestBed focused on developing variable and adaptive radio techniques making SCaN's networks more autonomous and responsive. Leveraging the Digital Video Broadcast Second Generation (DVB-S2) standard, the project developed a closed-loop system to detect interference and adjust frequencies to reduce error rates. The SCaN TestBed continued performing research towards the capability to handle autonomous spacecraft-initiated service requests, which will reduce the need for labor-intensive scheduling of events and increase mission operational flexibility.

SCaN represented NASA on key spectrum requirements at the international World Radiocommunication Conference in November 2015. The Conference resulted in approval of U.S. proposals on issues of interest to NASA. To improve efficiency, SCaN also developed NASA's Electronic Radio Database System (NERDS) consolidating spectrum information housed in multiple disparate systems throughout NASA.

WORK IN PROGRESS IN FY 2017

SCaN will baseline NASA's space communications network requirements, architecture, and concept of operations to upgrade the three networks into a more unified infrastructure with interoperable, standardized services to user missions. Efforts will continue to insert new technologies and advance next generation near Earth (TDRS system replacement) and deep space (Mars network) architecture options. SCaN will also study alternative business options for acquisition and operation to reduce cost and use commercial capabilities where possible.

As part of SCaN's new technology development, SCaN will work with STMD to continue to support LCRD development in FY 2017. SCaN will complete major reviews for both OGS-1 and OGS-2. OGS-1 will complete its System Integration Review to evaluate the readiness of the project to begin its assembly, integration, and test. In addition to completing facility construction, OGS-2 will complete its installation and begin initial field calibration of its adaptive optics system against stars.

While LCRD will work toward demonstrating bidirectional optical communications relay services between geosynchronous orbit and Earth, SCaN will also continue to partner with the SMD and STMD on Deep Space Optical Communication. The goal is to increase data rates 10-100 times without increasing mission burden in mass, volume, power and/or spectrum. A SMD Discovery Mission launching in the early 2020's will demonstrate this technology. STMD is funding the flight segment while

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

SCaN is funding the ground segment. SCaN will complete preliminary design and begin the detailed design of uplink and downlink stations in FY 2017.

To push new frontiers in communication and future network operations, the SCaN TestBed will demonstrate navigation protocols for using Europe's Galileo global navigation system working with the European Space Agency (ESA) and will demonstrate cognitive radios that learn from experience and improve performance autonomously.

The U.S. Air Force will host the Deep Space Atomic Clock demonstration unit and payload as part of the U.S. Air Force's Space Test Program 2 mission aboard a SpaceX Falcon 9 Heavy booster currently expected to launch in September 2017. The payload will demonstrate its functionality and utility for one-way-based navigation over at least a year of operations. The clock will make use of GPS satellite signals to demonstrate precision orbit determination and confirm its performance.

The Standards team will develop specifications for a wireless local area network protocol, supporting communications for both human and robotic activities on planetary surfaces. SCaN will work in 2017 with the National Telecommunications and Information Administration Policy and Plans Steering Group to help identify Federal spectrum for auction and repurpose for commercial mobile broadband. In addition to selecting frequencies for NASA missions, SCaN will continue to participate in domestic and international meetings to protect NASA use of the electromagnetic spectrum, including protection of the downlink required for commercial crew vehicles supporting ISS.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

SCaN will continue advancements of NASA's next generation network architecture, incorporating new capabilities for on-demand services, Delay/Disruption Tolerant networking, and autonomous navigation. SCaN will also work to infuse new technologies, like optical communication, that could enable significant reductions in system acquisition and operations cost while improving network flexibility, scalability, and security.

SCaN will continue to work with STMD on LCRD. Both OGS-1 and OGS-2 will begin their integration and testing work with facility readiness planned for FY 2019 to support the LCRD launch in FY 2019. Development will continue on the ILLUMA-T modem and terminal with completion planned for FY 2020. The Deep Space Optical Communication project will complete its detailed design of uplink and downlink stations and begin fabrication to support an operational readiness date in late FY 2020 for the ground terminal.

Through participation in the CCSDS and other standards development organizations, SCaN will continue development of internationally interoperable space communication and data system standards and demonstrate their capabilities for use by NASA missions and networks to lower the life cycle costs and risks, and provide innovative capabilities for current and future missions.

SCaN will continue to participate in domestic and international meetings to protect use of the Electromagnetic spectrum for NASA current and future missions. SCaN will focus on planned agenda items at the World Radiocommunication Conference in FY 2020, which could take actions that would

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

reallocate some spectrum currently used by NASA to other users. This will be especially challenging in light of increasing spectrum demand. In addition, SCaN will continue to select frequencies for all domestic and international deep space missions, and JPL near-earth missions.

Project Schedule

The table below includes significant Space Communication Support milestones in FY 2017 and FY 2018.

Date	Significant Event
FY 2017 - Q2	ILLUMA-T RFP for Commercial modem
FY 2017 - Q2	Deep Space Atomic Clock payload complete and ship to commercial spacecraft host
FY 2017 - Q3	LCRD Payload integration and testing begins
FY 2017 - Q3	ILLUMA-T Flight-like optical modem integration and testing
FY 2017 - Q3	Deep Space Optical Communications SRR
FY 2017 - Q4	LCRD OGS-2 Facility Operational Readiness
FY 2017 - Q4	Deep Space Atomic Clock launch
FY 2018 - Q1-Q4	Deep Space Atomic Clock operations
FY 2018 - Q1	LCRD OGS-2 System Design Review
FY 2018 - Q2	Deep Space Optical Communication Preliminary Design Review
FY 2018 - Q2	LCRD System Integration Review

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 uses multiple small contracted efforts, most of which are support services functions. Studies are in progress to assess alternate acquisition approaches for the next generation architecture, including collaborative research and development agreements to develop new optical communications technologies.

MAJOR CONTRACTS/AWARDS

Space Communications Support does not have any major contracts planned at this time.

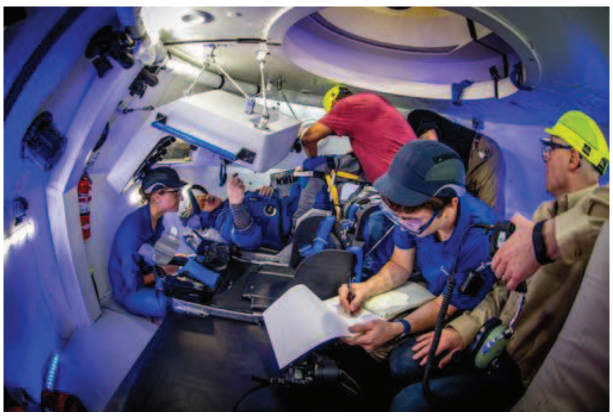
HUMAN SPACE FLIGHT OPERATIONS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	100.6	--	124.4	136.1	143.9	147.8	147.8

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



One of the first planned commercial crew astronauts, Eric Boe, evaluates Boeing Starliner spacesuit in mockup of spacecraft cockpit.

Credits: Boeing

The Human Space Flight Operations (HSFO) program supports the training, readiness, and health of crewmembers before, during, and after each spaceflight mission to the International Space Station (ISS). All crews on board the Space Station 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 Human Exploration and Operations Mission Directorate (HEOMD) Human Research Program (HRP), answers these questions and others 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.

In FY 2017, HSFO added the Aerosciences Ground Test Capability, which establishes centralized funding to support mission access to test facilities throughout the year, enabling mission testing, advancements of capabilities and tools, and innovation. This new capability accounts for the increase in the HSFO budget from the FY 2016 enacted level to the FY 2018 request.

HUMAN SPACE FLIGHT OPERATIONS

EXPLANATION OF MAJOR CHANGES IN FY 2018

The "To Research, Evaluate, Assess, and Treat" Astronauts Act, or TREAT Act was signed into law March 21, 2017 and establishes spaceflight-associated occupational healthcare for former American astronauts, and will allow NASA to use this information to examine the effects of spaceflight exposure on astronauts over their lifetime.

ACHIEVEMENTS IN FY 2016

In FY 2016, SFCO began training astronauts to operate the new commercial space vehicles being developed by the Commercial Crew Program. In addition, SFCO partnered with the ISS program in the Revolutionize ISS for Science and Exploration (RISE) effort, whose goal is to streamline core ISS processes to support its primary customers' payloads and research.

In September of 2016, SFCO purchased a Gulfstream-V aircraft, to provide health-stabilized transportation with the necessary level of security for ISS crewmembers returning from the ISS after long-duration missions. The aircraft will provide direct crew return from Kazakhstan to the medical facility in Houston in less than 24 hours, allowing NASA to gather and analyze data associated with how humans change during extended stays in microgravity environment and how they re-acclimate to gravity upon return to Earth.

During FY 2016, SFCO began the process of selecting the astronaut candidate class of 2017 and received over 18,300 applications for this prestigious opportunity, far surpassing the previous record of 8,000 in 1978. From all those applicants, NASA selected 120 highly qualified candidates to continue with the selection process, and invited them to travel to Johnson Space Center for extensive first-round interviews.

NASA astronaut and Commander of ISS Expedition 46 Scott Kelly completed his historic 340-day mission aboard the ISS on March 1, 2016. The mission provided insight into long-duration spaceflight and its effects on the human body and psyche. Results from the studies conducted on Scott Kelly and his Russian counterpart are currently being released. Research results will be used to help mitigate the effects of long-duration spaceflight on humans. In addition, CHS provided real time support to the ISS One-Year Mission for on-orbit health monitoring, exercise regimen management, behavioral health support; post-landing health evaluation, reconditioning, and monitoring. Combined, these measures helped assure the best possible mission performance of the 12-month crew.

CHS provided clinical certification and mission support for active astronauts, assuring that they were medically ready for assigned missions. In addition, CHS provided physical, behavioral, and reconditioning health support for returning ISS expedition crewmembers. Further, CHS standardized astronaut occupational space suit exposure tracking during operations and training exercises. Standardized tracking provides a more informed understanding of the potential hazards to crewmembers during the donning and doffing of the current space suit and will improve future space suit designs.

CHS supported long-term improvement in crew occupational health and maintenance and deployed data visualization tools to promote analysis in support of operational, clinical, and risk management decision-making.

Since the early days of human spaceflight, NASA has accumulated and archived crew health and safety data for use by the human health clinical research community. During FY 2016, CHS data management and epidemiology teams updated crew health data and analytics to guide CHS-hosted working groups. This resulted in increased quantity and quality of crew health and safety data to research and clinical communities.

In FY 2016, an updated Radiation Risk Model, employing a multiple exposure modeling capability, continued to advance towards becoming operational. This enhancement refined radiation risk projections to astronauts, and takes into account the dose effects of multiple spaceflight missions as well as non-spaceflight radiation exposure.

CHS continued the lifetime surveillance program, monitoring retired astronauts for potential adverse health outcomes related to their service with NASA. Data collection under this surveillance program broadens our understanding of the long-term health risks of human spaceflight and allows NASA to better develop and provide mitigation materials and strategies.

WORK IN PROGRESS IN FY 2017

During FY 2017, SFCO will continue to provide astronaut training to support the crewed test flight of the first commercial crew vehicle. To train for the test flights, crews are using part-task trainers, and will soon use the recently delivered full-scale simulator for the Boeing CST-100 Starliner, one of the two new vehicles being developed by the Commercial Crew Program, which will provide higher fidelity training for the crew.

In October 2016, SFCO finished the first round of interviews conducted as part of the selection process for the astronaut candidate class of 2017. From the first round of 120 interviewees, 50 individuals were selected in January 2017 for another round of evaluation. NASA will complete the second round of interviews by May. CHS provides medical test and evaluation of the candidates as part of the selection process. NASA plans to announce the final astronaut candidate selections in June, and they will report to JSC in August to begin formal training. This training and evaluation period will last between 1.5 to 2 years to develop the basic knowledge and skills required for specific mission training upon selection for a spaceflight on the ISS, Russian Soyuz spacecraft, a Commercial Crew partner’s spacecraft, and/or NASA’s Orion spacecraft.

Spaceflight readiness training continues throughout an astronaut’s career to prepare them for living and working in space as well as responding to any emergency scenarios—this includes high-performance aircraft training. SFCO aircraft are expected to log over 2,700 hours in 2017 in support of crew training. SFCO is also responsible for maintaining these planes and will begin planned structural upgrades to the 55-year-old T-38 spaceflight readiness training aircraft to replace critical parts that exhibit stress corrosion cracking. In addition, SFCO’s Super Guppy aircraft, NASA’s over-sized cargo transporter, will receive a floor modification in order to transport the Orion Crew Service Module.

CHS will continue physical, behavioral, return, and reconditioning health support for returning ISS Expeditions and provide crew health support for astronauts training to fly on commercial crew vehicles. In addition, CHS will continue providing clinical certification and mission support for active astronauts who are either departing or returning to the ISS. CHS will continue to accumulate and archive crew health and safety data for use by both the medical and research communities.

In FY 2017, HRP will finish transitioning the Integrated Medical Model 4.0 to CHS. The Integrated Medical Model is a computer-based tool that is a central part of NASA risk management activity from the crew medical and mission performance perspective. The model uses the best available evidence from spaceflight, terrestrial medical literature, spaceflight analog studies, and other sources of information to perform a modeled simulation that allows traceable answers to questions for both current and future mission planning. This unique capability merges expertise in clinical medicine, epidemiology, and probabilistic risk assessment to promote astronaut health and performance during spaceflight missions.

CHS will update the Astronaut Radiation Exposure and Analysis Database to incorporate exposure data from multiple missions to ISS. CHS will continue to work with HRP on progress towards developing mitigation strategies for astronaut exposure and protection from solar and galactic radiation during space missions. Mitigation of solar and galactic radiation beyond the protection of the Earth's atmosphere is an occupational and safety concern particularly for long duration human spaceflight. CHS will also continue to coordinate with HRP in other areas, such as behavioral health, supporting the research to reduce the risk of behavioral health challenges.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

In FY 2018, SFCO will continue to support flight crew training requirements and mission operations for test flights of the SpaceX Dragon and Boeing Starliner Commercial Crew spacecraft. SFCO will also continue training the 2017 astronaut candidate class.

To support ISS mission increments 53 through 58, CHS will provide pre-flight, in-flight and post-flight medical, behavioral health management, and physical conditioning services to NASA crewmembers. In FY 2018, CHS will also track and monitor emerging hazards for NASA's new flight programs, Commercial Crew and Orion. For example, CHS will evaluate progress on radiation environmental data to inform future Exploration Mission crewed flights. The program will provide preflight and operations support to test flights of SpaceX Dragon and Boeing CST-100 Starliner commercial spacecraft carrying NASA astronauts. CHS will also expand its Lifetime Surveillance of Astronaut Health program for former crew members to better understand the long-term health consequences of space exploration. The evidence acquired not only benefits the health of the former astronaut, but also helps make future spaceflight missions safer.

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 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/SLS development flights. Today, it takes three years from the decision to select a new astronaut class until the process is completed. 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.

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 through 2024, 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 Vision Impairment and Intracranial Pressure (VIIP) syndrome. CHS has continued to collaborate with several non-NASA organizations, including the National Academies, for the risk decisions associated with long duration and exploration missions.

Program Schedule

Date	Significant Event
Aug 2017	Astronaut Class of 2017 will arrive at JSC to begin new astronaut training (8-14 candidates expected)

Program Management & Commitments

Program Element	Provider
SFCO will provide trained astronauts for all U.S. human spaceflight endeavors and bring experienced astronauts' expertise to help resolve operations or development issues.	Provider: SFCO Lead Center: JSC Performing Center(s): JSC Cost Share Partner(s): None
CHS will assess and maintain the health of astronauts before, during, and post flight.	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 Maintenance and Modification Program	DynCorp International LLC (POP ends May 2017)	Ellington Field, Houston, TX, El Paso, TX
Aircraft Logistics, Integration, Configuration and Engineering	TBD (POP begins June 2017)	Ellington Field, Houston, TX, El Paso, TX
Human Health and Performance Contract	KBRWyle	Houston, TX

HUMAN SPACE FLIGHT OPERATIONS

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	
Performance	NCRP	Feb 2016	The NCRP conducted a phase one review of potential central nervous system effects from radiation exposure during space activities.	NCRP Commentary Report 25 recommending forward work into the potential CNS effects that crews might experience during and after exposure the radiation environment of space	Phase II ongoing

LAUNCH SERVICES

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	**81.2**	**--**	**86.8**	**88.6**	**88.6**	**88.6**	**88.6**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

January 16, 2016: SpaceX Falcon 9 rocket at Vandenberg Air Force Base Space Launch Complex 4 East with the Jason-3 spacecraft onboard. Jason-3 is an international cooperative mission between NASA and the National Oceanic and Atmospheric Administration (NOAA), the Centre National d'Etudes Spatiales (CNES), and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT).

The Launch Services Program (LSP) provides NASA and civil sector missions with access to a dependable and secure Earth-to-space bridge, launching spacecraft to orbit our planet or to venture into deep space. Utilizing commercially-available domestic launch services, LSP has provided affordable and reliable space access for uncrewed science, exploration, communication, weather forecasting, and technology development spacecraft for over 18 years. NASA and civil sector missions need these launch services to get into space and begin their critical work.

Acting as a launch system technical expert, LSP matches NASA and other civil sector government spacecraft with commercially-available launch services through a competitive acquisition process. Starting with pre-mission planning and continuing through the spacecraft's post-launch phase, LSP works with the spacecraft mission team and the commercial launch vehicle provider to accomplish the required mission integration activities and to maximize the probability for mission success.

In addition to acquiring the commercial launch service, LSP also arranges pre-launch spacecraft processing facility support, and communications and telemetry during ascent for their customers. Additionally, LSP offers insight into the commercial launch vehicle industry, 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 agency 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 2018

None.

LAUNCH SERVICES

ACHIEVEMENTS IN FY 2016

Two major payloads were successfully launched utilizing LSP-acquired services:

Launch Date/Location	Launch Vehicle	Payload	Customer	Mission Objectives
Jan 2016 Vandenberg Air Force Base	Falcon 9 v1.1	Jason-3	NASA SMD, CNES, NOAA, Eumetsat	Monitor global ocean circulation, study ties between the ocean and the atmosphere, improve global climate forecasts and predictions, and monitor events such as El Niño and ocean eddies.
Sep 2016 Cape Canaveral Air Force Station	Atlas V	Origins, Spectral Interpretation, Resource Identification, and Security - Regolith Explorer (OSIRIS-REx)	NASA SMD	Visit an asteroid in 2018, perform six months of surface mapping, and use a robotic arm to collect samples to return to Earth. This data helps explain our solar system's formation and how life began, as well as improve understanding of asteroids that could impact our planet.

LSP's customers own and manage the payload mission objectives described above.

In addition, LSP continued efforts to expand the selection of available launch vehicles, working across industry to support commercial space sector growth by providing competitive opportunities to U.S. providers.

LSP acquired launch services for one future science mission:

Launch Date/Location	Launch Vehicle	Payload	Customer	Mission Objectives
July 2020	Atlas V	Mars 2020	NASA SMD	The rover will conduct geological assessments of its landing site on Mars, determine the habitability of the environment, search for signs of ancient Martian life, and assess natural resources and hazards for future human explorers.

LSP's customers own and manage the payload mission objectives described above.

LSP added the Falcon 9 Full Thrust, Falcon Heavy, and Antares 230 vehicles to the NASA Launch Services (NLS) II Contract. As part of the Transiting Exoplanet Survey Satellite (TESS), and Solar Probe Plus (SPP) launch activities, LSP also began vehicle certification efforts for the Falcon 9 Full Thrust and Delta IV Heavy launch vehicles. Certification is vital because it enhances NASA's understanding of commercially built launch vehicles and enables LSP to better identify and manage launch risks.

Certification enhances competition as it results in multiple qualified, launch vehicles and launch providers, which in turn promotes cost control.

LSP completed NASA Independent Review Team activities for the SpaceX Falcon 9 v1.1 (CRS-7) accident investigation and subsequently managed the SpaceX-provided launch service that resulted in the successful return to flight for that Falcon 9 variant. LSP independently reviewed launch vehicle telemetry and created a detailed millisecond event timeline; reviewed the SpaceX-led Accident Investigation Team's findings and corrective actions; developed and analyzed additional alternative failure scenarios; conducted independent testing; and made its own independent accident related findings and recommendations which were briefed to the NASA Flight Planning Board on December 4, 2015. The successful return to flight for the SpaceX Falcon 9 v1.1 occurred with the successful launch of the Jason-3 mission for NOAA on January 17th, 2016.

LSP also participated on the Orbital ATK Accident Investigation Team for the Orb-3 mission failure that occurred on October 28, 2014, from the Mid-Atlantic Regional Spaceport on Wallops Island, Virginia. Orbital ATK's Antares rocket returned to flight in a new configuration on October 17, 2016, two years after the Orb-3 mishap.

LSP participated in the SpaceX-led Accident Investigation Team (AIT) for the Falcon 9 anomaly that occurred on September 1, 2016, when the rocket exploded on the launch pad during a routine prelaunch fueling operation on a non-NASA mission to launch the commercial communications satellite Amos 6. The AIT was comprised of members from SpaceX, Federal Aviation Administration (FAA), NASA, U.S. Air Force, and industry experts. A separate LSP-led independent review for the September 1, 2016 Falcon 9 anomaly is still on-going in an effort to find the definitive set of conditions that caused the anomaly in preparation for the launch of the NASA TESS mission planned for launch in March 2018.

NASA and LSP continued the partnership with several universities to launch small research satellites through the Educational Launch of Nanosatellites project and the CubeSat Launch Initiative, providing 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 38 states across the United States, with 46 missions launched and 52 manifested on NASA, National Reconnaissance Office, U.S. Air Force, and commercial missions.

WORK IN PROGRESS IN FY 2017

LSP provides expertise and active launch mission management for over 40 NASA scientific spacecraft missions in various stages of development. In FY 2017, the program continues to acquire new launch services for future NASA missions. Four science missions are planned for launch in FY 2017. The program has recently competitively awarded the commercial launch service for the NASA Science Mission Directorate's (SMD's) Surface Water & Ocean Topography (SWOT) mission to SpaceX for launch on a Falcon 9 Full Thrust in 2021.

The program has one additional launch service acquisition in work to support SMD and civil sector missions to include the Joint Polar Satellite System 2 (JPSS-2) mission for NOAA in 2021.

LAUNCH SERVICES

Launch Date/Location	Launch Vehicle	Payload	Customer	Mission Objectives
Nov 2016	Atlas V	Geostationary Operational Environmental Satellite (GOES)-R	NOAA, NASA SMD	First in a series of next generation geostationary weather satellites that will provide continuous imagery and atmospheric measurements of Earth's Western Hemisphere and space weather monitoring.
Dec 2016	Pegasus XL	Cyclone Global Navigation Satellite System (CYGNSS)	NASA SMD	Measure ocean surface winds throughout the life cycle of tropical storms and hurricanes, to facilitate better weather forecasting.
2017	Delta II	JPSS-1	NOAA, NASA SMD	Gather data on a wide range of Earth's properties, including the atmosphere, clouds, radiation budget, clear-air land and water surfaces, and sea surface temperature.
Aug 2017	Atlas V	Tracking and Data Relay Satellite System (TDRS)-M	NASA HEOMD	Provide NASA with crucial crosslink communications capability between control and data processing facilities on the ground, and Earth-orbiting spacecraft such as the Hubble Space Telescope, the ISS, and dozens of unmanned scientific satellites.

LSP's customers own and manage the payload mission objectives described above.

The Venture Class Launch Services (VCLS) contracts for CubeSat satellites foster a commercial launch market dedicated to flying small satellite payloads by serving as an alternative to the current rideshare approach, in which one or more CubeSats takes advantage of excess payload capacity on a rocket whose primary mission is to launch a larger satellite. Rocket Lab USA has the first VCLS launch scheduled for FY 2017 aboard the Electron launch vehicle. Virgin Galactic will follow with a scheduled launch in FY 2018 aboard the LauncherOne. The VCLS contract for Firefly Space Systems was terminated due to Firefly's loss of investor funding and their inability to complete the remaining contract requirements.

LSP will continue work towards certifying new commercial launch vehicles to launch high-value payloads.

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 missions, including:

- ISS Cargo Resupply Service missions;
- Commercial Crew Program; and

- SMD's Gravity Recovery and Climate Experiment Follow-On (GRACE-FO), James Webb Space Telescope (Webb), and NASA-Indian Space Research Organization Synthetic Aperture Radar (NISAR) missions

KEY ACHIEVEMENTS PLANNED FOR FY 2018

LSP is planning six civil sector missions for launch:

Launch Date	Launch Vehicle	Mission Name	Customer	Mission Objectives
Nov 2017	Pegasus XL	Ionospheric Connection Explorer (ICON)	NASA SMD	A suite of instruments designed to explore the mechanisms controlling the environmental conditions in space and how they are modified by weather on the planet
NET Mar 2018	Falcon 9 Full Thrust	TESS	NASA SMD	Space telescope designed to survey the brightest stars near the Earth. The telescope will utilize an array of cameras to perform an all-sky survey to 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.
Mar 2018	Atlas V	GOES -S	NOAA, NASA SMD	Follow on mission in a series of satellites that will provide continuous imagery and atmospheric measurements of Earth's Western Hemisphere and space weather monitoring.
May 2018	Atlas V	Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight)	NASA SMD	Address fundamental issues of planet formation and evolution with a study of the deep interior of Mars.
Jul 2018	Delta H	Solar Probe Plus (SPP)	NASA SMD	Provide new data on solar activity and makes critical contributions to our ability to forecast major space-weather events that impact life on Earth.
Sep 2018	Delta II	Ice, Clouds, and Land Elevation Satellite (ICESat-2)	NASA SMD	Collect altimetry data of the Earth's surface optimize to measure ice sheet elevation change and ice thickness, while also generating an estimate of global vegetation biomass.

LSP's customers own and manage the payload mission objectives described above.

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 40 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.

Program Management & Commitments

Program Element	Provider
Expendable Launch Vehicle (ELV) Launch Services	Provider: United Launch Services (ULS), Orbital ATK, SpaceX, Lockheed Martin Space Systems Lead Center: KSC Performing Center(s): KSC Cost Share Partner(s): N/A

Acquisition Strategy

LSP put a unique acquisition strategy in place under the original 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 expires in June 2020. To keep competition fresh and encourage new launch capability development on these 10-year 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 SPP 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 was 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 ordering period expires in December 2017.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
SPP	ULS, LLC	Centennial, CO
Venture Class	Virgin Galactic, Rocket Lab USA	Long Beach, CA Los Angeles, CA
NLS-II-A	Lockheed Martin Space Systems	Denver, CO
NLS-II-U	ULS, LLC	Centennial, CO
NLS-II-S	SpaceX	Hawthorne, CA
NLS-II-O	Orbital ATK Corporation	Dulles, VA
Payload Processing Facility	Astrotech Space Operations	Titusville, FL
Payload Processing Facility	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 CY 2019.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
PIR	Standing Review Board (SRB)	May 2014	Life Cycle Review	Board 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. Standing Review Board recommended continuation of LSP operations as currently performed.	2019

Historical Performance

LSP managed ELV Missions from inception through FY 2016.

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 ULS	2 14	2 14	0 0
Delta II	Boeing Launch Services ULS	27 14	27 14	0 0
Falcon 9 v1.1	Space X Launch Services	1	1	0
Pegasus Hybrid	OSC	1	1	0
Pegasus XL	OSC	14	14	0
Taurus XL	OSC	2	0	2
Titan II	Lockheed Martin	3	3	0

ROCKET PROPULSION TEST

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	42.7	--	47.6	47.6	47.6	47.6	47.6

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

RPT continues to support SLS RS-25 engine testing on the A-1 test stand at Stennis Space Center in Mississippi. Six tests for a total 3,000 seconds of run time are planned in FY 2017 in a multi-year testing effort required to prepare the engine for use on the Space Launch System (SLS) Core Booster Stage.

The development and test of 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, reliable, and accurate. 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 world-class 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 manages facility usage and eliminates redundant capability by closing, consolidating, and streamlining 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 Manager serves as a co-chair of the NRPTA Senior Steering Group, and appoints NASA's alliance co-chair. This 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 2018

None.

ACHIEVEMENTS IN FY 2016

During FY 2016, RPT safely performed 540 tests of rocket engines and components at various levels of thrust. Hot fire test time totaled 15,538 seconds and 38 hours of thermal vacuum testing. These tests were completed with only three facility-caused test delays resulting in a 99.4% readiness metric, exceeding the 90% performance goal.

In FY 2016 RPT performed four RS-25 engine tests on the Stennis Space Center (SSC) A-1 test stand. The four tests accounted for 1,768 seconds of hot fire test time in a multi-year effort necessary to certify the engine for use on Space Launch System (SLS) core booster stage, which is required to support Exploration Mission-1 (EM-1), the first flight of SLS, and other exploration goals. Other test activities included testing for SpaceX, Aerojet Rocketdyne, and numerous internal research and development projects such as the NASA Morpheus multi-use thruster. This thruster will enable Morpheus, a prototype planetary lander, to be capable of vertical takeoff and landing. SSC personnel continued preparations on the E-1 Cell 1 test stand for the U.S. Air Force (USAF) Hydrocarbon Boost program, 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 entered into a reimbursable agreement with Aerojet Rocketdyne to prepare the E-1 Cell 2 test stand to test subscale hydrocarbon components at SSC. RPT completed the replacement of high risk elements of the SSC High Pressure Industrial Water system. This included completely replacing the "B-leg" which will be supporting SLS core stage testing in FY 2018 and high risk elements of the "A-leg". These systems supply thousands of gallons of water to the large test stands needed to cool the engines' exhaust. In addition, RPT continued refurbishing and repairing critical infrastructure on the B-2 test stand for SLS core stage testing.

RPT completed the SLS Liquid Oxygen (LOx) anti-geyser testing at Marshall Space Flight Center (MSFC) test stand 4670 to enhance understanding of the LOx tanking effects during SLS launch preparations. Personnel also tested several rocket engine components, including those using advanced technologies such as “metal printing” 3D manufacturing techniques. If proven successful, the “metal printing” technology could lead to significant improvements in rocket engine development, manufacturing processes and reduced costs.

At the Johnson Space Center (JSC) White Sands Test Facility (WSTF), engineers conducted tests to support NASA's Commercial Crew Program (CCP), Aerojet Rocketdyne, the Missile Defense Agency engine and thruster program, the U.S. Air Force (USAF) Peacekeeper missile safing project, and hot fire test for the USAF Minuteman missile life extension program. RPT continued the refurbishment and reactivation of test stand 301 to support the Orion European Space Agency (ESA) Service Module and the construction of test stand 301A under a reimbursable task order with Boeing to conduct testing of the Crew Space Transportation (CST)-100 Service Module. RPT also continued rehabilitating the Large Altitude Simulation System (LASS) to support testing in a simulated high altitude space environment. The LASS maintains three test stands that provide a test start altitude of 115,000 feet.

In the third quarter of FY 2016, RPT completed the reactivation of the Glenn Research Center Altitude Combustion Stand (ACS) to support critical in-space propulsion research and development projects. The ACS completed 119 tests by the end of the fiscal year.

ROCKET PROPULSION TEST

At Glenn Research Center Plum Brook Station (GRC-PBS), RPT performed one thermal vacuum test in the B-2 facility and continued the methodical refurbishment of critical systems required to activate the facility's hot fire capability. In addition, RPT began the preparation which will be needed to perform the facility characterization test using the NASA Morpheus lander vehicle in 2017. This test will help RPT learn more about the facility's capabilities to run propulsion tests in the future.

WORK IN PROGRESS IN FY 2017

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 testing USAF designed and developed Hydrocarbon Boost components for the RD-180 replacement project and Aerojet Rocketdyne hydrocarbon engine components. 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 finishing B-2 test stand refurbishment to prepare for SLS core stage testing.

The WSTF team will conduct testing for NASA Commercial Crew Program, Boeing CST-100, Aerojet Rocketdyne, the Missile Defense Agency, USAF, and U.S. Navy. Construction and final preparations of the new Test Stand 301-A for the Boeing CST-100 Service Module will be completed. Refurbishment of Test Stand 301 for the Orion European Space Agency Service Module (ESA SM) will be completed and the first tests of the ESA SM will be performed. WSTF will complete the refurbishment activities for the LASS to support future NASA and commercial test customers.

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 GRC-PBS B-2 facility, engineers will perform an integrated system test to demonstrate the ability to perform small-scale rocket engine hot fire tests in a simulated space vacuum environment.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

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 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 continue hot fire testing the SLS RS-25 engine on SSC's A-1 test stand and begin preparations to test the SLS Exploration Upper Stage (EUS) testing on the newly refurbished B-2 test stand. The core stage uses four RS-25 engines to propel the SLS core stage upon launch. At PBS, RPT will also provide data to SLS by performing the Evolvable Cryogenics Project–eCryo, SHIVER (Structural Heat Intercept, Insulation and Vibration Evaluation Rig) testing in a simulated space environment (vacuum and thermal) and begin refurbishment of critical B-2 infrastructure to enable simulated space testing for propulsion systems with up to 30k lbf thrust and 300 seconds of run-time.

ROCKET PROPULSION TEST

At WSTF, RPT will complete testing activities for the Orion ESA Service Module and Boeing CST-100 Service Module. RPT will continue the propulsion Acceptance Test Program (ATP) for the Commercial Crew Program Boeing CST-100 support, Missile Defense Agency, Aerojet Rocketdyne and USAF test articles. RPT will continue testing the Aerojet Rocketdyne RS-68 engine, as well as testing for the USAF and other commercial engine developers including combustion device testing for SpaceX. RPT facilities and personnel will continue maintaining and modernizing these unique facilities which are critical for testing future space vehicles in a simulated space environment and ambient conditions.

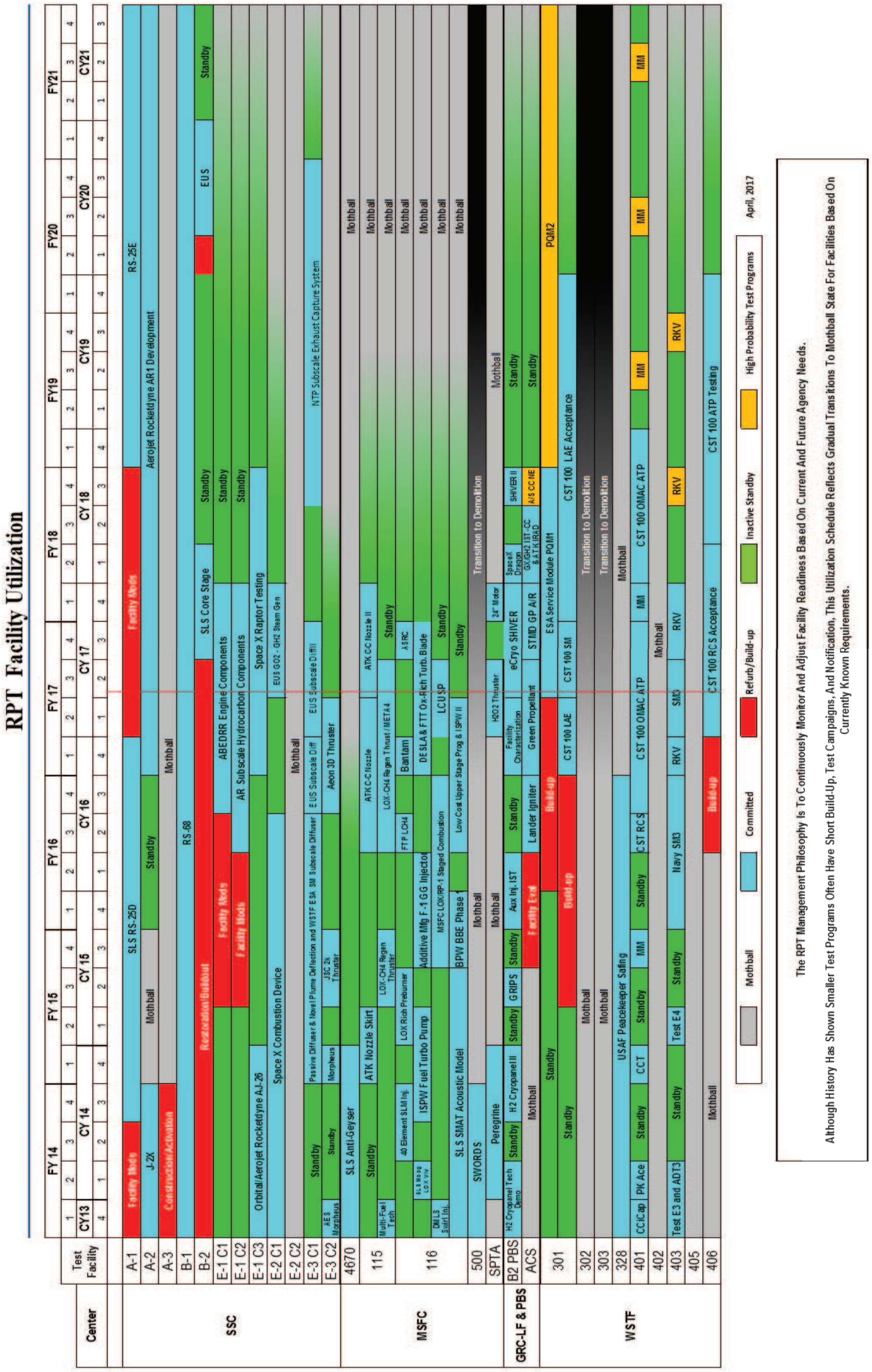
Program Schedule

The following chart shows past, current, and planned test campaigns at SSC, MSFC, GRC and WSTF rocket propulsion test facilities. The designations at the far left of the chart refer to the facility, the top of each 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 customer to design testing programs for FY 2018 and beyond.

ROCKET PROPULSION TEST

RPT Facility Utilization



ROCKET PROPULSION TEST

Program Management & Commitments

Program Element	Provider
RPT	Provider: RPT Lead Center: N/A Performing Center(s): SSC, JSC/White Sands Test Facility, GRC-PBS, MSFC, KSC, WFF Cost Share Partner(s): Various other NASA programs, DoD, and commercial partners

Acquisition Strategy

No major acquisitions identified for FY 2018.

MAJOR CONTRACTS/AWARDS

No major contracts or awards planned for FY 2018.

INDEPENDENT REVIEWS

No reviews planned.

EDUCATION

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	**115.0**	**100.0**	**37.3**	**0.0**	**0.0**	**0.0**	**0.0**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

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EDUCATION

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	**115.0**	**100.0**	**37.3**	**0.0**	**0.0**	**0.0**	**0.0**
Change from FY 2017			**-62.7**				
Percentage change from FY 2017			**-62.7%**				

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

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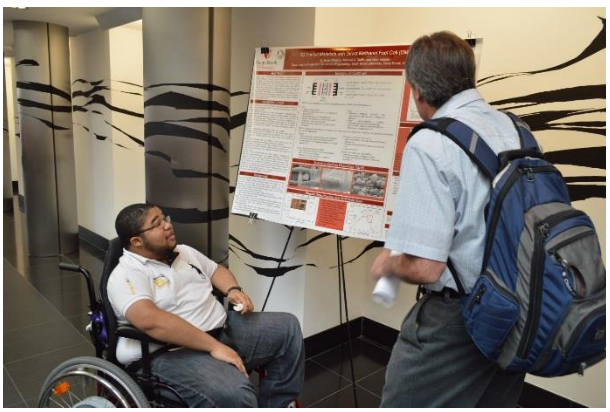

Mckingsley Williams of the New York Space Grant Consortium at Stony Brook University's Department of Material Sciences discusses his investigation into the use of methane fuel cells.

NASA's FY 2018 budget proposes the termination of the Office of Education (OE) and its portfolio of programs and projects. OE's portfolio consist of over 200 federal domestic assistance awards (grants and cooperative agreements) that are fully funded in the year of the award or annually funded with a performance period of three to five years. Awardees receive annual funding based upon satisfactory performance and availability of funds.

The FY 2018 budget supports the orderly closeout and/or transition of these activities needed to comply with federal laws and regulations regarding contracts, grants/cooperative agreements, civil servants, records management, and administrative infrastructure.

While this budget no longer supports the formal Office of Education programs, NASA will continue to inspire the next generation through its missions and the many ways that our work excites and encourages discovery by learners and educators. The Science Mission Directorate's (SMD) STEM Science Activation program will continue to focus on delivering SMD content to learners of all ages through cooperative agreement awards. NASA does not intend to transfer ownership of programs formerly funded by OE to SMD, as these activities fall outside the scope and resources of SMD's STEM Science Activation program.

EXPLANATION OF MAJOR CHANGES IN FY 2018

The Office of Education has experienced significant challenges in implementing a focused NASA-wide education strategy. While output data (e.g., number of people funded, number of papers generated, number of events supported) has been tracked, outcome-related data demonstrating program effectiveness has been insufficient to assess the impact of the overall OE portfolio. Given these challenges and current fiscal constraints, the NASA budget terminates OE. The reduced funds in the FY 2018 budget will support the following overarching goals:

- Minimize negative impact to awardees;
- Perform closeout in a cost-effective and efficient manner

OE will conduct transition and close-out activities under a single budget authority line item executed in alignment with the overarching goals. The budget includes closing-out elements from OE, as well as closing-out the OE-funded activities at the nine NASA Centers and the Jet Propulsion Laboratory (JPL) Education offices. NASA will establish plans to maintain access to capabilities and/or legacy content deemed necessary for historical purposes.

WORK IN PROGRESS IN FY 2017

Space Grant

Space Grant consortia will receive full funding for the final year of the three-year award for all 52 Space Grant consortia awards. Space Grant awards consist of scholarships, fellowships, or internships in support of higher education, research infrastructure, precollege, and informal education. Space Grant consortia will also support flight project activities led by student teams. Some of those flight activities include, but are not limited to:

- RockOn! Workshop
- RockSat-C
- RockSat-X
- DemoSat
- High Altitude Student Platform (HASP)
- Undergraduate Student Instrument Project (USIP)
- Independent External Evaluation

EPSCoR

- Provide full funding for the final year of the three-year award for all 27 Research Infrastructure Development awards;
- Make new research awards based on availability of funding.

MUREP

- Provide final year of funding for four MUREP activities and begin closing and transitioning awards and activities where possible to minimize impact to awardees;
- Provide funding for year four of the five-year MUREP Institutional Research Opportunity awards; and
- Support funding for year four of the five-year award for the Educator Professional Development Collaborative.

STEM Education and Accountability Project (SEAP)

- Maintain funding, through competitive processes, for internal and external innovative education efforts by NASA Centers, JPL, and third parties.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

NASA will implement an orderly shutdown of the OE 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.

The FY 2018 budget will focus on effectively executing in three main areas:

- Completion of external awards to institutions and students including fellowships, scholarships, and internships;
- Continuation of performance monitoring and performance analysis by civil servants and JPL employees, maintaining accountability for execution of awards and activities, and providing for orderly decommissioning of projects and activities; and
- Sustainment of program operational costs to support the process of decommissioning office including: IT applications and systems used by programs; personnel IT seat costs; contract staff to assist with close-out and activity; development of decommissioning and/or transition plans for specific sections within the NASA website, social media, and listserv accounts directly related to the OE.

SAFETY, SECURITY, AND MISSION SERVICES

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Center Management and Operations	1987.6	--	**1992.5**	2036.8	2036.8	2036.8	2036.8
Agency Management and Operations	784.8	--	**837.7**	822.6	822.6	822.6	822.6
Total Budget	**2772.4**	**2768.6**	**2830.2**	**2859.4**	**2859.4**	**2859.4**	**2859.4**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

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SAFETY, SECURITY, AND MISSION SERVICES

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Center Management and Operations	1987.6	--	**1992.5**	2036.8	2036.8	2036.8	2036.8
Agency Management and Operations	784.8	--	**837.7**	822.6	822.6	822.6	822.6
Total Budget	**2772.4**	**2768.6**	**2830.2**	**2859.4**	**2859.4**	**2859.4**	**2859.4**
Change from FY 2017			**61.6**				
Percentage change from FY 2017			**2.2%**				

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

NASA workforce and facilities provide the tools and services needed to safely conduct its mission.

The Safety, Security, and Mission Services (SSMS) activities manage the administration of the Agency; operate and maintain NASA centers and facilities in ten states and the District of Columbia, including Headquarters; and provide oversight to reduce risk to life and mission for all NASA programs.

SSMS provides both institutional and program capabilities for the Agency. Institutional capabilities ensure that Agency operations are effective, efficient, and meet statutory, regulatory, and fiduciary responsibilities. 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 Agency practices are safe and reliable. Together, these capabilities provide the workforce and infrastructure that enable NASA's mission.

Missions rely on SSMS program and institutional capabilities to accomplish their 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, and small business programs contribute to the strategic and operational planning and management that ensure resources are available when needed. International and interagency relations, legislative and intergovernmental affairs, and strategic communications facilitate communications with a broad range of external communities. These program and institutional capabilities and related processes speak to the complexity of the support necessary for successful NASA missions and safe Agency and Center operations.

SAFETY, SECURITY, AND MISSION SERVICES

EXPLANATION OF MAJOR CHANGES IN FY 2018

NASA is increasing Agency IT Services to strengthen cybersecurity capabilities and safeguard critical systems and data. The FY 2018 request includes investments in critical IT infrastructure and enterprise solutions. Funding will support modernizing Agency systems, increased automation, and optimized delivery of enterprise-wide IT service solutions. Center Management and Operations (CMO) funding increases reliability-centered maintenance and condition-based monitoring activities at centers to provide more efficient and effective systems maintenance.

ACHIEVEMENTS IN FY 2016

NASA is working to instill a culture of innovation in its workforce by recognizing and rewarding innovative performance; engaging and connecting the workforce to make it easy for employees to collaborate, network, and innovate; and creating an environment in which leaders view developing innovative employees as a productive and vital use of their time. SSMS activities provide the facilities, tools, and services needed to conduct NASA's missions safely and effectively. For example, in FY 2016, NASA:

- Named the "Best Place to Work" for the fifth year in a row among large agencies in the Federal Government. The annual results of the Employee Viewpoint Survey are published by the Partnership for Public Services. It ranks nearly 400 federal organizations by overall employee satisfaction and commitment and also evaluates key workplace focus areas such as innovation, training and development, leadership and diversity;
- Met the Office of Management and Budget (OMB) goals for Energy Intensity reductions, Renewable Energy Consumption, Potable Water Intensity and Fleet Petroleum Use. The Energy Intensity reductions since 1995 resulted in a cost avoidance in utility bills of $45 million for FY 2016;
- Continued implementation of a discipline and system-level Capability Leadership model to improve technical support to the missions. Completed "State of the Capability" reviews and addressed actions derived from 2015 reviews, including a first-ever detailed assessment of the Agency's nuclear power and propulsion capabilities and implementation of a centralized aeronautics test facility management model. The latter will reduce the testing costs currently borne by programs and encourage rigorous, test-based solutions to technical problems.
- Continued the Business Services Assessment (BSA) process by completing a comprehensive review of select business service areas, including facilities management and budget planning. By engaging the Mission Support functions through the BSA, NASA is defining the health of selected business service areas; identifying opportunities for optimization; and developing risk-informed recommendations; and
- NASA's globally popular website, NASA.gov, was honored again in 2016 with the People's Voice award for best government website at the Webby Awards. The popular vote was the eighth People's Voice award for the site, and after 2015's redesign, it was the fourth different design for which NASA has won. Traffic to the site continued to increase steadily, rising 20 percent over 2015 numbers to just more than 300,000 visits per day. The site also continues to receive customer satisfaction ratings that put it near the top of all government websites.

Safety, Security, and Mission Services

Work in Progress in FY 2017

SSMS continues its crosscutting support of the Agency's aeronautics and space activities, using innovative approaches in providing the required programmatic, business, and administrative capabilities. Key activities underway include:

- NASA continues to gain efficiencies through its BSA activities. This includes performing deep dives, developing implementation plans and institutionalizing previously made business service decisions. Decisions have been made based on the assessment of Budget and Program Planning and Control and assessments are on-going in the areas of Education and Outreach and Technical Authority. NASA also plans to initiate deep dives in the areas of Security and Logistics in FY 2017;
- Implementing improvements from the BSAs for IT, acquisition, human capital management, budget management, and facilities management. During FY 2017, NASA Office of Human Capital Management (OHCM) will launch a multi-year transformation effort to re-design, automate, and consolidate its Talent Acquisition program, including classification, hiring, and staffing across the Agency. NASA will also begin a two-year effort to implement a new Learning Management System;
- The Office of the Chief Health and Medical Officer (OCHMO) is continuing 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 Occupational Health and Safety Administration (OSHA) or the Environmental Protection Agency. OCHMO will lead the Multilateral Medical Policy Board in addressing and resolving several critical issues dealing with crew health and medical operations support to Soyuz landing; and
- NASA's Enterprise Protection Program will increase focus on threat analysis covering cyber, Counterintelligence/Counterterrorism, and insider threats to help identify, qualify, and mitigate the growing scope of threats across NASA's overall enterprise.

Key Achievements Planned for FY 2018

In FY 2018, 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 aeronautics and space activities. SSMS programs will:

- Implement long-term changes identified through the BSAs to optimize services, and maintain a minimum set of capabilities to meet mission needs;
- Improve the Agency's information security posture and assure NASA's IT systems and networks support the Agency's critical missions;
- Operate and maintain NASA Centers and major component facilities to ensure a safe, healthy, and environmentally responsible workplace;
- Provide essential operations such as Center security, environmental management, safety services, and facility maintenance;
- Support the workforce with utilities, IT, legal, occupational health, equal employment opportunity, financial management, and human resources services;

- Provide the technical facilities, workforce expertise and skills, equipment, and other resources required to implement the program at the Center; and
- Ensure engineering and safety oversight of NASA's programs.

Themes

CENTER MANAGEMENT AND OPERATIONS

CMO provides the ongoing management, operations, and maintenance of NASA Centers and component facilities across the country. Missions rely on the Centers to provide the skilled staff and specialized infrastructure required to accomplish their objectives.

AGENCY MANAGEMENT AND OPERATIONS

Agency Management and Operations (AMO) provides management and oversight of Agency missions and performance of NASA-wide mission support activities. AMO activities at NASA Headquarters ensure that core services are ready and available across the Agency for performing mission roles and responsibilities.

CENTER MANAGEMENT AND OPERATIONS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Center Institutional Capabilities	1533.1	--	**1533.3**	1561.5	1561.5	1561.5	1561.5
Center Programmatic Capabilities	454.5	--	**459.2**	475.3	475.3	475.3	475.3
Total Budget	**1987.6**	**--**	**1992.5**	**2036.8**	**2036.8**	**2036.8**	**2036.8**

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Operators at the Langley Research Center use Condition-Based Monitoring (CBM) to centrally monitor building systems. NASA is increasing the use of CBM to improve system availability and reduce maintenance costs.

NASA's 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 2018

Increases reliability-centered maintenance and Condition-Based Monitoring (CBM) activities at all centers to provide more efficient and effective systems maintenance. CBM provides continuous or periodic monitoring and diagnosis of systems and equipment to forecast failure. The data obtained allows for planning and scheduling preventive maintenance or repairs in advance of failure. Since FY 2014, NASA has targeted $3.5M annually to deploy CBM sensors and equipment across centers to reduce scheduled maintenance inspections and transition to condition monitoring. For example, since FY 2016

CENTER MANAGEMENT AND OPERATIONS

LaRC has instrumented 280 pieces of equipment, reducing required maintenance hours by approximately 750 hours and avoiding more than $140K in failure repairs. These investments and similar ones at all

Centers have demonstrated the success of CBM. Expansion of the CBM program will further reduce maintenance requirements and facilitate correction of maintenance problems before costly failures occur. The FY 2018 budget provides $9.8M for investigating and outfitting approximately 40 existing buildings with sensors and monitoring equipment.

ACHIEVEMENTS IN FY 2016

NASA continued to improve operations to enable the Agency to meet mission requirements and conduct its day-to-day technical and business operations more effectively. For example:

- To reduce risk in its technical capabilities, Marshall Space Flight Center (MSFC) developed a Layered Pressure Vessel risk mitigation plan and completed inspection of vessels on its main campus. Layered high-pressure gas storage vessels are critical to meeting technical mission requirements, but many are more than 50 years old and require assessment to assure their continued safe operations;
- To provide for early detection and correction of facility maintenance issues, Centers continued to increase reliability-centered maintenance and condition-based monitoring activities. Stennis Space Center (SSC) installed sensors in critical Heating Ventilation and Air Conditioning air handlers, expanded its Energy Management Control System monitoring of equipment, upgraded building automation panels, and purchased predictive testing and inspection equipment. Langley Research Center (LaRC) completed its CBM initiative, with the majority of all assets connected to the integrated system. Efficient maintenance through the expansion of the CBM program at these centers and similar efforts agency-wide reduced maintenance requirements and facilitated correction of maintenance problems before costly failures occurred;
- To reduce energy and water use and improve operations, Johnson Space Center (JSC) and Glenn Research Center (GRC) expanded their use of Energy Savings Performance Contract through the Department of Energy's Federal Energy Management Program. The program allows federal agencies to partner with utility companies to achieve energy and cost savings by implementing energy conservation projects. Energy cost savings funds the project, thereby reducing the need for federal funding;
- Centers expanded partnership activities to reduce operating costs. Ames Research Center (ARC) and Armstrong Flight Research Center (AFRC) began regionalizing their Continuous Monitoring Program and Travel functions to share capabilities across both centers, reducing duplication. MSFC began operation of a Joint 911 Emergency Dispatch Center under partnership with the Redstone Arsenal. SSC transitioned to a new facility maintenance and operations contract, which supports both SSC and MSFC’s Michoud Assembly Facility. These efforts leverage the synergies between the sites to reduce overall operating costs; and
- Centers continue to optimize their mission support workforce to maximize performance and build the skills required to support future missions. LaRC strengthened its administrative support, financial, and program analysis capabilities by consolidating and aligning these capabilities with mission requirements. These efforts improve efficiency and reduce the administrative burden on technical managers.

CENTER MANAGEMENT AND OPERATIONS

WORK IN PROGRESS IN FY 2017

In FY 2017, Centers are providing the essential day-to-day technical and business operations required to conduct NASA's 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:

- Focus on employee engagement and development to attract and advance the highly skilled and diverse workforce needed to conduct NASA's mission. LaRC is using the results of its Technical Gap Analysis Study to ensure the Center's training and development resources focus on closing any gaps. Resources, such as the Goddard Space Flight Center (GSFC) web-based career path site for employees provides a high-level view of career development paths for all employees and increases awareness of developmental opportunities;
- Energy saving initiatives to reduce consumption and improve efficiency. Kennedy Space Center (KSC) is installing LED lighting in several facilities to incorporate long lifecycle components and reduce energy intensity;
- Replacement of aging radio systems at SSC and KSC to improve security and safety. The new KSC Land-Mobile Radio (LMR) system provides public safety grade, critical, two-way radio communications to the Center, including first responders (security, fire, medical), mission support, hazardous operations, and base support personnel. The KSC LMR replacement and upgrade also provides interoperability to allow radio communications to external local and federal government agencies. These include Brevard County Emergency Services, National Park Service, Fish and Wildlife, U.S. Air Force, U.S. Coast Guard and the U.S. Forestry Service to name a few;
- KSC is replacing is static power systems map board with a dynamic power systems display and video wall. The updated system will provide a real-time comprehensive visual display of the overall power systems grid status at KSC to enable console operators to respond faster and more intelligently to systems issues and alarms; and
- Installation of new Voice over IP (VoIP) phone systems will significantly reduce operating costs and improve reliability. Installations are underway at ARC, SSC, Glenn Research Center (GRC), KSC, and JSC.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

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 2018, CMO will support:

- Facility maintenance and operations, 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.
- 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;
- Physical security, fire protection and response, emergency management, export control, and other basic and specialized protective services; KSC will upgrade their Enterprise Physical Access Control System to enhance the Center's security posture and eliminate costly obsolete technology.
- Compliance with environmental regulations, executive orders, and related requirements to protect human health and the environment;
- Human resource management; including: recruitment, hiring, workforce planning, training, and performance management supporting approximately 16,100 civil servants at the Centers;
- Occupational and environmental health and medical support, such as industrial hygiene, health physics, hearing conservation, and licensed and credentialed medical personnel and facilities to meet specialized mission requirements;
- Personal property management, transportation management, mail management, and other logistical support;
- Duplicating and printing support, video production, audio/visual services, and publications and graphics (includes specialized support for the production and archiving of scientific and technical information);
- Senior leadership and management of the Centers, executive staff and administrative support, student programs, and developmental assignments;
- Routine public affairs activities, dissemination of information about NASA programs and projects to the general public, and responses to public inquiries;
- 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; and
- 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 at the Centers: (1) provide, support, and oversee the technical work, and (2) provide formally delegated Engineering ($139 million) and Safety and Mission Assurance Technical Authorities ($51 million) 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 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Agency Management	361.9	--	**361.2**	376.3	376.3	376.3	376.3
Safety and Mission Success	176.2	--	**171.4**	171.4	171.4	171.4	171.4
Agency IT Services (AITS)	219.8	--	**278.1**	247.9	247.9	247.9	247.9
Strategic Capabilities Asset Program	26.9	--	**27.0**	27.0	27.0	27.0	27.0
Total Budget	**784.8**	**--**	**837.7**	**822.6**	**822.6**	**822.6**	**822.6**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

NASA has been investing in cybersecurity capabilities to manage risk and mitigate cyber threats. NASA continues to improve cybersecurity by preventing malicious cyber activity, enhancing the protection of NASA's Federal systems and information, and strengthening cybersecurity awareness across NASA's workforce.

NASA's AMO budget provides management and oversight of Agency missions and performance of NASA-wide mission support activities. AMO activities at NASA Headquarters ensure that core services are ready and available, Agency-wide, for performing mission roles and responsibilities and that Agency operations are effective and efficient and meet statutory, regulatory, and fiduciary requirements.

NASA Headquarters develops policy and guidance for the Centers and provides strategic planning and leadership. Headquarters 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, and direction for all corporate functions. AMO supports the operational costs of the Headquarters installation. The AMO theme consists of four programs: Agency Management, Safety and Mission Success (SMS), Agency IT Services (AITS), and Strategic Capabilities Assets (SCA).

EXPLANATION OF MAJOR CHANGES IN FY 2018

NASA is increasing AITS services to strengthen cybersecurity capabilities to safeguard critical systems and data, along with investments in critical IT infrastructure and enterprise solutions. Funding will support modernizing Agency systems, increased automation, and optimized delivery of enterprise-wide IT service solutions. These investments in infrastructure and IT management will improve

NASA's ability to comply with OIG audit and Federal Information Technology Acquisition Reform Act (FITARA) requirements.

ACHIEVEMENTS IN FY 2016

NASA maintained its position as the top large agency in the 2016 rankings as the Best Place to Work in the Federal Government, improving our employee satisfaction and commitment score by focusing on three key priority areas: connecting people to each other and the mission; building model supervisors; and recognizing and rewarding innovative performance.

SMS conducted nine formal, stringent Safety and Mission Success Reviews and five Safety and Mission Success Assessments. These reviews are the culmination of the identification and mitigation of potential safety and mission assurance risks for launches and high criticality events. The NASA Safety Center conducted 18 audits, assessments, and reviews at six separate NASA Centers and component facilities in FY 2016.

NASA upgraded tools for the on-boarding and reporting of foreign nationals to ensure that individuals obtain the proper classification and corresponding level of investigation within NASA’s Identity, Credential, and Access Management (ICAM) environment.

NASA improved IT security by implementing tools to improve email security and anti-phishing capabilities across the Agency. These tools included record checking to analyze incoming email and reduce spam and untrusted emails from reaching users.

For the sixth consecutive year, the Agency received a clean (unmodified) audit opinion of its accounting and financial systems.

WORK IN PROGRESS IN FY 2017

The Safety and Mission Assurance (SMA) program will continue to develop assurance capabilities to mitigate risks associated with rapidly advancing industry capabilities in additive manufacturing, commercial-grade EEE parts, model-based systems engineering, and software design practices.

In FY 2017, the Independent Verification and Validation (IV&V) Program is currently providing software expertise to 18 projects, including 14 NASA missions, Commercial Crew Program, two multi-agency missions, and across eight NASA Centers.

The NASA Engineering and Safety Center (NESC) plans to conduct over 50 independent assessments of NASA’s highest risk challenges maintaining prioritization on the ISS, Commercial Crew, Orion/Space Launch System (SLS), James Webb Space Telescope (Webb), and Space Technology.

The Agency will continue to improve IT security with the implementation of an enterprise firewall, web content filter policies, and improved network access control on NASA’s guest and internal networks. NASA is implementing two-factor authentication of Enterprise applications to heighten security on internal applications. NASA is completing the activities for the new procurement contract writing system, Contract Management Transformation. NASA completed the four-certificate-on-a-card project in the first quarter of FY 2017 and issued 68,000 cards. The four certificate effort was an Agency-wide personal identity verification (PIV) card effort to standardize and comply with HSPD-12 and FIPS 201-2.

Specifically, the four certificates are used to (1) authenticate use for applications and computers, (2) encrypt messages, (3) sign emails and documents, and (4) card authentication. NASA will target to complete the effort to issue a Level of Assurance 4 PIV to current PIV ineligible users in the fourth quarter of FY 2017.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

Collaborative efforts between the Office of Safety and Mission Assurance (OSMA), Office of Chief Engineer (OCE), and OCHMO will continue to strengthen the Agency's Technical Authority capability. The offices will continue to 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.

NASA will consolidate communications services to improve workforce efficiency and reduce cost by reducing duplication and using Agency-wide licensing and enterprise contracts.

NASA IT Security will deliver final tools for Continuous Diagnostics and Mitigation (CDM) Phase I and begin CDM Phase II.

The Agency plans for the completion of the NASA Visitor Management solution by the second quarter of FY 2018, which will standardize visitor management systems across the NASA Centers.

The Agency will improve the NASA Security Operations Center (SOC) capabilities and deploy tools to monitor encrypted traffic for intrusion to help improve NASA's cybersecurity posture and compliance with statutory requirements and government-wide cybersecurity policies.

Program Elements

AGENCY MANAGEMENT

Agency Management 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 program is a critical enabling capability dedicated to IT excellence to ensure every mission can achieve success within NASA’s complex environment. The AITS mission improves management and security of IT systems while systematically improving the efficiency, collaboration capabilities, and streamlined service delivery and visibility for the entire Agency.

STRATEGIC CAPABILITIES ASSETS PROGRAM

SCA 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 SCA are thermal vacuum chambers, simulators, and the Arc Jet Facility.

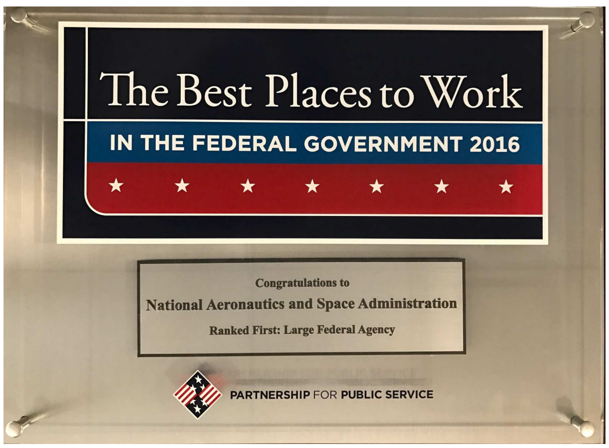
AGENCY MANAGEMENT

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	361.9	--	361.2	376.3	376.3	376.3	376.3

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



NASA Headquarters in Washington, DC provides overall planning and policy direction for Headquarters and the corporate management for all of its field Centers, which includes approximately 50,000 civil servant employees, and on and near site contractors NASA-wide. NASA maintains its ranking as the top large agency as the Best Place to Work in the Federal Government.

Agency Management provides functional and administrative management oversight for the Agency and operational support for NASA Headquarters. Agency Management supports the activities necessary to conduct business in the Federal sector and provides the capability to respond to legislation and other mandates. The Agency Management program supports over 35 discrete operations and mission support activities.

Agency Management provides policies, controls, and oversight across a range of functional and administrative management service areas. This includes governance and oversight activities such as finance, protective services, general counsel, public affairs, international and interagency relations, 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. The Agency Management program supports operational activities of Headquarters similar to a Center. These activities 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).

EXPLANATION OF MAJOR CHANGES IN FY 2018

None.

AGENCY MANAGEMENT

ACHIEVEMENTS IN FY 2016

NASA maintained its position as the top large agency in the 2016 rankings as the Best Place to Work in the Federal Government, improving employee satisfaction and commitment score by focusing on three key priority areas: connecting people to each other and the mission, building model supervisors, and recognizing and rewarding innovative performance.

During FY 2016, NASA delivered a number of leadership programs focused on developing supervisors and leadership at all levels - NASA First (early career), NASA Mid-Level Leadership Programs (MLLP) and Senior Executive Service (SES) Candidate Development Program. The OHCM has increased focus on virtual collaboration and tools, and continued to emphasize innovative practices with Champion of Innovation and Lean Forward; Fail Smart Awards which honor the valuable contributions of NASA employees' demonstrated innovative behavior.

For the sixth consecutive year, the Agency received a "Clean" financial audit opinion while closing one significant deficiency from FY 2015. This achievement also enabled NASA to receive the Associate of Government Accounts Certificate of Excellence in Accountability Reporting (CEAR) for the second year in a row. The CEAR award recognizes federal agencies for producing high-quality Agency Financial Reports.

The ICAM Modernization Project final release was completed and included updates to business processes, system user interfaces, auditing and reporting functions, and an electronic Access Control Plan (ACP) capability. New identity management business processes for position designation, Foreign National Access Management (FNAM), Access Control Plan, and more were deployed. The National Security Systems (NSS) Team completed all network requirements outlined under the umbrella of the Committee on National Security Systems Directive on Protecting National Security Systems from Insider Threat.

NASA Headquarters enhanced its continuity of operations (COOP) capabilities to provide for the continued management and operations of the Agency in the event that Agency management is not able to remain in or operate from the National Capital Region. Headquarters participated in the 2016 FEMA Eagle Horizon exercise that tested NASA's ability to conduct mission-essential functions and maintain effective leadership of the Agency on a "no notice" basis. Headquarters updated and tested policies and plans related to active shooter scenarios via simulations and drills.

As part of efforts to improve efficiency, NASA excessed/divested 20 manned aircraft and 59 small and medium unmanned aircraft systems (UAS) recouping over $2.3M through use of the Exchange Sale Authority. In FY 2016, the Agency met the OMB goals for Energy Intensity reductions, Renewable Energy Consumption, Potable Water Intensity and Fleet Petroleum Use. The Energy Intensity reductions since 1995 resulted in a cost avoidance in utility bills of $45 million for FY 2016.

In an effort to increase efficiencies and enhance effectiveness across the Agency, NASA completed three BSAs in FY 2016 covering Procurement, Human Capital, and Facilities. In the area of procurement, NASA is expanding the use of strategic sourcing contracts and making strategic assignments by leveraging centers to award and manage multi-center contracts while streamlining the contract selection process. Human Capital process improvements include implementing a long-term strategic workforce planning process and consolidation of staffing and classification to enable efficient and consistent operations. Improved facilities processes maximize use of maintenance dollars across NASA.

AGENCY MANAGEMENT

NASA is standardizing and incentivizing divestments through demolition and leasing while enabling reliability centered maintenance and computer based monitoring.

WORK IN PROGRESS IN FY 2017

NASA's Small Business Programs Office is improving the Agency performance in small business subcategories by identifying, increasing, and promoting small business prime contracting opportunities. By the end of FY 2017, each Center will have set aside new requirements to one of three small business sub-categories including Woman-Owned Small Business, Historically Underutilized Business Zone, and Service-Disabled Veteran-Owned Small Business.

NASA Headquarters, in concert with the GSA and the District of Columbia, will complete the installation of a Level IV Physical Security perimeter at its E Street location. The Level IV Physical Security protocol includes the development and installation of bollards and benches on all sides of the building, as well as operable vehicle entry barriers at the garage and alley entrances.

NASA's Enterprise Protection Program will increase focus on threat analysis covering cyber, Counterintelligence/Counterterrorism, and insider threats to help identify, qualify, and mitigate the growing scope of threats across NASA's overall enterprise. The National Security Systems (NSS) Team will deploy Public Key Infrastructure (PKI) services on the NASA Interconnected Network (NIN) in response to Executive Order 13587 -- Structural Reforms to Improve the Security of Classified Networks and the Responsible Sharing and Safeguarding of Classified Information under the provisions of National Security Directive 42- National Policy for the Security of National Security Telecommunications and Information Systems using PKI.

During FY 2017, NASA OHCM will launch a multi-year transformation effort to re-design, automate, and consolidate its Talent Acquisition program, including classification, hiring, and staffing across the Agency. NASA will also begin a two-year effort to implement a new Learning Management System.

NASA continues to gain efficiencies through its BSA activities. This includes performing detailed assessments, developing implementation plans and institutionalizing previously made business service decisions. Decisions have been made based on the assessment of Budget and Program Planning and Control and assessments are on-going in the areas of Education and Outreach, and Technical Authority. NASA also plans to initiate deep dives in the areas of Security and Logistics in FY 2017.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

NASA will consolidate the aviation safety Program and operational aircraft management under Aircraft Capability Leadership to optimize functional oversight and organizational effectiveness.

NASA will continue work on developing/deploying the new Case Management System suite of tools to manage OPM investigation processes and National Security Clearances. Anticipating a successful launch of the Visitor Management System for U.S. citizens in FY 2017, NASA plans to expand it to include visitor management for foreign nationals in FY 2018.

In FY 2018, NASA will continue BSA efforts and plans to conduct deep dives in the areas of Institutional Safety and potentially General Counsel and the Diversity and Equal Opportunity. NASA will continue the

AGENCY MANAGEMENT

implementation of previously made BSA decisions, establishing a more effective, efficient and transformative Mission Support operating model to meet current and future Agency objectives.

Program Elements

HEADQUARTERS OPERATIONS

Headquarters Operations manages and sustains the Headquarters employees and contractors, facilities, and operations required for program and institutional execution. Areas include:

- IT and communications infrastructure hardware and software acquisitions and maintenance, as well as contracted services for IT support of the Headquarters staff;
- Facility operations support, including physical security, custodial, and maintenance services; equipment; expendable supplies; mail services; printing and graphics; motor pool operations; logistics services; and emergency preparedness;
- Human resources 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 for accounting and procurement operations; configuration maintenance; automated business and administrative systems; contract close-out services; and payments to the NASA Shared Services Center for grants management.

MISSION SUPPORT

The Agency Management budget also provides for functional leadership of administrative and mission support activities at Headquarters 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 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 ICAM and other security systems, including communications; 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. These offices engage the Agency in proactive equal opportunity and diversity and

inclusion initiatives, workforce development and alternate dispute resolution services and complaint investigations.

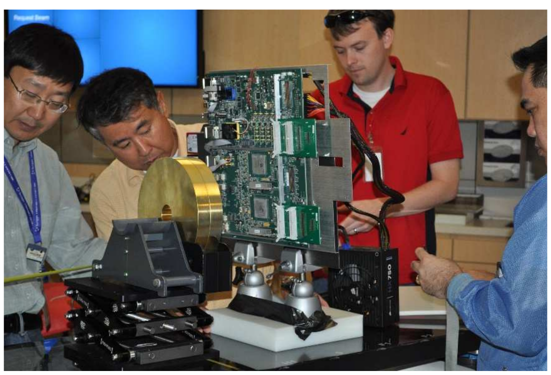
SAFETY AND MISSION SUCCESS

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Safety and Mission Assurance	49.7	--	**49.8**	49.8	49.8	49.8	49.8
Chief Engineer	83.4	--	**83.7**	83.7	83.7	83.7	83.7
Chief Health and Medical Officer	4.0	--	**4.4**	4.4	4.4	4.4	4.4
Independent Verification and Validation	39.1	--	**33.5**	33.5	33.5	33.5	33.5
Total Budget	**176.2**	**--**	**171.4**	**171.4**	**171.4**	**171.4**	**171.4**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



NASA's Electronic Parts and Packaging (NEPP) is leading a government/industry/academia team evaluating electronics radiation testing for space applications. This research is being conducted at the SCRIPPS Proton Therapy Center and includes representatives from the Air Force, NRO, Boeing, Vanderbilt University, and SpaceX.

SMS programs protect the health and safety of the NASA workforce and improve the likelihood that NASA's programs, projects, and operations will be completed safely and successfully. SMS includes programs that provide technical excellence, mission assurance, and technical authority. It also includes work managed by OSMA, including the NASA Safety Center and IV&V; OCE including the NASA Engineering and Safety Center (NESC); and 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 for 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 the effective application of the strategic management framework and the technical authorities defined in NASA's Strategic Management and Governance Handbook. SMS funds provide training and maintain a competent technical workforce within the disciplines of system engineering, including system safety, reliability, and quality, as well as space medicine.

SMS resources are essential for evaluating the implications on safety and mission success, including the health and medical aspects of new requirements and departures from existing requirements. With this funding, 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 2018

None.

ACHIEVEMENTS IN FY 2016

SMS conducted nine formal, stringent Safety and Mission Success Reviews and five Safety and Mission Success Assessments. These reviews are the culmination of the identification and mitigation of all potential SMA problems for launches and high criticality events. Substantive participation in Directorate Program Management Council (DPMC), Flight Planning Boards, Key Decision Point (KDP) reviews, and selected lower level reviews and assessments collectively enable effective governance and successful mission implementation.

OSMA provided policy direction, functional oversight, and assessment for all Agency safety, reliability, maintainability, and quality engineering and assurance activities. This office served as the principal advisory resource for the Administrator and other senior officials on matters pertaining to safety and mission assurance. In FY 2016, OSMA successfully executed these functions and enhanced its efforts to assess and communicate the health of safety and mission assurance throughout the Agency in support of NASA’s strategic goals and governance approach.

OSMA updated six Agency directives and standards. Significant changes include updates to NASA policies for measurement and calibration; NASA procedures for reporting and investigating mishaps and close calls; and NASA workmanship requirements.

The NASA Safety Center conducted 18 audits, assessments, and reviews at six separate NASA Centers and component facilities in FY 2016. The audit and assessment program categorizes findings that provide NASA installations opportunities to improve the safety and quality of their operations and activities. NASA programs and projects at these locations are reviewed to optimize and enhance their safety and quality assurance accomplishments. During the fiscal year, the NASA Safety Center documented 243 findings that included potential systemic issues, critical concerns, non-compliances, observations, commendations, and best practices.

NASA’s IV&V Program provided software expertise to 17 projects and eight NASA Centers. The IV&V Program uses a rating system for issues identified in software artifacts. The issue ratings range from one to five. 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. In 2016, the IV&V Program identified and documented 29 issues with a rating of one.

In FY 2016, the IV&V Program continued its cyber security assessment of several key Agency assets. In all cases critical vulnerabilities were found and fixed across multiple agency systems, leading to the increased system security posture for the Agency. The IV&V Program provided information assurance to NASA missions via the ability to assess threats and review protection plans and security controls to combat cyber-attacks.

SAFETY AND MISSION SUCCESS

The IV&V Program achieved third party assessor accreditation for the Federal Risk and Authorization Management Program (FedRAMP) - a first for NASA and one of three for the entire Federal Government. The IV&V Program is now certified to assist cloud service providers and government agencies in complying with FedRAMP regulations.

In FY 2016, the Mission Directorate Chief Engineers and OCE representatives participated in all critical milestone reviews and activities for the Agency. This included four missions to ISS by NASA Commercial Cargo partners; significant hardware development by the Orion and SLS Programs and NASA's Commercial Crew partners; launch of the OSIRS-Rex, GOES-R, and CYGNSS spacecraft; development and initial testing of JWST; preliminary design of QueSST supersonic flight demonstrator; resumption of X-Plane development; and technology advancements in areas such as solar electric propulsion. As a part of the Technical Authority process, OCE ensured that risks were adequately communicated to decision makers and that alternate points of views were heard and considered.

The OCE continued to lead the implementation of discipline and system-level Capability Leadership model. Through the efforts of the Technical Fellows (TF's) and their supporting Capability Leadership Teams (CLT's), "State of the Capability" reviews were completed in mid-2016. Each of the 20 discipline- and system-level CLT's reported its findings to the Agency Engineering Management Board (EMB), and a package of recommendations was prepared for consolidation and presentation to Agency leadership. In addition, the EMB addressed the actions derived from 2015 reviews, including a first-ever detailed assessment of the Agency's nuclear power and propulsion capabilities and implementation of a centralized aeronautics test facility management model. The latter is especially important since it will reduce the testing costs currently borne by programs and encourage rigorous, test-based solutions to technical problems.

The NESC completed 29 independent assessments in FY 2016 and satisfied 20 requests for technical support touching all of NASA's Mission Directorates. These assessments furthered NASA goals and contributed directly to the Agency mission through better-informed decision-making and an overall reduction of risk. Results included a wide range of topics from testing, modeling, and analysis of the frangible joints used as stage separation devices by the Commercial Crew Program (CCP), SLS, and Orion to a detailed assessment of analytical tools, Non-Destructive Evaluation (NDE) methods, and tests suitable for verifying the bond between ablative tiles and the surface of Orion's heatshield. The bond verification work led to new analytical techniques and NDE methods the Program had not previously entertained but now considers essential for certifying flight readiness of the Orion spacecraft.

The NESC participated in the evaluation of numerous alternate standards and variances proposed by CCP commercial partners, providing technical expertise to the NASA CCP Engineering team. Independent Entry, Descent, and Landing (EDL) models and simulations for the CCP and integrated ascent trajectory and separation analyses for the SLS and Orion programs were furthered during FY 2016. In addition, the NESC continued work on development of shell buckling knockdown factors, already adopted by Boeing for a 2000-3000 pound mass reduction in the SLS core stage, by expanding the work from metallic to composite shells. The NESC invested in the development of an innovative method for rapid Coupled Loads Analysis (CLA) conceived to address a need for a fast but accurate method to reduce Design Analysis Cycle schedules and costs. Analysis results to date have confirmed the accuracy of the new CLA technique as compared to traditional methods, providing spacecraft projects with a tool for conducting multiple "what-if" structural design optimization cycles without the expensive and time-consuming involvement of the launch vehicle provider.

SAFETY AND MISSION SUCCESS

The NESC contributed to the capture and transfer of knowledge acquired during assessments in the form of briefings, inputs to the Agency's lessons learned system, formal engineering reports, and a series of innovative online videos and webcasts. The NESC produced 18 engineering reports in FY 2016, six Position Papers, one Technical Bulletin, and a detailed, Agency-wide Technical Update publication.

The OCE-led NASA Technical Standards Program (NTSP) led the development of four Voluntary Consensus Standards in collaboration with Standards Developing Organizations (SDO's). In addition, the NTSP developed and published six NASA Engineering Standards and Handbooks, while the use of the NASA Standards web site has resulted in over 120,000 technical standards products downloaded. This web site provides the NASA user community a single-point instantaneous access to approximately 1.6M Standards/Handbooks/Specifications from over 370 sources, plus engineering tools, thus reducing research time, streamlining workflows, and avoiding unnecessary costs. This capability helps promote best industry practices and provides electronic notification of revisions for registered standards to help users verify that the documents they are using are current. Lessons Learned from Agency's Lessons Learned Information System (LLIS) are also integrated/linked, as they become available, to applicable NASA technical standards, and application. The Academy of Program/Project and Engineering Leadership (APPEL) delivered 146 courses with 3,355 NASA participants. APPEL also managed the Federal Acquisition Certification for Program/Project Managers (FAC-P/PM) which added 11 new members for a total of 161 certified PMs for FY 2016.

WORK IN PROGRESS IN FY 2017

OSMA will develop assurance capabilities to mitigate risks associated with rapidly advancing industry capabilities in additive manufacturing, commercial-grade EEE parts, model-based systems engineering, and software design practices. These capabilities provide technical and cost saving opportunities for future NASA missions. OSMA will also continue improving methodologies for risk identification and perform independent SMA assessments and process verification reviews when appropriate.

OCHMO is continuing 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 Environmental Protection Agency. In cases where there is no NASA-unique or federally mandated health/medical requirement or standard, OCHMO is also responsible for establishing policies, procedures and standards. In addition to providing direction and oversight for a rapid review of crew health and safety in support of the one-year on-orbit International Space Station mission, OCHMO will lead the Multilateral Medical Policy Board in addressing and resolving several critical issues dealing with crew health and medical operations support to Soyuz landings.

The IV&V Program is currently providing software expertise to 18 projects, including 14 NASA missions, Commercial Crew Program, two multi-agency missions, and across eight NASA Centers. Additionally, the IV&V Program is continuing 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, Orion/SLS, Webb, and Space Technology. Several activities underway in FY 2017 will be continued into FY 2018 including independent 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 shell buckling knockdown factors for composite shells. OCE continues to be an active participant in the Agency's Technical Capability Leadership efforts and provides leadership for a number of discipline-related assessments.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

At the core of the Agency's preventive approach to achieve safety, health, and mission success are:

- Active engagement with NASA programs and institutions to advise, advocate, and ensure safety and mission success;
- Routine on-site inspections and regular self-audits to ensure compliance with mandatory regulations, Agency policies, industry standards, and best practices;
- Robust knowledge management and communities of practice that capture and inculcate lessons learned into future missions;
- Multi-faceted training and development programs to ensure the SMS workforce has the necessary skills and capabilities;
- Comprehensive review processes to identify and mitigate risks and to analyze and understand failures when they occur. This strategy and practice will continue to provide a systematic approach to support mission success; and
- Independent tests and analyses for resolving critical technical issues faced by NASA programs and projects.

OCHMO will continue to implement the health and medical technical authority as it pertains to all technical standards for research & technology and human space flight programs and projects, as well as those that relate to occupational and/or environmental health requirements that are not established by OSHA or EPA. Additionally, OCHMO will continue to support the only two non-military Aerospace Medicine residencies in the U.S. - Wright State University and the University of Texas Medical Branch - to ensure the sustainability of the discipline, as well as to support the pipeline for future talent.

In FY 2018, IV&V will continue to provide expert software analysis on NASA's safety and mission critical software to help assure safety and mission success by identifying software problems as early as possible, minimizing the cost of rework, and supporting key milestone decisions. Additionally, the IV&V Program will continue to enhance its technical capabilities and focus on continuous improvement and value.

Collaborative efforts between OSMA, OCE, and OCHMO will continue to strengthen the Agency's Technical Authority capability. The offices will continue to 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.

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.

OFFICE OF THE CHIEF ENGINEER

The 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. 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. SMS funding provides for the core NESC organization of senior engineering experts from across the Agency, including the Technical Fellows and technical discipline teams. Technical Fellows, in turn, manage the capabilities of their respective technical disciplines. 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. The OCE is also responsible for the implementation of Discipline-level Capability Leadership through the NASA Technical Fellows.

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 OCE professional development programs directly support project teams in the field through workshops, coaching, interactions with technical experts, training, forums, and publications. The office enables technical collaboration and information sharing through the NASA Engineering Network. The

SAFETY AND MISSION SUCCESS

NASA Engineering Network is an Agency-wide capability providing single point access to technical standards, communities of practice, and lessons learned in a secure operating environment. The engineering standards program maintains compliance with OMB Circular A-119, “Federal Participation in the Development and Use of Voluntary Consensus Standards and in Conformity Assessment Activities,” and offers a centralized source of required engineering standards for NASA programs and projects at one-fourth the cost of a decentralized approach.

OFFICE OF THE CHIEF HEALTH AND MEDICAL OFFICER

OCHMO 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. The office monitors the implementation of health and medical related requirements and standards in all developmental human space flight programs through designated discipline experts at NASA Centers. The office provides oversight of medical and health related activities in operational human space flight through Center-based discipline experts and clinical boards. 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. OCHMO developed a health and medical standards guide for NASA’s biomedical research programs to support of human space flight.

INDEPENDENT VERIFICATION AND VALIDATION

Software on NASA’s missions is extremely critical. IV&V is a proven means of making sure this critical software works properly. Because IV&Vs can identify software problems as early as possible, it can help minimize the cost of software development and potential rework.

The NASA IV&V Program provides software expertise, services, and resources to improve the likelihood for safety and mission success for NASA’s programs, projects, and operations. The IV&V Program analyzes mission software, independently from the developing organization, on NASA’s most critical software systems to assure safety and mission success of those systems.

IV&V applies state of the art analytical methods and techniques, complemented with effective software engineering tools and best practices, to evaluate the correctness and quality of critical and complex software systems throughout the project’s system development life cycle.

IV&V provides resources and software expertise to other SMA elements in support of independent evaluations of software related approaches and processes. The IV&V Program supports sustaining software technical excellence in the SMA community, sustaining software domain knowledge within the SMA organization, and formulating software development improvement recommendations to the Agency.

IV&V performs independent testing of critical system software to enhance the likelihood of discovering the most difficult kinds of problems in mission software early in the development lifecycle. Critical system software problems can surface because of multiple complex interactions, under specific environmental and operational conditions, and under unique software configurations. The 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.

AGENCY IT SERVICES (AITS)

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
IT Management	15.1	--	**26.0**	20.7	21.1	20.8	20.9
Applications	55.8	--	**59.0**	57.2	56.4	56.4	56.4
Infrastructure	148.9	--	**193.1**	170.0	170.4	170.7	170.6
Total Budget	**219.8**	--	**278.1**	**247.9**	**247.9**	**247.9**	**247.9**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

NASA Mission Control Center room at Johnson Space Center. The mission networks are managed by Agency IT Services.

NASA's AITS program provides information technologies and services to make optimal delivery of NASA's mission safely and securely. NASA AITS not only provides the Agency with access to the information needed to fulfill its mission, but works to secure the data and NASA's vast IT infrastructure, from the computers aboard the International Space Station to mobile devices used by Agency employees. NASA documents the AITS strategy in the 2017 NASA IT Strategic Plan. NASA's Information Resources Management (IRM) Strategic Plan sets goals and objectives for delivering excellence to our customers, capitalizing on innovation, safeguarding our national information assets, optimizing our IT investments, and drawing upon the diversity of our people today while preparing them for tomorrow. NASA AITS also ensures citizen access to NASA scientific data and promotes citizen participation in NASA's activities. The Office of the Chief Information Officer (OCIO) provides leadership, planning, policy direction, and oversight for the management of NASA AITS and ensures that IT investments align to the NASA Agency Strategy.

EXPLANATION OF MAJOR CHANGES IN FY 2018

The FY 2018 request includes an increase in cybersecurity and IT management spending over the FY 2016 enacted budget. This increase of $32M will be used to accelerate personal identity verification (PIV) compliance, mature SOC capabilities, improve the detection and response to malicious activity, and to develop and deploy IT Portfolio tools and processes. Funding will support the implementation of the agency's compliance with the Federal IT Acquisition Reform Act (FITARA) and cybersecurity.

AGENCY IT SERVICES (AITS)

This request also includes a $20M increase over the FY 2016 enacted budget for an IT Investment Fund (ITIF), implementing agency's compliance with the Federal IT Acquisition Reform Act (FITARA) and cybersecurity. The ITIF was created to afford the NASA CIO increased visibility and involvement in the management and oversight of IT resources across the Agency. This additional infrastructure funding is requested to address NASA’s critical IT infrastructure and enterprise solutions needs. The funding will be used to modernize Agency systems, increase automation, and optimize delivery of enterprise-wide IT service solutions. Investments in IT Management and Infrastructure within Agency Management Operations (AMO) and AITS improve the Agency CIO’s ability to comply with OIG audit and FITARA requirements. The increase strengthens cybersecurity capabilities to safeguard critical systems and data.

ACHIEVEMENTS IN FY 2016

IT MANAGEMENT

In FY 2016, NASA completed the Business Services Assessment (BSA), which assessed the NASA OCIO business and mission support services, evaluated the health of IT services, and identified opportunities for optimization. The resulting BSA implementation plan provided a roadmap for improving AITS at NASA.

In the area of IT Governance, the OCIO restructured and streamlined existing IT boards. The OCIO has also established a formal Annual Capital Investment Review as part of the Planning Programming Budget Execution (PPBE) process that will include investments for highly specialized IT (which had not previously been included in the review process). The OCIO has also worked with NASA procurement to establish guidance on strategic sourcing for IT. OCIO also strengthened and expanded the Agency CIO’s role in monitoring Agency IT program performance through IT Portfolio Management processes. Finally, in FY 2016, the OCIO began planning functional reviews for all Centers on a three-year rotating basis and conducted a pilot of that review process.

In the area of IT Portfolio Management, NASA developed an implementation plan, to provide insight, oversight, and portfolio management of all IT. OCIO Program Executives were designated to manage performance of the entire IT portfolio and shift the focus from operational duties to strategy and evaluate the IT Investment Portfolio against NASA’s strategic priorities, domain enterprise strategies and standards, existing capabilities, and size of investment.

The NASA Agency Project Management Office (APMO) has developed and implemented an updated policy “NASA Information Technology Program and Project Management Requirements” to provide consistency and accountability in project implementation.

In FY 2016, the NASA Enterprise Architecture (EA) program upgraded and enhanced the online Agency Enterprise Architecture System (AEAS) to improve user capabilities and ease of use. Users are now able to view, populate and manage their architecture through an online tool. Updates to the EA Framework and approach support the implementation of management improvements that were directed by the BSA.

AGENCY IT SERVICES (AITS)

APPLICATIONS

In the Applications program area, NASA had a number of significant achievements in FY 2016. NASA completed the upgrade of the business systems infrastructure to improve Agency business systems performance, stability, and efficiency. In addition, NASA completed the NASA Aircraft Management Information System - Logistic Upgrade (NAMIS-LU), which replaced obsolete IT the vendor no longer supports. NASA improved efficiencies by transitioning the financial Business Warehouse (BW) on the High-Performance Analytic Appliance (HANA) Project so that NASA was able to save costs by decommissioning the Business Warehouse Accelerator (BWA). NASA continued to expand its utilization of cloud based products by onboarding Software as a Service (SaaS) projects such as Google Suite (a collaborative working environment) and MagicDraw (an engineering modeling tool). NASA also leveraged Platform as a Service (PAAS) to modernize applications for Extra Vehicular Activity (EVA) data integrations and to deploy new web sites such as: https://science.nasa.gov.

NASA reviewed its information management organization and established an Agency-level Information Management Program in order to centralize information related services such as data access, records management, and other information management mandates. NASA developed more than a dozen Application Protocol Interfaces (APIs) to allow consumers to cull data directly from authenticated sources; and added over 1,000 datasets. NASA initiated an Agency-wide federated code-sharing process to enable collaboration and government sharing; while providing a security framework to safeguard NASA people, tools, platforms, and systems.

INFRASTRUCTURE

NASA's End User Services Program (EUS) completed over 13,000 computer and 4,800 mobile refreshes and updated Personal Identity Verification (PIV) authentication on Windows machines. EUS improved cybersecurity by implementing Targeted Attack Protection (TAP), Enhanced Mitigation Experience Toolkit and single-sign-on for the Large File Transfer. NASA successfully migrated the Enterprise Service Desk from an on-premise ticketing and ordering system to the cloud-based solution using ServiceNow for improved cost savings, flexibility and security.

NASA continued to expand the use of cloud computing, launching two more communities into the infrastructure as a service environment, and commencing a large earth science data prototyping activity in the cloud to cut down on high costs of hardware. NASA developed a governance framework for managing SaaS at the enterprise level and completed a prototype deployment of a cloud access security broker tool. NASA increased cost avoidance by $12.7 million with the closing of four additional data centers in 2016.

The Communication program strengthened the performance and security of internal networks and improved collaboration and communication across NASA. The communication program improved security by deploying an enterprise network border and Network Access Control systems at all NASA Centers. The program supported FITARA implementation by implementing a common communications baseline architecture to manage Agency communications investments. Additionally, the program contributed to cost savings by consolidating monitoring and management of NASA’s networks and Voice over IP (VoIP). NASA completed implementation of the Mission Next Generation Architecture Core Network, which strengthened infrastructure for flight project requirements and improved NASA Continuity of Operations/Disaster Recovery capability.

AGENCY IT SERVICES (AITS)

NASA improved security by implementing tools to improve email security and anti-phishing capabilities across the Agency. These tools included record checking to analyze incoming email and reduce spam and untrusted emails from reaching users. NASA also deployed a tool that analyzes incoming email for nefarious attachments and enables users to open attachments in a sandboxed environment. NASA completed the deployment of an intrusion protection system in FY 2016 to protect all endpoints on its network. NASA also continued deploying wireless authentication and monitoring and wired monitoring and logging services across the agency.

NASA upgraded tools to support the on-boarding and reporting of foreign nationals to ensure that individuals obtain the proper classification and corresponding level of investigation within NASA's Identity, Credential and Access Management environment. The Four Certificate (personal identity verification) PIV card initiative strengthened security and reduced costs by ensuring that all PIV cards contain the encryption, signing, authentication, and card authentication key.

NASA completed a Phase 1 Internet of Things (IoT) assessment to ensure system security protocols are in place to safeguard NASA's data and information. NASA created dashboards and data visualizations to enable stakeholders to make information-centric decisions; and built agency capabilities to share files with encryptions and other security protocols. NASA instituted a data science capability and established a big data working group to share experiences, test tools, and investigate data-related issues.

WORK IN PROGRESS IN FY 2017

IT MANAGEMENT

In FY 2017, NASA will continue to implement the IT management improvement decisions determined by the IT Business Services Assessment in FY 2016. These activities will include conducting the three Center Functional Reviews, the IT Capital Investment Review, and implementing a comprehensive IT Portfolio Management process which will link with the Capital Planning and Investment Control process.

To support collaboration, NASA will provide a data-driven framework for measuring, managing and communicating the budget, cost, consumption, and value of NASA's IT portfolio and incorporate the Technology Business Management (TBM) taxonomy into the NASA EA Framework. The TBM taxonomy will integrate with IT Portfolio Management and other management areas to provide consistency across IT Management.

APPLICATIONS

NASA will implement two-factor authentication of Enterprise applications to heighten security on internal applications. NASA is completing the activities for the new procurement contract writing system, Contract Management Transformation (CMT). CMT is a COTS solution that will reduce costs by reducing the need for custom point-to-point interfaces and implementing standard integrations to Federal Procurement. CMT also reduces costs by supporting three objectives of NASA's Destination Paperless Initiative: 1) e-Signature, 2) a single enterprise data container and 3) automated archive and destruction capabilities. In FY 2017, the focus is adding certificate lifecycle management (CLM) capability. CLM provides certificate-based authentication to email and Wi-Fi as well as access to encrypted email on iOS and Android devices. NASA is also planning the replacement of its current learning management solution, reducing its obsolescence risk and improving customer service.

AGENCY IT SERVICES (AITS)

NASA will conduct a review of its web site inventory to further streamline and modernize its web footprint. NASA is working on a framework for the onboarding of SaaS products as IT vendors move to this model over the next few years. NASA is moving forward in implementing “HTTPS only” on all its web sites.

Under the Information Management Program, NASA will conduct an assessment of tools for data sharing, including tools for the review and approval process for science and technology assets. In addition, NASA will conduct a study of Agency-wide library services to determine streamlined access and sharing processes for journals, books, and digital assets required from external sources. NASA will enable data hosting for NASA-funded grantees to support peer-reviewed manuscripts. Building on data analytics tools developed in 2016, NASA is training algorithms to mimic human tagging to automate the ingest process for scientific and technical documents into the data hosting system.

INFRASTRUCTURE

NASA will deploy the final Mobile Device Management (MDM) service that will incorporate a suite of managed mobile applications. EUS Program will build and evolve the EUS team and improve NASA’s security posture for end-user devices. The Agency will also begin to migrate email capabilities to a cloud-based infrastructure to increase storage capacity and archiving of emails and attachments. NASA will improve customer service by deploying new enterprise service desk features to allow users to opt for a callback rather than wait on hold, allow users to chat with an agent, allow agents to remotely control a user’s desktop, and also allow users access to all features of our service catalog on certain mobile devices.

Because not all cloud computer services are secure, NASA is deploying a cloud access security broker capability for enterprise discovery and management of software as a service. Cloud based applications and services will be integrated into the Agency’s application portfolio and all cloud products will have security plans and will be properly authorized to operate. NASA will be introducing an additional infrastructure as a service provider into the NASA catalog of cloud services. NASA plans to close four more data centers this year.

The Agency will continue to improve IT security with implementation of an enterprise firewall, web content filter policies, improved network access control on NASA’s guest and internal networks, and replacement of multiple Center virtual private networks with a single enterprise-enabled solution. NASA will implement NASA’s obsolescence and network standardization initiatives to address technology updates for Land Mobile Radio, cable plant, and core network infrastructure. The Agency will also unify communications capabilities such as voice/video/web conferencing. NASA will establish an initiative for transition to GSA’s new Enterprise Infrastructure Services. The Mission Backbone Transition project will continue transition to an improved backbone, and will downsize and decommission legacy mission data circuits to achieve cost savings.

Modernization of the NASA Consolidated Active Directory will make each user log-in process identical and bring cost savings through standardization and improve security management. To reduce the reliance on commercial certificates and their associated security risks, NASA plans to deploy a Code Signing and Time Stamping Service to support our PKI infrastructure.

NASA will improve security and identify opportunities for cost savings by testing IoT capabilities and working with stakeholders in security, applications development, and cloud computing disciplines; and complete work on Network Activity Cybersecurity Risk Assessment and Data Tagging for Cyber Security and Data Discovery prototypes.

AGENCY IT SERVICES (AITS)

KEY ACHIEVEMENTS PLANNED FOR FY 2018

IT MANAGEMENT

NASA is committed to strengthening its IT Portfolio Management with continued focus and commitment to assess the effectiveness of current IT management practices and to address opportunities to improve management of IT resources. To meet these goals, NASA plans to implement an IT Portfolio Management structure and investment process. This process will provide IT portfolio management through powerful analytics to help empower the CIO and NASA leaders to collaborate on the tough decisions that improve value, provides transparency into costs, utilization, and performance of services across the entire IT value chain. As a result, IT leaders can establish accountability, cost ownership, and apply economic rationales to daily decisions.

The NASA OCIO and OCFO have partnered to tackle a strategic issue on achieving greater understanding out of IT and R&D dollars. The strategic issue is to improve NASA's mission through tagging financial data during the Budget Formulation and Execution cycle. NASA's IT data tagging initiative will allow NASA to design and implement a financial and IT business management tool that will enable making better decisions through data analysis.

In FY 2018, the EA program will assist NASA IT Programs as they base-line their capabilities; perform EA assessments of all IT Program capabilities to identify gaps; and establish vision, goals, and objectives for cross-cutting architectures which will allow for greater integration between the programs and a single roadmap for NASA IT.

APPLICATIONS

As a result of the BSA reviews, numerous opportunities for improved business process automation and streamlining have been identified which will result in the implementation of new enterprise applications including:

- An end-to-end Talent Acquisition capability that provides NASA hiring managers with workflow transparency, and applicants with status information, throughout the hiring and staffing process;
- An integrated data management capability to analyze facilities and real estate data so that facilities data can readily support facilities management decisions; and
- An easily accessible repository of contract information to facilitate more effective strategic sourcing and acquisition activities.

To support streamlining and save costs, NASA will analyze the information flow of critical agency information assets, establish an enterprise governance and accountability process for information management, and implement advanced technology and capabilities for data hosting and concept tagging for data and publication management.

INFRASTRUCTURE

The End User Service Program will push the Agency to the goal of 80 percent utilization of NASA's enterprise contract for end user services, and develop a strategy for discovering and documenting all end user client systems. End User Services will also enhance customer experience based on customer feedback.

AGENCY IT SERVICES (AITS)

Activities associated with reconciling the SaaS portfolio will continue for the Computing Program. In alignment with the “cloud first” mandate that was introduced in 2010 in the “25 Point Plan to Reform Federal Information Technology Management”, NASA plans to introduce a third infrastructure as a service provider into the NASA catalog of cloud services and onboard more NASA projects into the cloud. NASA plans to close two more data centers in FY 2018.

In FY 2018, to improve and strengthen its security, NASA will implement internal and external network borders. NASA will consolidate communications services to improve workforce efficiency and reduce cost by reducing duplication and using Agency wide licensing and enterprise contracts. Continued Agency modernization efforts will include the completion of VoIP implementations at two Centers, the consolidation of Centers’ long distance services, and downsizing and decommissioning of legacy mission data circuits. NASA will also begin the next generation mission voice system migration.

To support improved security, NASA IT Security will accelerate the delivery of security tools for CDM Phase I and begin CDM Phase II. These tools will provide Agency insight into mission systems, significantly enhancing the Agency’s risk purview. CDM Phase II will allow the Agency to enhance access control, privileges, and security behavior and credentialed management. Finally, the Agency will begin planning for CDM Phase III, which will deploy tools that enhance boundary protection and event management, to include network, physical, and virtual boundary protection as well as event planning, auditing, and response. The Agency plans for the completion of the NASA Visitor Management solution by the second quarter of FY 2018, which will standardize visitor management systems across the NASA Centers. IT Security will also accelerate PIV Solutions, improve NASA Security Operations Center (SOC) capabilities, and deploy capability to monitor encrypted traffic for intrusion to help improve NASA's cyber security posture and compliance.

IT INVESTMENTS

IT investment funds will enable NASA to improve security, reduce costs, and increase efficiency by modernizing Agency systems, improving cybersecurity, increasing automation, delivering affordable enterprise-wide IT service solutions, strengthening technical capabilities and achieving cost avoidances and savings through strategic investment. These investments enable NASA to comply with IG audit, OMB, and FITARA requirements to:

- Improve agency CIO control and oversight of IT management, funding and IT investments;
- Improve the IT Investment review process and Agency CIO responsibility for the agency IT portfolio;
- Increase the focus on eliminating duplication and rationalizing commodity IT Investments; and
- Ensure that the Agency CIO has a significant role in budgeting, contracting, management and governance of IT; and approval authority for the OMB Capital Planning Guidance.

The projects that comprise this request are critical to maintaining security and continuous operations. Projects include mission network security modernization, corporate network obsolescence, and enterprise collaboration tools. The mission network security modernization project will reduce carrier costs and improve the network for mission data and voice services. The corporate network obsolescence project will allow the OCIO to make network refresh decisions at the enterprise level while reducing redundancies and inefficiencies. Enterprise collaboration tools will establish a standardized collaborative tool suite, introducing new technology to support end-user services, and saving costs through strategic sourcing initiatives.

AGENCY IT SERVICES (AITS)

Program Elements

IT MANAGEMENT

The IT Management project provides Agency-level capabilities for managing IT and meeting Agency and Federal mandates. This project includes the budget for the NASA Office of the CIO to meet OMB guidance, Executive Orders, laws, and regulations. This project provides funding for the E-Government activities and Federal CIO Council Committees in which NASA participates. The IT Management project also supports digital services for stakeholders who contribute to or support NASA scientific and technical research.

APPLICATIONS

The Applications Program (AP) has programmatic responsibility for enterprise service delivery and governance of applications and web sites. AP monitors the NASA applications ecosystem and identifies opportunities to simplify, eliminate and optimize applications usage. An overarching goal of the AP is to anticipate and align customer requirements with IT solutions that best enable the Agency's mission. In addition to the service delivery roles described below, each area under Applications supports the AP Program Executive in areas of IT authority, portfolio management, enterprise architecture, investment reviews, oversight of web and other activities required to maintain a current knowledge of project status and risks.

INFRASTRUCTURE

The IT Infrastructure project provides core infrastructure capabilities across NASA, including enterprise-wide e-mail, calendaring, directory services, software management, and the corporate network as well as PIV card systems required for identity and credential management for logical access control. The project also provides NASA public Web portal, data center and cloud computing services, and enterprise licensing management. To protect NASA's vast information assets, the IT Infrastructure project provides enterprise cybersecurity capabilities such as the SOC, continuous monitoring, third-party penetration testing, vulnerability scanning, patch management, and other threat detection and prevention services.

The Continuous Diagnostics and Mitigation (CDM) Program, centrally managed by the Department of Homeland Security, and also implemented at NASA, is intended to create a common baseline of cybersecurity capability and protection across the Federal Government. The program provides federal departments and agencies with CDM-certified capabilities and tools that identify and prioritize cybersecurity risks on an ongoing basis and enable cybersecurity personnel to mitigate the most significant problems first. The CDM tools also allow departments and agencies to better manage their IT assets, helping to reduce their overall attack surface.

The CDM tools provide near real-time awareness of NASA networks and environments. Data from the tools are automatically ingested into an individual dashboard at NASA. The Agency Dashboard provides current visibility into the overall organization's security posture based on a 72 hour data currency. With the full implementation of CDM, data from the individual agency dashboards across the Federal Government will be aggregated into one federal-level dashboard with planned synchronization every eight hours. The Federal Dashboard is maintained by the CDM Program and allows DHS to monitor and respond to federal cybersecurity threats and incidents much more quickly and efficiently.

AGENCY IT SERVICES (AITS)

The CDM Program is currently managed under four phases. Since FY 2013, Congress has supported all four phases of CDM. Below are the four phases of CDM:

• Phase 1 is “what is on your network.” The tools allow agencies to figure out the number of agency computers, what software those computers run, and if they are vulnerable to attack. The result for this improved asset management is that it immediately reduces an agency’s attack surface.

• Phase 2 is “who is on your network.” The tools allow agencies to better manage users and their accounts, including those privileged users with enhanced network access. There is a further reduction in an agency’s attack surface by limiting user based vulnerabilities.

• Phase 3 is “what is happening on your network.” The tools allow agencies to strengthen the management of events/incidents, border protection, and the entire security lifecycle. In addition, the automation of the tools in phases 1, 2, and 3 will enable agencies to conduct ongoing assessments of their networks, leading directly to enabling agencies to manage assessment and accreditation of their networks on a close to real-time basis rather than periodic assessments.

• Phase 4 is “protect key data.” It focuses on protecting the critical data on agency networks and includes capabilities to encrypt data and segment networks so that intruders who break in cannot access the entire network.

Historically, it has taken agencies days or weeks to determine that cybersecurity incidents have occurred in their environment. Once fully deployed, the CDM Program will shorten this timeframe to hours and minutes.

DHS, through the CDM Program Management Office, also provides support for training and governance activities, ensuring that CDM deployments and governance activities reinforce agency responsibilities for Information Security Continuous Monitoring as identified in OMB 14-03, as well as in the Federal Information Security Modernization Act of 2014.

DHS, through the CDM Program Management Office, will pay for the operations and support costs of NASA’s CDM Phase 1 tools and services that were originally purchased by DHS, including Task Order 2 Software License Maintenance, Dashboard, and Delivery Order 1 tools. In addition to these tools and services, NASA is requesting $14M in order to ensure that CDM is effectively implemented at NASA in FY 2018 on licensing, PIV solutions as well as deploying and managing CDM on mission networks.

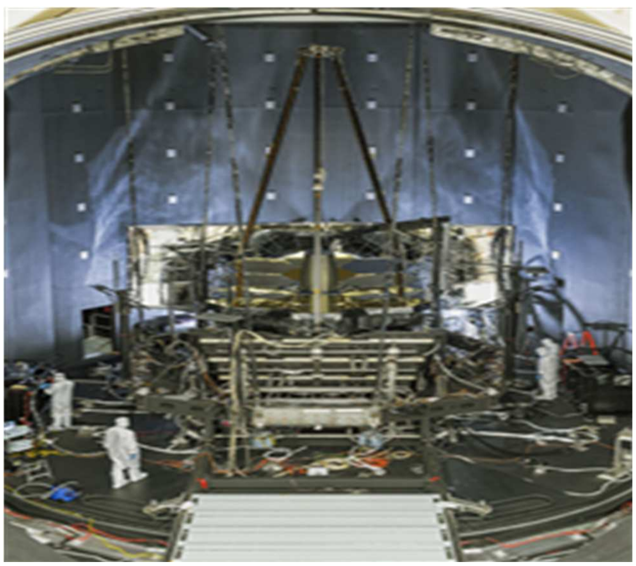
STRATEGIC CAPABILITIES ASSET PROGRAM

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	**26.9**	**--**	**27.0**	**27.0**	**27.0**	**27.0**	**27.0**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



Preparations for testing of the Optical Ground Support Systems with the Webb Pathfinder in Chamber A, located at NASA’s Johnson Space Center, Houston, Texas.

SCA ensures that select critical test facilities are operationally ready to meet mission and program requirements by sustaining the skilled workforce and performing essential preventative maintenance. Core capabilities that SCA supports include: thermal vacuum chambers, simulators, and the Arc Jets.

SCA manages assets across Centers, reviews the Agency’s assets and capabilities each year to ensure the requirements for the facilities continue to be valid, identifies re-investment/re-capitalization requirements within and among classes of assets, makes recommendations on the disposition of capabilities no longer required, and implements changes.

SCA ensures maximum benefit across the government by broadening its alliances outside the Agency for capabilities (e.g., thermal vacuum chambers). The Space Environment Test Alliance Group, a collaborative working group consisting of NASA, DoD, and other partner entities, facilitates this effort. The group members gain awareness of capabilities across agencies, academia, and industry; share best practices; provide technical support; and refer test programs to facilities best suited to meet test requirements.

EXPLANATION OF MAJOR CHANGES IN FY 2018

None.

STRATEGIC CAPABILITIES ASSET PROGRAM

ACHIEVEMENTS IN FY 2016

In FY 2016, the Agency created the Space Environments Testing Management Office (SETMO) to centralize the management of the Agency's space environments testing capabilities with assets from the SCA. In addition to the SCA core capabilities of thermal vacuum chambers, simulators, and the Arc Jets, SETMO provides management of acoustic chambers, vibration tables, and clean rooms.

SCA reviewed and identified high-risk areas for the thermal vacuum capability at the Jet Propulsion Laboratory (JPL) to assess the condition and health of the assets.

In addition, SCA managed capabilities supported NASA's mission by enabling the following:

- SCA's Space Power Facility at the GRC completed the Orion Service Module Structural Test Article testing series;
- SCA's thermal-vacuum test facility Chamber A at JSC completed the Optical Ground Support Equipment test #2, and began the thermal pathfinder testing for Webb. SCA's thermal-vacuum test facility Chamber B at JSC supported Z2 space suit Carbon Dioxide washout test; and
- SCA's Vertical Motion Simulator at the ARC began the Motion Cue 4 testing for the Federal Aviation Administration (FAA).

WORK IN PROGRESS IN FY 2017

In FY 2017, SCA is assessing the condition and health of the space environments testing capability at GSFC and reviewing and identifying high-risk areas such as loss of controls due to equipment failure.

SCA managed capabilities are supporting NASA's mission by enabling the following:

- SCA's GRC Space Power Facility will support the Orion EM-1 testing series and the SpaceX Falcon 9 Fairing deployment testing;
- SCA's thermal-vacuum test facility JSC Chamber A will continue to support Webb and complete the Thermal Pathfinder test series and prepare for the testing of the Optical Telescope Element/Integrated Science Instrument Module;
- SCA's Vertical Motion Simulator will continue to support the FAA in testing to study differences in pilot performance in several aircraft tasks under different simulator motion configurations; and
- SCA's ARC Arc Jets will continue to support thermal protection system Thermal Protection System development for Orion.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

SCA will assess the condition and health of the space environments testing capability at GRC and review and identify high-risk areas.

SCA will continue to sustain the strategic technical capabilities needed by NASA to achieve successful missions.

STRATEGIC CAPABILITIES ASSET PROGRAM

SCA asset capabilities will continue to support the development, testing, verification, and validation for NASA, DoD, National Oceanic and Atmospheric Administration (NOAA), FAA, and commercial companies in the following areas:

- Simulators: air traffic management technology demonstration, Unmanned Aerial System airworthiness standards and guidelines, motion cueing, loss of control and recovery, enhanced stall modeling and other ongoing development and testing;
- Thermal vacuum and acoustic chambers: Orion, Webb, Mars2020, NASA-Indian Space Research Organization Synthetic Aperture Radar, Commercial Crew and Crew Cargo launch program testing, and other space environmental testing; and
- Arc Jets: thermal protection materials, system development, and qualification testing.

Planned testing in SCA managed assets include:

- SCA's thermal-vacuum test facility JSC Chamber A will complete testing series and transition to stand-by mode for the Webb; and
- SCA's GRC Space Power Facility will continue to support Orion in thermal vacuum and acoustics and vibrations testing.

Program Elements

SCA maintains the skilled workforce and performs the maintenance required to keep essential NASA assets available to meet program requirements.

SIMULATORS

Simulators are critical components of the success of NASA's aeronautics research in the areas of fundamental aeronautics and aviation safety. These capabilities provide scientists and engineers with tools to explore, define, and resolve issues in both vehicle design and missions operations.

This capability includes an array of simulator assets used for the research and development of flight and crewed operations phase:

- The Vertical Motion Simulator and its associated laboratories and equipment located at ARC; and
- The Cockpit Motion Facility and its supporting suite of simulators (the differential maneuvering simulator and the visual motion simulator) and central support facilities for aeronautics and spaceflight vehicle research located at LaRC.

THERMAL VACUUM, VACUUM, AND ACOUSTIC CHAMBERS

This capability includes assets located at AFRC, ARC, GRC, GSFC, JPL, JSC, KSC, LaRC, MSFC, White Sands Test Facility, and Wallops Flight Facility. These assets have a minimum size threshold and, in some cases, can accommodate a complete spacecraft. The acoustic chambers can generate similar noise levels experienced during launch. The thermal vacuum and vacuum chambers can simulate ultra-low pressures and low temperatures experienced in deep space.

STRATEGIC CAPABILITIES ASSET PROGRAM

These chambers are used to perform significant risk mitigation for most NASA payloads launched into space, as well as many payloads in other government agencies, such as NOAA and DoD. Testing performed in these chambers ensures the equipment, sub-systems, and assembled spacecraft will meet the strict requirements of harsh launch and space environments. Recent successful tests in the thermal vacuum and acoustic chambers include NASA's Magnetospheric Multiscale Mission, the European Space Agency's Ariane launch vehicles, and SpaceX's launch vehicle payload fairing separations.

ARC JET

This capability located at ARC includes assets that provide simulated high-temperature, high-velocity environments and support the design, development, test, and evaluation activities of thermal protection materials, vehicle structures, aerothermodynamics, and hypersonic aerodynamics. 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 on atmospheric entry.

HEADQUARTERS BUDGET BY OFFICE

AGENCY MANAGEMENT BUDGET BY HEADQUARTERS OFFICE

	Actual	Estimate	Request	Notional			
($ in millions in full cost)	**FY 2016**	**FY 2017**	**FY 2018**	**FY 2019**	**FY 2020**	**FY 2021**	**FY 2022**
Aeronautics Research	6.4	6.6	6.6	7.0	7.0	7.1	7.1
Human Exploration and Operations	28.5	28.8	28.5	30.2	30.5	30.8	30.8
Science	30.2	30.3	29.5	31.2	31.5	31.8	31.8
Space Technology	4.9	5.4	5.1	5.4	5.5	5.5	5.5
Mission Directorates	**70.0**	**71.0**	**69.7**	**73.8**	**74.5**	**75.2**	**75.2**
Office of the Administrator	7.2	7.0	7.0	7.4	7.5	7.5	7.5
Office of Strategy and Plans	2.6	2.3	2.5	2.5	2.5	2.5	2.5
Chief Engineer	4.6	4.5	4.4	4.7	4.7	4.8	4.8
Chief Financial Office	37.5	36.4	35.5	36.8	37.0	37.2	37.2
Chief Health and Medical Office	1.8	1.8	1.8	1.9	1.9	1.9	1.9
Chief Information Office	8.6	8.9	8.8	9.3	9.4	9.5	9.5
Chief Scientist	1.8	1.8	1.8	1.8	1.9	1.9	1.9
Chief Technologist	1.5	1.5	1.5	1.6	1.6	1.6	1.6
Communications	14.5	14.2	14.3	14.8	14.9	15.0	15.0
Diversity and Equal Opportunity	4.5	4.3	4.2	4.4	4.4	4.5	4.5
Education	2.9	3.0	2.9	3.1	3.1	3.2	3.2
General Counsel	9.9	9.9	9.8	10.2	10.3	10.4	10.4
International and Interagency Relations	12.9	12.9	12.5	13.0	13.1	13.2	13.2
Legislative and Intergovernmental Affairs	3.7	3.7	3.7	3.9	3.9	4.0	4.0
Safety and Mission Assurance	7.3	7.2	6.9	7.4	7.4	7.5	7.5
Small Business Programs	1.9	1.9	1.6	1.7	1.7	1.7	1.7
Staff Offices	**123.2**	**121.1**	**119.2**	**124.4**	**125.4**	**126.3**	**126.3**
NASA Management Office at JPL	8.4	8.4	7.0	8.3	8.3	8.4	8.4
Human Capital Management	8.4	8.1	8.6	9.1	9.2	9.2	9.2
Headquarters Operations	96.5	95.2	103.2	105.1	102.8	100.7	100.7

HEADQUARTERS BUDGET BY OFFICE

	Actual	Estimate	Request	Notional			
($ in millions in full cost)	**FY 2016**	**FY 2017**	**FY 2018**	**FY 2019**	**FY 2020**	**FY 2021**	**FY 2022**
Strategic Infrastructure	15.0	15.8	15.4	16.0	16.1	16.2	16.2
Procurement	11.6	11.5	10.6	11.0	11.1	11.2	11.2
Mission Support Directorate Front Office	3.8	3.8	3.6	3.8	3.8	3.8	3.8
NASA Shared Services Center	4.5	4.8	3.8	5.0	5.3	5.4	5.4
Protective Services	20.5	20.9	20.1	19.9	19.9	20.0	20.0
Mission Support	**168.8**	**168.4**	**172.3**	**178.1**	**176.4**	**174.8**	**174.8**
Total, Agency Management	**361.9**	**360.5**	**361.2**	**376.3**	**376.3**	**376.3**	**376.3**

HEADQUARTERS TRAVEL BUDGET BY OFFICE

HEADQUARTERS TRAVEL BUDGET BY OFFICE

($ in millions in full cost)	Actual FY 2016	Estimated FY 2017	Request FY 2018
Aeronautics Research*	0.6	0.6	0.6
Human Exploration and Operations*	3.0	3.1	3.1
Science*	2.4	2.5	2.5
Space Technology*	0.7	1.2	1.2
Mission Directorates	**6.8**	**7.4**	**7.4**
Office of the Administrator	0.9	0.8	0.8
Office of Strategy and Plans	0.1	0.2	0.2
Chief Engineer	0.6	0.7	0.7
Chief Financial Office	0.7	1.0	1.0
Chief Health and Medical Office	0.1	0.1	0.1
Chief Information Office	0.4	0.8	0.8
Chief Scientist	0.1	0.2	0.2
Chief Technologist	0.8	0.8	0.8
Communications	0.2	0.2	0.2
Diversity and Equal Opportunity	0.1	0.1	0.1
Education*	0.5	0.6	0.2
General Counsel	0.2	0.1	0.1
International and Interagency Relations	0.6	0.5	0.5
Legislative and Intergovernmental Affairs	0.1	0.1	0.1
Safety and Mission Assurance	0.3	0.3	0.3
Small Business Programs	0.1	0.1	0.1
Staff Offices	**5.9**	**6.6**	**6.2**
NASA Management Office at JPL	0.4	0.2	0.2
Human Capital Management	0.7	1.0	1.0
Headquarters Operations	0.1	0.1	0.1
Strategic Infrastructure	0.5	0.4	0.4
Procurement	0.2	0.3	0.3
Mission Support Directorate Front Office	0.1	0.1	0.1

HEADQUARTERS TRAVEL BUDGET BY OFFICE

($ in millions in full cost)	Actual FY 2016	Estimated FY 2017	Request FY 2018
Protective Services	0.2	0.2	0.2
Mission Support	**2.2**	**2.3**	**2.3**
Total, Headquarters Travel Budget	**14.8**	**16.2**	**15.9**

**Travel for the Mission Directorates and Education are funded from their respective appropriation accounts. This chart represents the total travel funding at Headquarters (not just in the SSMS Agency Management program account).*

HEADQUARTERS WORKFORCE BY OFFICE

HEADQUARTERS WORKFORCE BY OFFICE

	Actual				Estimated				Request			
	FY 2016				FY 2017				FY 2018			
	FTE	SES	NC*	WYE	FTE	SES	NC*	WYE	FTE	SES	NC*	WYE
Aeronautics Research	31	7	0	12	33	8	0	11	35	8	0	11
Human Exploration and Operations	137	16	0	36	138	19	0	61	144	19	0	62
Science	152	21	0	64	152	22	0	64	155	22	0	64
Space Technology	27	3	0	5	31	3	0	5	32	3	0	5
Mission Directorates	**347**	**47**	**0**	**117**	**354**	**52**	**0**	**141**	**366**	**52**	**0**	**142**
Office of the Administrator	29	7	7	14	29	6	8	14	29	6	8	14
Office of Strategy and Plans	4	0	0	2	4	0	0	2	4	0	0	2
Chief Engineer	20	4	0	18	20	5	0	18	20	5	0	18
Chief Financial Office	118	10	1	34	118	10	1	34	115	10	1	34
Chief Health and Medical Office	9	2	0	1	9	3	0	1	9	3	0	1
Chief Information Office	41	4	0	67	42	5	0	67	42	5	0	67
Chief Scientist	6	2	0	1	6	1	0	1	6	1	0	1
Chief Technologist	7	1	1	3	8	1	2	3	8	1	2	3
Communications	50	2	3	27	50	1	7	27	50	2	7	27
Diversity and Equal Opportunity	15	2	0	18	15	1	0	18	15	2	0	18
Education	14	3	0	6	14	2	0	6	14	1	0	6
General Counsel	41	6	1	0	41	6	0	0	41	6	0	0
International and Interagency Relations	50	7	1	9	50	7	1	9	49	7	1	9
Legislative and Intergovernmental Affairs	23	1	6	1	23	1	7	1	23	1	6	1
Safety and Mission Assurance	33	6	0	8	33	6	0	8	33	6	0	8
Small Business Programs	5	1	0	4	5	1	0	4	4	1	0	4
Staff Offices	**465**	**59**	**20**	**213**	**467**	**56**	**26**	**213**	**462**	**57**	**26**	**213**
NASA Management Office at JPL	22	1	0	2	22	2	0	2	22	2	0	2
Human Capital Management	33	4	0	14	33	5	0	14	33	5	0	14
Headquarters Operations	94	3	0	339	94	4	9	339	91	4	0	339
Strategic Infrastructure	52	5	0	2	52	5	0	2	51	5	0	2
Procurement	32	4	0	0	32	4	0	0	32	4	0	0
Mission Support Directorate Front Office	15	4	0	2	15	4	0	2	14	4	0	2
Protective Services	50	3	0	8	50	3	0	8	49	3	0	8
Mission Support	**297**	**24**	**0**	**367**	**297**	**27**	**0**	**367**	**291**	**27**	**0**	**367**
Total Agency Management	**1,110**	**130**	**20**	**697**	**1,119**	**135**	**26**	**721**	**1,119**	**136**	**26**	**722**

**NC is Non-Career*

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Construction of Facilities	352.9	--	**408.2**	280.7	280.7	280.7	280.7
Environmental Compliance and Restoration	74.5	--	**87.9**	87.9	87.9	87.9	87.9
Total Budget	**427.4**	**360.7**	**496.1**	**368.6**	**368.6**	**368.6**	**368.6**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Construction of Facilities	352.9	--	**408.2**	280.7	280.7	280.7	280.7
Environmental Compliance and Restoration	74.5	--	**87.9**	87.9	87.9	87.9	87.9
Total Budget	**427.4**	**360.7**	**496.1**	**368.6**	**368.6**	**368.6**	**368.6**
Change from FY 2017			**135.4**				
Percentage change from FY 2017			**37.5%**				

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

Aerial view of Research Support Building at Glenn Research Center (GRC). This facility is the second step in the GRC master plan, allowing for the consolidation of offices across the center.

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 projects and programs with the test, research, and operational facilities required to accomplish their missions. About 82 percent of NASA's infrastructure and facilities are beyond their constructed design life, posing elevated and rising risk to current and future missions. Aging, Apollo-era legacy infrastructure is inefficient and costly to maintain and operate, and assets over 40 years old pose a significant risk to NASA's unique research and development mission. To address these challenges, NASA's programs focuses on reducing and modernizing NASA's infrastructure into fewer, more efficient sustainable facilities.

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 cleanups to protect human health and the environment, and preserve natural resources for future missions.

Together, these construction and remediation activities help ensure that NASA's assets are ready, available, and appropriately sized to conduct NASA's missions.

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

EXPLANATION OF MAJOR CHANGES IN FY 2018

The FY 2018 request increases Exploration CoF for new construction and modifications of existing facilities at the Kennedy Space Center (KSC) necessary to support the Exploration Upper Stage (EUS).

ACHIEVEMENTS IN FY 2016

NASA completed significant infrastructure repair projects, including Repair by Replacement Plum Brook Station Main Gatehouse (GRC), Repair Central Compressed Air System, Phase 1 (GRC), Repair Domestic Water Mains, Phase 1 (GRC), B48 Chiller Replacement (JSC), Upgrade Potable Water Lines, Site-wide (JSC), Revitalize Medium Voltage Electrical Distribution Systems, Industrial and Payload Processing Areas (KSC), Integrated Engineering Services Building (LARC), Upgrades to Fire Station and Emergency Operations Center (LARC), Upgrade Sanitary Sewer System (LARC), Potable Water Supply and Metering (LARC), Express Steam Line Repair (LARC), Repair 14x22 Main Drive (LARC), Renovate East Test Area Industrial Water Distribution System (MSFC), Replace Asbestos Siding Buildings 4755/4619 (MSFC), Revitalize Building Electrical Systems 4619 (MSFC), Revitalize Building 4666 (MSFC), Construct Replacement Building 4260 (MSFC), Revitalize and Repair Chilled Water System 4473 (MSFC), Refurbish and Replace Helium Compressors (SSC), Refurbish Canal Lock Water Replenishment Pumping System (SSC).

NASA initiated projects to repair and revitalize its aging infrastructure. A key recapitalization project is the Langley Research Center Measurement Systems Laboratory to consolidate existing aging laboratories into a smaller efficient and modern research facility. This project will make progress toward correcting deficiencies noted by the National Academies and support core NASA research efforts. Other discrete projects include: Repair Central Compressed Air Equipment (GRC), which, when completed will eliminate schedule delays caused by the frequent breakages of the high-pressure compressed air system, Repair Domestic Water Main (GRC), which repairs/replaces the aging deteriorated underground water piping infrastructure, and the Safety and Reliability Upgrade – Upgrade Institutional Power Systems (KSC).

To reduce the Agency’s footprint, NASA demolished approximately 198,000 square feet of office and warehouse space.

NASA continued the Energy Savings Investments portion of Institutional CoF by completing construction of a Chilled Water Thermal Energy Storage System at KSC; this shifts chilled water production in the industrial area to off-peak electricity rates resulting in reduced energy expenditures. The program began construction to expand the Central Campus solar photovoltaic system at KSC, and initiated heating, ventilation, and air conditioning (HVAC) projects at JSC, GRC, and GSFC that will reduce energy intensity through modernizing and expanding Energy Management Control Systems, implementing efficiency improvements for steam and chilled/hot water systems, and retro-commissioning building systems. The program also initiated projects at JSC and KSC to replace existing lights with high efficiency LEDs and provide occupancy sensors where appropriate.

Programmatic CoF activities made tremendous progress on transitioning facilities to support the Space Launch System (SLS) and Orion Programs for Exploration Missions. At KSC, construction continued in the Vehicle Assembly Building and at Launch Complex 39B to support SLS and Orion, and at the Launch

Abort System Facility the final phase of modifications started. At MSFC, Test stand 4693 and 4697 were designed and construction for SLS. At SSSC, the major construction for SLS on the B-2 Test Stand is nearing completion. At Michoud Assembly Facilities, the SLS program continued construction to transition the facility to support the SLS Core Stage.

For the Deep Space Network Aperture Enhancement Project, Phase I construction in Canberra, Australia, completed the second of two new 34-meter Beam Wave Guide antennas, and Phase II construction broke ground in Madrid, Spain.

NASA also completed a proof-of-concept prototype for the Modular Supercomputing Facility (MSF) at the Ames Research Center (ARC). The prototype demonstrates 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.

Within the ECR program:

- Santa Santa Susana Field Laboratory (SSFL) continued demolition of buildings not associated with test stands and development of work plans for soil cleanup, continued soil, and groundwater cleanup treatability studies, groundwater field investigations, operations of groundwater treatment system and long-term monitoring of groundwater. Cultural resource actions were prepared per the Programmatic Agreement with the State Historic Preservation Office, Native Americans, and consulting parties.
- MSFC began cleanup activities at eight sites where waste oils are managed. MSFC is developing designs for the Industrial Sewer operable unit and monitoring/ characterization of groundwater.
- Glenn Research Center began decontamination and decommissioning activities of its Cyclotron Facility. This work is required per NASA's license with the Nuclear Regulatory Commission.
- White Sands Test Facility (WSTF) continued to operate the plume front and mid-plume front treatment systems to capture and treat contaminated groundwater. They also continued source area investigations and closure activities of the sewage lagoon.
- KSC installed several new groundwater treatment systems, completed extensive contaminated soil removal at various sites, continued sampling of over 400 monitoring wells, and continued operations of existing groundwater cleanup systems.
- At the JPL, the program continued to operate and maintain systems to clean up contaminated groundwater emanating from JPL, and operations and system upgrades to the Lincoln Avenue and Monk Hill drinking water treatment systems.

WORK IN PROGRESS IN FY 2017

Planned Institutional CoF projects will protect the Agency's critical assets, improve mission assurance, reduce mission risk, and maintain mission essential capabilities. These include utility system repairs and replacement of obsolete buildings.

- Commence construction of the Biosciences Collaborative Facility that will consolidate and modernize existing aging technical facilities at ARC. The new complex will support biological research and development initiatives unique to the Agency to support Fundamental Space Biology, Astrobiology/Exobiology, and Synthetic Biology.

- Repair Emergency Power System for Mission Control Center- Emergency Power B48, (JSC), Compressor Station Upgrades (LaRC), Revitalize Building Electrical Systems (4708) (MSFC), and Steam Distribution Replacement (MSFC).
- KSC's Central Campus Phase 1 – construction is ongoing to complete the modernization and consolidation at Kennedy Space Center. These upgrades will incorporate sustainable and energy efficient design.

In the Energy Savings Investments, NASA initiated a project to replace the window walls of the mall area buildings at JSC. This will reduce energy intensity by decreasing solar heat gain and outdoor air infiltration.

Exploration construction activities continue to focus on meeting the first Exploration Mission (EM-1). At KSC, GSDO will continue the ongoing work in the VAB by installing the remaining 3 of 10 platform levels, while completing the EM-2/EUS study for facility modifications required in VAB HB-3 and HB-4. At MSFC, the SLS Program will finish the two structural test stands prior to delivery of the structural test articles in early 2017. Construction will also be finished of the B-2 test stand at SSC in preparation of the core stage 1 delivery.

SCaN will continue the second phase of the DAEP, 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. The DSN will also complete the BWG Antenna Chiller Replacement project. This project will provide reserve chiller systems and three water-cooling, purification, and storage systems for supporting the BWG transmitters throughout the Network.

Facilities at NASA's Michoud Assembly Facility (MAF) sustained significant damage from an EF-3 tornado on February 2, 2017. Damage included major impacts to 5 buildings within the facility and some damage to many other buildings and SLS Ground Support Equipment. The damage has caused at least 2 month slip to the SLS production. Once plans for repairs are clearer, NASA will assess the overall impact to the SLS and Exploration Construction of Facilities program.

Work continues at KSC to repair the facilities damaged by Hurricane Matthew. Emergency repair and recovery to numerous facilities is underway, including repair of the Operations Support Building II, the Booster Fabrication Facility, JJ Railroad Bridge, and Electrical Shop. Design for the full repair to the Utility Annex Building is underway and will be completed to allow construction to begin by the end of FY 2017.

NASA's ECR program includes cleanup activities at all NASA centers, with priority given to protecting human health and the environment in balance with Environmental Protection Agency and state regulatory agreements and requirements. NASA demonstrated this priority at the SSFL, where NASA is continuing its investigation of contaminated groundwater, completing treatability studies and preparing plans for remediation of soils, and demolition of facilities under the State of California consent order.

Construction and Environmental Compliance and Restoration

Key Achievements Planned for FY 2018

Planned construction and environmental activities include:

- Major repair and replacement projects that address deficiencies noted by the National Academies and support core NASA research efforts.
- Commence construction of the following critical recapitalization projects: Instrument Development Facility (GSFC) and the Research Support Building (GRC).
- 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.
- New construction at KSC in the VAB and at the LC-39B to support the new Exploration Upper Stage (EUS) required for EM-2, a manned flight beyond low earth orbit
- Beginning construction of the Modular Supercomputing Facility (ARC).
- Continue 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.
- Continue 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.
- 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.
- Complete demolition. Finalize cleanup plans and begin cleanup of contaminated groundwater and soil, continue operations of groundwater treatment systems, and continued long term monitoring of the groundwater at SSFL under the consent order with the State of California.
- Complete decontamination and decommissioning of the Cyclotron at GRC
- Continue cleanup activities and long-term monitoring at ARC, MSFC, and MAF.
- Continue operations of treatment systems and monitoring at AFRC, GSFC, LaRC, SSC, and WFF.

CONSTRUCTION OF FACILITIES

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Institutional CoF	278.2	--	**280.7**	280.7	280.7	280.7	280.7
Exploration CoF	28.3	--	**95.9**	0.0	0.0	0.0	0.0
Space Operations CoF	36.7	--	**16.6**	0.0	0.0	0.0	0.0
Science CoF	4.6	--	**15.0**	0.0	0.0	0.0	0.0
Aeronautics CoF	5.1	--	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**352.9**	**--**	**408.2**	**280.7**	**280.7**	**280.7**	**280.7**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

The MSFC Steam Distribution System is the second of a two phase project to convert buildings to a more efficient natural gas fired boiler system that reduces operating and maintenance costs.

NASA's CoF program includes programmatic and non-programmatic 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 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.

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 2018

The FY 2018 CoF request includes funding transferred from the Exploration ($95.9M) and Space Operations ($16.6M) accounts to achieve Space Launch System and Space Communications and Navigation (SCaN), and funding transferred from the Science ($15.0M) account to achieve supercomputing capabilities to support all Science missions. Funding associated with all program designs and out-year programmatic construction activities remains in program accounts.

INSTITUTIONAL COF

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	**278.2**	**--**	**280.7**	**280.7**	**280.7**	**280.7**	**280.7**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

Rendering of the Instrument Development Facility at GSFC. This building provides state of the art space for development of instruments and new technology for space flight mass spectroscopic instruments.

NASA’s Institutional CoF program includes projects to reduce risk, increase efficiency, and reduce operational costs

CoF projects that repair and/or improve NASA’s existing facilities reduce facility-related risks to mission success, property, and personnel. NASA prioritizes these projects using a risk-informed process. Projects to increase efficiency support NASA’s core capabilities within a smaller, more efficient footprint. These include replacement of old, obsolete, costly facilities with new, high-performance facilities that consolidate core functions and improve flexibility over the life of the facilities. These replacement facilities are flexible so they can address programmatic requirements, both known and still evolving over the next 40 years.

NASA’s demolition program eliminates obsolete, unneeded infrastructure to improve efficiency and eliminate safety and environmental risks.

EXPLANATION OF MAJOR CHANGES IN FY 2018

None.

ACHIEVEMENTS IN FY 2016

NASA constructs facilities using cost effective life-cycle analytic design methods to meet current Federal requirements. In FY 2016, NASA executed numerous CoF projects, including construction of two new sustainable-rated facilities that provide 21,000 square feet of sustainable area.

INSTITUTIONAL COF

During FY 2016, NASA:

- Demolished approximately 198,000 square feet of office and warehouse space. Demolition of inactive and obsolete facilities eliminates the cost of maintaining old, abandoned facilities in a safe and secure condition.

- Began construction of the following critical projects:
  - Repair Central Compressed Air Equipment, Phase II (GRC)
  - Repair Domestic Water Main, Phase II of II (GRC)
  - Safety and Reliability Upgrades; Upgrade Institutional Power Systems, Phase II of V (KSC)
  - Repair Aircraft Hangar B4802 HVAC Systems (AFRC)
  - Repair Research Aircraft Integration Facility (AFRC)
  - Hangar 4802 Apron Subsurface Replacement (AFRC)
  - Replace Arc Jet Aerodynamic Heating Facility Heat Exchanger (ARC)
  - Replace Roofs, Life Research Laboratory N239 (ARC)
  - Replace Substation 115kV High Voltage Cables (ARC)
  - Replace Primary Electrical System Infrastructure, Greenbelt (GSFC)
  - Utility Reliability Upgrades Mission Operational Complex (GSFC)
  - South Island Electrical Upgrades (GSFC)
  - T-1722 and T-1723 Consolidation (JPL)
  - Repair Central Heating and Cooling Plant Compressed Air System (24) (JSC)
  - Repair Mechanical Systems, Planetary and Earth Sciences Laboratory (31) (JSC)
  - Upgrade Water Wells and Distribution System, WSTF (JSC)
  - Electrical Distribution System Upgrades, Part 3 of 6 (LaRC)
  - Renovate Building 1230 for Avionics Systems Laboratory (LaRC)
  - Revitalize Building Electrical Systems (4711) (MSFC)
  - Revitalize Building Electrical Systems (4755) (MSFC)
  - ATCC (A Test Control Center) HVAC Refurbishment (SSC)
  - Repair Bascule Bridge (SSC)

- Completed construction of the following essential projects:
  - Repair by Replacement Plum Brook Station Main Gatehouse (GRC)
  - Repair Central Compressed Air System, Phase 1 (GRC)
  - Repair Domestic Water Mains, Phase 1 (GRC)
  - B48 Chiller Replacement (JSC)
  - Upgrade Potable Water Lines, Site-wide (JSC)
  - Revitalize Medium Voltage Electrical Distribution Systems, Industrial and Payload Processing Areas (KSC)
  - Integrated Engineering Services Building (LARC)
  - Upgrades to Fire Station and Emergency Operations Center (LARC)
  - Upgrade Sanitary Sewer System (LARC)
  - Potable Water Supply and Metering (LARC)
  - Express Steam Line Repair (LARC)
  - Repair 14x22 Main Drive (LARC)
  - Renovate East Test Area Industrial Water Distribution System (MSFC)

- Replace Asbestos Siding Buildings 4755/4619 (MSFC)
- Revitalize Building Electrical Systems 4619 (MSFC)
- Revitalize Building 4666 (MSFC)
- Construct Replacement Building 4260 (MSFC)
- Revitalize and Repair Chilled Water System 4473 (MSFC)
- Refurbish and Replace Helium Compressors (SSC)
- Refurbish Canal Lock Water Replenishment Pumping System (SSC)
- Continued the Energy Savings Investments portion of Institutional CoF by completing construction of a Chilled Water Thermal Energy Storage System at KSC; this shifts the chilled water production to off-peak electricity rates resulting in reduced energy expenditures. The program began construction to expand the Central Campus solar photovoltaic system at KSC, and initiated HVAC projects at JSC, GRC, and GSFC that will reduce energy intensity through modernizing and expanding Energy Management Control Systems, implementing efficiency improvements for steam and chilled/hot water systems, and retro-commissioning building systems. The program also initiated projects at JSC and KSC to replace existing lights with high efficiency LEDs and provide occupancy sensors where appropriate.

WORK IN PROGRESS IN FY 2017

Significant work in progress includes award to begin construction of Reduce Seismic Risk N266, N240, and N245 (ARC), Replace Arc Jet Diffusers (ARC), Repair Emergency Power System for Mission Control Center, Emergency Power Building 48 (JSC), Revitalize Water & Waste Water Systems, Various Locations, Phase 5 of 6 (KSC), and Refurbish High Pressure Air Dryer System (SSC).

Completed sustainable rated facilities expected in FY 2017 include three projects within the GSFC. At Greenbelt, MD, the Flight Projects Building is an approximately 100,000 sf, multi-story facility supporting 300 staff. At the GSFC WFF, NASA planned two facilities for sustainable certifications in FY 2017. The WFF Island Fire Station is a 16,000 sf two-story emergency response facility relocated north of the launch hazard zone. The facility is required to ensure safe operations for personnel and equipment allowing the Wallops Range to meet emergency response requirements and protect NASA assets. Also at WFF, the Mission Launch Command Center, an approximately 15,000 sf facility is divided into three distinct launch control rooms, each able to function independently. NASA designed all three facilities to meet United States Green Building Council (USGBC) LEED Silver sustainability ratings.

In the Energy Savings Investments, NASA initiated a project to replace the window walls of the mall area buildings at JSC. This will reduce energy intensity by decreasing solar heat gain and outdoor air infiltration.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

NASA is planning to complete several significant infrastructure projects under construction, including:

- Restore Power Supply Reliability of Arc Jet Facility (ARC)
- Replace Arc Jet Diffusers (ARC)
- Reduce Seismic Risk to Bldgs. N226, N240, N244 & N245 (ARC)
- Repair Central Compressed Air Equipment, Phase 2 (GRC)

INSTITUTIONAL COF

- Repair Domestic Water Main, Phase 2 (GRC)
- 9x15 Low Speed Wind Tunnel Phase 1&2 (GRC)
- Airfield Repairs (GSFC)
- Upgrade South Island Electrical Infrastructure (GSFC)
- Utility Reliability Upgrades Mission Operations Complex (GSFC)
- Water Tower Repairs (LaRC)
- Compressor Station Upgrades, Phase 1 (LaRC)
- B1230 Renovations (LaRC)
- Replace Primary Electrical System Infrastructure B24 (GSFC)
- Construct Replacement Building 4221 (MSFC)
- Rehab Site-wide HPG He, GN and Air Distribution, Phase1 (SSC)
- Repair Bascule Bridge (SSC)

NASA will initiate several projects to repair and revitalize its aging infrastructure. These include construction of the Instrument Development Facility at GSFC and the Research Support Building at GRC; with each replacing 3 inadequate, inefficient, and failing facilities while investing in each center's approved Master Plan, and providing consolidation, efficiency improvements, and long term opportunity for other facility deconstruction. To improve inadequate and failing systems, NASA will initiate repairs to restore the coastal shoreline (KSC), and upgrades to the Steam Distribution System at MSFC and Sanitary Sewage System at SSC.

NASA plans to continue Energy Savings Investments that reduce energy cost and consumption in response to more stringent Federal energy requirements.

Institutional Discrete Construction of Facility Projects

Discrete construction of facilities projects have initial cost estimates of $10 million or greater.

Goddard Space Flight Center

Instrument Development Facility
FY 2018 Estimate: $41.3 million; Total Construction Project Cost: $43.3 million (FY 2019 $2.0 million)

This project constructs a state of the art Instrument Development Facility (IDF) to enable the development of required instruments and new technology for space flight mass spectroscopic measurements, replacing facilities whose age and configuration are impeding research and development efforts. NASA will use instruments developed in the IDF for studies of the chemistry of atmospheres and surfaces of distant planets, moons, and small bodies. These instruments have played significant roles on multiple recent missions (e.g., Mars Science Laboratory, Mars Atmosphere and Volatile Evolution Mission, and Lunar Atmosphere and Dust Environment Explorer).

Over the past 10 years, numerous significant flight instrument projects have expanded to multiple complex concurrent projects, exacerbating the inadequacy of the existing facilities. More significantly, advancing technology is critical for research and development activities targeting astrobiology, Mars instrument development, and other planetary instrument development.

Conditions in the facility are marginally adequate for limiting organic contamination as required for the Mars Organic Molecule Analyzer (MOMA) experiment under development for ExoMars, and will be inadequate for technologies under development for missions 5-10 years in the future. These include anticipated Venus probe, Saturn probe, Ocean Worlds, and future Mars surface missions, resulting in a minimum one year delay and/or the inability to deliver within required time or funding limits.

Supports Planetary Research.

Glenn Research Center

GRC Research Support Building
FY 2018 Estimate: $35.3 million; Total Construction Project Cost: $37.3 million (FY 2017 $2.0M)

Constructing a 60,000 square foot energy efficient research support building, which is the second major step in the approved GRC Master Plan toward the new campus Center, will allow the consolidation of research offices across the Center into the Glenn Downtown area and to replace the aging Engineering & Supply Building No. 21 (73,493 square feet), the K Site Test Building No. 2811 (15,835 square feet), and the Reactor Office Building No. 1142 (11,655 square feet).

The original Engineering & Supply Building No. 21, built in 1944 and renovated/expanded in 1968, is inefficient and beyond its useful life. The HVAC system is antiquated, and the indoor air quality is deficient. Mold problems in portions of the building pose health concerns for occupants. The building has no fire suppression system. The new Research Support Building will support the Office of the Orion European Service Module (ESM) Integration Office (EIO), the Exploration Systems Project Office for the Universal Stage Adapter (USA) Program, and Human Capital Management.

The approved GRC Master Plan places a high priority on investing in new, smaller, and more efficient facilities to replace existing high-maintenance and inefficient buildings. This project is an essential step in the sequence of demolition and replacement projects.

Supports Orion.

Kennedy Space Center

Restore KSC Coastal Shoreline, Phase 1
FY 2018 Estimate: $16.0 million; Total Construction Project Cost: $31.0 million (FY 2019 $15.0 million)

This project is the first of two phases to construct a new sand dune along approximately the 4.5+ miles of KSC shoreline required to be restored and plant it with native dune vegetation.

Natural forces have severely eroded KSC’s shoreline and interim fixes have not stabilized the shoreline long term. Storm activity including Hurricane Matthew resulted in loss of beach sand and sand dunes increasing significantly the risk of inland flooding, infrastructure loss and salt water intrusion. Breach of the sand dunes would cause a significant disruption of critical center-wide services and operational support for over a month.

The coastal dunes protect KSC’s facilities and infrastructure including Launch Complex 39A and B from the impact of storm surge and inundation. This project will replace, repair, stabilize, and strengthen the coastal dunes deemed critical for protecting NASA’s key launch complexes. This project will continue the approximately 1/3 of a mile provident test sand dune constructed in 2014. The provident test sand dunes had no significant damage from Hurricane Matthew; whereas, the surrounding dunes were washed away.

NASA does not recommend the No-Action alternative because (absent intervention) it is highly likely that during major storm events the KSC shoreline will experience dune breaches, resulting in inland flooding. KSC Center Management Council, chaired by the Center Director, has identified the KSC Shoreline Infrastructure risk as one of the top three worst risks for KSC. KSC will support numerous ISS cargo re-supply missions via the Commercial contracts, Commercial Crew missions, and at least seven SLS missions (AA-2, EM-2 through EM-7) using the launch pads at KSC over the next 10 years. If a dune breach occurred inland flooding would stop the missions. Shoreline protection is critical to protecting NASA's launch infrastructure. Breach of the sand dunes would cause a significant disruption of critical center-wide services and operational support for well over a month and operational cost impact of several million dollars during this period.

Supports all Kennedy core capabilities including SLS, Orion, and Commercial Space Flight.

Marshall Space Flight Center

Steam Distribution Replacement, Phase 2
FY 2018 Estimate: $16.3 million; Total Construction Project Cost: $32.5 million (FY 2017 $16.2M)

This project is the second of two phases to convert buildings from steam heating to a more efficient natural gas fired boiler system that generates hot water to heat the building. The projects also brings natural gas to these buildings.

Steam at MSFC is mission essential, providing heat to facilities throughout the Center. Failure to implement this project would cause MSFC potentially not having a source of heat past 2021 for the buildings under this Phase 2 project. By agreement with the Redstone Arsenal and the City of Huntsville Alabama (steam supplier), MSFC is expected to have an alternate source of steam by 2022.

This project will increase the center's energy efficiency through conversion to gas heating and eliminating significant steam line heat losses, reducing operating and maintenance costs.

Nearly all MSFC buildings are affected by the steam system. Buildings affected support the International Space Station (ISS) payload operations, and environmental control and life support systems. Losing adequate heat would affect ISS, and Advanced Exploration Systems, Space Launch Systems, Multipurpose Crew Vehicle, Solar Probe Plus, Technology Demonstration Missions, Space Technologies Demonstrations, Exploration Robotic Programs and others. MSFC also serves as the primarily communication hub for email traffic for all NASA personnel, and a failure during the heating session could cause an affected delay to all operating programs until the system was repaired.

Supports all MSFC core capabilities including SLS, ISS, Orion, Planetary Research, and Advanced Exploration Systems.

Stennis Space Center

Sanitary Sewage System Recapitalization
FY 2018 Estimate: $10.3 million

This project refurbishes portions of the sanitary sewer system at SSC.

The SSC sanitary sewage system is more than 50 years old and near the end of its useful life as evidence by the recent history of failures. The total site-wide corrective repair costs have exceeded historical norms over a five-year span, with increasing rates of lift station failures and conveyance system leaks. Storm water intrusion into the conveyance system has become an increasing strain on the treatment systems. In many locations, 50+ year old infrastructure is severely deteriorated. SSC has incurred over $400K for sanitary sewer repairs and investigative measures in its primary Administrative Building (B1100) alone since August 2016. Repair costs will to continue to escalate as failure rates increase due to the end-of-service life of many elements of the sanitary sewer system.

If left unmitigated, continued sewage leaks and untreated wastewater discharge excursions violating permit and regulatory requirements pose risk of EPA and/or the Mississippi Department of Environmental Quality fines of $25,000 per day per incidence. Also, work stoppage at various facilities due to sanitary conditions could cause personnel to be sent home, or rocket development, testing, and research to be affected, delaying certification of flight hardware for SLS.

Supports SLS.

Minor Revitalization and Construction of Facilities

Minor revitalization and construction of facilities projects have initial cost estimates between $1 million and $10 million.

FY 2018 Estimate: $101.0 million

These projects revitalize and construct facilities at NASA facility 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 includes 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 to nine 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:

- Replace Unitary Plan Wind Tunnel (UPWT) Three Stage Compressor Rotor Blades

Armstrong Flight Research Center:

- Revitalize Mission Control Electrical Systems

Glenn Research Center:

- Repair Water Intrusion and Institutional Plumbing, ERB
- Repair Exterior of Engine Research Building West Wing, Building 23

Goddard Space Flight Center:

- I&T Complex Electrical/Mechanical Repairs
- Replace Roofs

Johnson Space Center:

- Safety Upgrades to the Public Water System, White Sands Test Facility Phase I of II
- Repair Sanitary Sewer System

Kennedy Space Center:

- Revitalize Water & Wastewater Systems, Phase 6 of 6

Langley Research Center:

- Steam System Upgrade
- Potable Water Supply Upgrades, Part 2 of 2

Marshall Space Flight Center:

- Revitalize Pressure & Propellant Distribution Systems (Site Wide, Phase 1 of 3)

Stennis Space Center:

- Electrical Repairs to SSC Canal and Navigation Lock Water Replenishment System
- Rehab E-Complex Deluge System

Energy Savings Investments

FY 2018 Estimate: $12.4 million

These important projects focus on improving systems efficiencies and reducing utility costs. 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 11.3-year simple payback period – the time required to recover the initial investment through annual energy cost avoidances.

Failure to implement these projects will affect NASA's ability to meet Executive Order 13693, "Planning for Federal Sustainability in the Next Decade," and will require NASA to continue to pay an estimated annual $1.2 million in utilities expenditures avoided by implementing these projects.

Goddard Space Flight Center:

- Implement HVAC Efficiency Improvements, Wallops Flight Facility, Various Buildings; 8.5-year simple payback

Johnson Space Center:

- Repair and Replace Chilled Water and Steam Piping Insulation; 12.9-year simple payback

Kennedy Space Center:

- Implement Mechanical Upgrades, Various Buildings; 6.6-year simple payback

Marshall Space Flight Center:

- Install Compressed Air Station Heat Recovery, B4607, & Solar Photovoltaic System, B4663; 13.4-year simple payback

Demolition of Facilities

FY 2018 Estimate: $15.4 million

NASA continues to meet its national fiduciary responsibilities, leveraging Agency retained assets to increase their functionality to support mission success while disposing of unneeded Federal real estate-increasing the use of under-utilized assets, minimizing operating costs, and improving energy efficiency.

NASA will use the requested funding to eliminate inactive and obsolete facilities that are no longer required for NASA's Mission. Abandoned facilities pose potential safety and environmental liabilities and are eyesores at the Centers. The Agency must maintain these facilities at minimal levels to prevent increasing safety and environmental hazards, and these recurring maintenance costs impose a drain on the maintenance dollars available at the Centers. Demolishing these abandoned facilities allows the Agency to avoid non-productive operating costs required to keep abandoned facilities safe and secure. Demolition is the most cost-effective way to reduce the Agency deferred maintenance.

NASA identifies facilities for the demolition program through special studies to 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, potential liability, and project execution factors.

Facility Planning and Design

FY 2018 Estimate: $32.7 million

Facility planning and design funds provide 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.

INSTITUTIONAL COF

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.

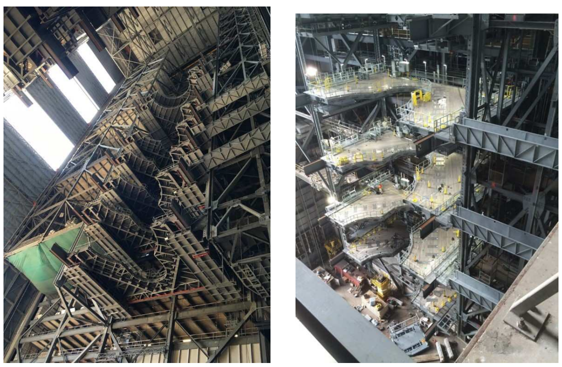
EXPLORATION COF

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	28.3	--	95.9	0.0	0.0	0.0	0.0

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



Left picture shows view from the floor of Vehicle Assembly Building (VAB) at Kennedy Space Center, High Bay 3 looking upward, with 7 of 10 extendable platform halves have been installed. Right picture shows view looking downward of platform installation progress in the VAB High Bay 3 with safety railing and egress ramps installed.

Exploration CoF provides construction required to support SLS, Orion, and Exploration Grounds 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 2018

Request for FY 2018 funding is higher than previous years because of new construction and modifications of existing facilities at the Kennedy Space Center (KSC) necessary to accommodate the Exploration Upper Stage (EUS).

ACHIEVEMENTS IN FY 2016

During FY 2016, NASA made 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 KSC, construction continued in the Vehicle Assembly Building (VAB) and at Launch Complex 39B (LC-39B). In the VAB, Ground Systems Development and Operations (GSDO) installed 7 of 10 platform levels (K-D) in high bay 3 including the mechanical, electrical and plumbing build out, egress ramp accesses, new elevator landing platforms and facility utility subsystems to support SLS launch vehicle and Orion spacecraft processing. At LC-39B, major construction efforts continue on the modifications to the environmental control systems to support SLS and Orion, and the re-bricking the flame trench and fabrication of an all new steel flame deflector. Other significant work at LC-39B included construction of the liquid hydrogen liquid-gas separator tank and reinforcement of the catacomb roof structure that was necessary to accommodate the combined weight of the launch vehicle and mobile launcher. Besides the construction efforts of GSDO in the VAB and the LC-39B, the Orion program started the final phase at the Launch Abort System Facility (LASF) to modify the fire suppression deluge water system, upgrade and modify the fire alarm system and provide electrical hazard proofing in the high bay to accommodate the additional height of Orion service and crew modules stack with the attached launch abort system.

The SLS Program continued progress on constructing the two structural test stands at MSFC to support the SLS Core Stage Qualification Testing. Test Stand 4693 was designed and constructed to test the Core Stage liquid hydrogen (LH2) tank, and most of the major elements of this project were completed in FY 2016 with the erection of both twin steel towers, assembly of the crosshead, and raising of the crosshead to final elevation. Electrical systems have been worked with permanent power established and lighting systems activated. Major construction of Test Stand 4697, designed and constructed to test the SLS liquid oxygen (LOX) tank, was completed in late FY 2016, only minor punch list items remain to be worked with the contractor.

At SSC, Major Construction on the B-2 Test Stand buildout to prepare for the SLS Green Run Testing is ongoing, with completion expected in FY 2017. Work Packages 1 and 2 were completed and contractually closed out finishing all restoration aspects of the test stand. All the major element of Work Package 3 was completed, including the added SLS superstructure that raised the height of the stand up to 335-foot level to accommodate the length of the SLS Core Stage. Major construction for Work Package 4 was also completed, and this package added the Cryogenic Piping for the Liquid Oxygen, Liquid Hydrogen, and the Fire Safety System piping, and the Gaseous Helium, Nitrogen, and High Pressure Air Piping. The B-2 Tarmac replacement package installed rebar structure and pouring the final concrete pad to ready the Tarmac for the larger and heavier SLS loads.

Despite setbacks from the recent tornado damage at the MAF, the SLS program continued construction to transition the facility from legacy tooling and manufacturing of the Space Shuttle External Tank to tooling and manufacturing for the SLS Core Stage. Modifications to the wash probe were completed in Building 110 Cells E & F for Core Stage Tank cleaning and test. Additional modifications continued in Building 103 for assembly and final integration, the scope included upgrading A2 Test Operations Office Area. Finally, the first phase of replacing roof purlins in Building 103 began.

WORK IN PROGRESS IN FY 2017

Exploration Construction of Facilities activities in FY 2017 will continue to focus on meeting the requirements for the launch of the first Exploration Mission - 1 (EM-1). At KSC, GSDO will continue the ongoing work in the VAB by installing the remaining 3 of 10 platform levels, complete work elevator landings in Towers E and F and turn over the facility for activation, verification, and validation. GSDO will also complete duplex control run testing, speed control, front, and rear landing functions and turnover for ground operation, and complete the final pump testing Tower F Level 32 substation. GSDO will complete the EM-2/EUS study for facility modifications required in VAB HB-3 and HB-4.

The SLS Program will finish the two structural test stands at MSFC, and test and checkout the ancillary systems and special test equipment with inspections and make final corrections. Both test stands will be available and ready for test prior to the delivery of the structural test articles. SLS will also finish construction of the B-2 test stand at SSC and will complete activation activity in preparation of the core stage 1 (CS-1) delivery.

At MAF, SLS program will finish modifications to Building 103 and Building 110 to support SLS Core Stage manufacturing. The work in in Building 103 includes the assembly and final integration, fall protection upgrades and GN2/GHe Ports modifications. In Building 110, the work includes Cells E & F Core Stage Tank Cleaning and Test lighting modifications. In Building 103, phase 1 of replacing purlins in the roof will be completed. Work will continue on the replacing Chiller #3, replacing Substations 20A, 43, 63, and 64, repairing and replacing the chilled water and south 50PSI steam distribution piping and first phase of the repairs to the fan house and substation structural supports. Work will be initiated on replacing Substation No. 1, and the second phase of the repairs to the fan house and substation structural support, the second phase of replacing purlins in Building 103 and replace Chiller #6.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

Exploration projects planned in FY 2018 at KSC will be new construction in the VAB and at the LC-39B necessary for the new EUS required for EM-2, a manned flight beyond low earth orbit. Adding an upper stage to the SLS launch vehicle will require moving / modifying four levels of existing platforms and adding two new levels of platforms. It will also require modifications in high bay 4 for the EUS build up prior to integration with the core stage and adding a new Environmental Control System. At LC-39B, a new 1.4 million gallon LH2 sphere will be constructed to provide additional LH2 required for a two-stage launch vehicle. Modifications to the Environmental Control System at LC-39B are also required. There are also three minor construction projects planned at MAF. The minor projects include repairs to B-102 roof, replacing the north 50 psi steam piping in B-103 and the second phase of the repairs to the fan housings in the B-103.

Exploration Discrete Construction of Facilities Projects

Kennedy Space Center
Modifications for SLS Block 1B (EUS)
FY 2018 Estimated: $90.1 million; Total Construction Project Cost: $201.5 million (FY 2019 $89.0 million, FY 2020 $18.9 million, and FY 2022 $3.5 million)

This project modifies selected facility systems in the VAB, LC-39B (Pad-B), and Converter Compressor Facility (CCF) to support the EUS. As SLS technical requirements mature, the Ground Systems Development and Operations Program Office may need to add, delete, or substitute, individual work elements within the project.

The upgrades reconfigure the facilities from their previous shuttle configurations to ones that will support SLS, while increasing the life safety of the facilities and operational efficiency. The VAB modifications reconfigure the high bay to process, integrate, and assemble the SLS launch vehicle. The Pad-B modifications will support SLS, Orion and other Launch vehicles; as they update the deteriorated 40 year old structure and systems. The CCF modifications increase the peak nitrogen and helium flows required for EUS support, while replacing the Apollo facility systems with modern technology.

These repairs and modifications must be completed in time to support future SLS launches because there are no other facilities with the size or capabilities necessary to support SLS assembly operations. Failure to implement this project will seriously affect NASA’s ability to transition and sustain the use of this launch complex to support SLS.

Supports SLS, Orion, and other launch vehicles.

EXPLORATION COF

Minor Revitalization and Construction of Facilities

FY 2018 Estimate: $5.8 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 equivalent to the originally intended and designed capability. Repair and modernization work includes the 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 it can serve its designated purpose, increase its functional capability, or so that it can meet new building, fire, and accessibility codes.

The minor projects below provide critical investments to support refurbishment of infrastructure to support the SLS manufacturing at MAF. During the year, some rearrangement of priorities may be necessary, which may cause a change in some items to be accomplished. These repairs are independent of, and unrelated to damage caused by the recent tornado.

Michoud Assembly Facility

- Repair Roof B-102
- Replace North 50 PSI Steam Piping B-103
- Rehab Fan House B-103 phase 1 of 2

SPACE OPERATIONS COF

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	**36.7**	**--**	**16.6**	**0.0**	**0.0**	**0.0**	**0.0**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

View of the recently completed and operational 34-meter Beam Wage Guide antenna DSS- 36 in Canberra, Australia.

Space Operations CoF provides construction to support Space Communication and Navigation (SCaN), the 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 2018

None.

ACHIEVEMENTS IN FY 2016

FY 2016 marked the accomplishment of two significant milestones for the Deep Space Network (DSN) Aperture Enhancement Project (DAEP). In Canberra, the DSN, Aperture Enhancement Program (DAEP) phase I completed the second of two new 34-meter Beam Wave Guide (BWG) antennas; both operational to support NASA missions. In Madrid, ground breaking and excavation work began for DAEP phase II; construction of two new 34m BWG antennas.

FY 2016 was also a significant year for DSN projects. In Australia, the DSN completed the Canberra Deep Space Communication Complex Site Wide Uninterrupted Power Supply (SWUPS) project increasing the reliability for operations.

At Goldstone, road repairs providing safer access to the Apollo Antenna site were completed. Completion of the first phase of upgrades in eight buildings resulted in significant progess on seismic safety.

Throughout the Network, each complex also experienced improvements at their facilities; the 34 meter BWG Antenna HVAC Chiller Replacement project boosted the reliability for cooling the transmitters at the antenna stations.

Other accomplishments include the commencement of four minor construction projects at KSC, two for 21st Century Space Launch Complex (21CSLC) and one each for the ISS Program and Launch Services Program (LSP). One of the 21CSLC projects provides a new conduit for communications cables from the launch and range complexes to the launch control center and the other replaces the roof on the Launch Equipment Shop. The ISS project is also a roof replacement project that replaces the roof on the Space Shuttle Processing Facility. The LSP project replaces the HVAC and chilled water systems at both Hanger AE and the PHSF.

WORK IN PROGRESS IN FY 2017

SCaN will continue the second phase of the DAEP, 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 (MDSCC). Activity in FY 2017 will include the completion of the excavation efforts for both antenna locations. Also, construction and fabrication of the DSS-56 antenna pedestal and structure will begin.

The DSN will also complete the BWG Antenna Chiller Replacement project. This project will provide reserve chiller systems and three water cooling, purification, and storage systems for supporting the BWG transmitters throughout the Network.

The 34-m BWG Azimuth Track and Wheels Replacement project will continue with DSS-13’s track and wheels. As will the Seismic Upgrade project, to include additional buildings at the Goldstone complex.

The Goldstone Fire Detection Upgrade project will move forward with the much-needed safety improvements, and at Madrid, the Antenna Apron and Subsoil Remediation project will commence.

Work will also continue on four minor constructions projects at KSC. The 21CSLC projects to install a new communications conduit and replace the roof of the Launch Equipment Shop in FY 2017, as will the roof on the SSPF for the ISS Program. The work HVAC and chilled water project for LSP will continue throughout the Fiscal Year.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

SCaN will continue the construction of the two new 34-meter BWG DSS Antennas at the Madrid Complex with completing the first antenna pedestal at DSS-56. Steel fabrication of the antenna structure will also be near completion and prepared for delivery to site. On-site assembly will commence and continue throughout FY 2018. Also, the DSS-53 antenna pedestal work will commence during FY 2018.

At the Goldstone Complex, the replacement Azimuth tracks and wheels will be installed at both DSS-25 and DSS-13 during scheduled down-times. The Seismic Upgrade project will also complete during 2018, bringing key buildings into compliance, and the GDSCC Fire Detection Upgrade project will be well underway.

SPACE OPERATIONS COF

Space Operations Discrete Construction of Facility Projects

Jet Propulsion Laboratory
BWG 34m Antenna (DSS-56 and DSS-53), Madrid, Spain
FY 2018 Estimate: $14.8 million; Total Construction Project Cost: $57.75 million (FY 2019 $1.5 million)

The Deep Space Network (DSN) consists of three complexes located approximately 120 degrees apart on Earth: Goldstone, California; Madrid, Spain; and Canberra, Australia. Construction of these antennas is in the planned Phase 2 of the SCaN DSN Aperture Enhancement Project (DAEP) that was originally scheduled to begin after completion DAEP Phase 1 at Canberra Deep Space Communications Complex (CDSCC). However, the third antenna at CDSCC was delayed because the 70-meter DSS 63 and the 34-meter DSS 54 antennas at Madrid experienced severe concrete degradation in their pedestals. To ensure reliable communications across the spectrum, DAEP Phase 2 was accelerated. In this Phase, two new 34-meter Beam Waveguide antennas will be built in Madrid, Spain, designated as Deep Space Stations (DSS) 56 and 53. The project includes the fabrication and installation of the antenna structures, systems, and supporting facilities and infrastructure.

These projects improve the reliability of NASA's Deep Space Network, and increase the resiliency for mission support in the northern hemisphere. The DAEP allows missions, both robotic and human, to uplink and downlink larger amounts of science and telemetry, tracking, and command data back and forth to Earth. The work anticipates for additional mission loading from projects in development; and is part of a recommended solution to provide additional assets on a routine basis by 2020.

The 70-meter antennas are increasingly in need of substantial maintenance and repairs, and are approaching their operational lifecycles. Without the continued work, the Agency would be at risk of losing valuable data as the existing antennas required significant repair work.

Supports Deep Space research.

Minor Revitalization and Construction of Facilities

FY 2018 Estimate: $1.8 million

The FY 2018 request includes on minor construction project for the Launch Services Program (LSP) for sustainability upgrades that will improve the energy efficiency of buildings 836 and 840 at the Vandenberg Air Force Base (VAFB) launch complex.

Kennedy Space Center

- Energy Efficiency Upgrades to B-836/840, VAFB

SCIENCE COF

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	**4.6**	**--**	**15.0**	**0.0**	**0.0**	**0.0**	**0.0**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

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Artist's rendering of the fully populated modular computing facility, which will house energy efficient supercomputing modules.

Science CoF typically provides construction required to support NASA’s programs in Earth Science, Planetary Science, Astrophysics, and Heliophysics. However, 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 2018

None.

ACHIEVEMENTS IN FY 2016

In FY 2016, NASA completed a proof-of-concept prototype for the MSF at ARC. Rather than meeting computing requirements through the expansion of capability within conventional facilities, this pilot project constructed lower cost modular container-based capability adjacent to the NASA Advanced Supercomputing Facility at ARC. The MSF comprises a well-integrated computing module (including the superstructure of a container and the supporting power distribution and cooling equipment) sitting on top of a concrete pad. The prototype demonstrates 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.

NASA also awarded a contract for procurement and installation of three fuel tanks to improve aircraft operations at the AFRC. In addition to increasing operational efficiency, the new fuel tanks will address significant safety concerns, bringing operations into compliance with local building and fire codes. The project directly benefits NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA), as well as Airborne Research activities in Earth Science.

WORK IN PROGRESS IN FY 2017

In October 2016, site preparation began for the AFRC fuel tank installation. The new tanks are scheduled to be operational in summer 2017.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

In FY 2018, NASA will proceed with the Modular Supercomputing Facility at Ames Research Center, providing the infrastructure and utilities required to support the modular container-based capability.

Science Discrete Construction of Facilities Projects

Ames Research Center
Modular Supercomputing Facility
FY 2018 Estimate: $15.0 million; Total Construction Project Cost: $25.0 million (FY 2017 $2.7 million)

This project provides the infrastructure and utilities to support 16 modular containerized data units that will provide supercomputing capability necessary to meet NASA's mission requirements.

The project provides a flexible, cost effective, energy efficient and environmentally friendly solution to expand NASA's supercomputing capability. This agile, high performance solution has a low life cycle cost, and ensures there is the flexibility to adjust for the fast-changing technology with minimal risk. The project will support an additional 200 percent of current high-end computing capacity, enabling groundbreaking discoveries in all Mission Directorates.

This project is essential in allowing NASA's scientists and engineers to utilize supercomputing to meet NASA's mission goals and objectives. The existing facility cannot support future needs due to constraints in power and cooling

Supports all Mission Directorates.

ENVIRONMENTAL COMPLIANCE AND RESTORATION

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	**74.5**	**--**	**87.9**	**87.9**	**87.9**	**87.9**	**87.9**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

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Before and after of removal of radioactively contaminated equipment at the Glenn Research Center Cyclotron.

NASA's ECR program cleans up hazardous materials and wastes 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 to ensure operation of remedial treatment processes and sites as part of remediation and cleanup measures.

For additional information aboutNASA's ECR program, go to: http://www.nasa.gov/offices/emd/home/ecr.html.

EXPLANATION OF MAJOR CHANGES IN FY 2018

None.

ACHIEVEMENTS IN FY 2016

NASA continued to execute restoration activities at all NASA centers and facilities. NASA accomplished the following notable restoration activities in FY 2016:

- SSFL continued demolition of buildings not associated with test stands and development of work plans for soil cleanup, continued soil, and groundwater cleanup treatability studies, groundwater field investigations, operations of groundwater treatment system and long-term monitoring of groundwater. Cultural resource actions were prepared per the Programmatic Agreement with the State Historic Preservation Office, Native Americans, and consulting parties.

ENVIRONMENTAL COMPLIANCE AND RESTORATION

- MSFC began cleanup activities at eight sites where waste oils were managed. MSFC is developing designs for the Industrial Sewer operable unit and monitoring/ characterization of groundwater.
- GRC began decontamination and decommissioning activities of its Cyclotron Facility. This work is required per NASA's license with the Nuclear Regulatory Commission.
- WSTF continued to operate the plume front and mid-plume front treatment systems to capture and treat contaminated groundwater. They also continued source area investigations and closure activities of the sewage lagoon.
- KSC installed several new groundwater treatment systems, completed extensive contaminated soil removal at various sites, continued sampling of over 400 monitoring wells, and continued operations of existing groundwater cleanup systems.
- At the JPL, the program continued to operate and maintain systems to clean up contaminated groundwater emanating from JPL, and operations and system upgrades to the Lincoln Avenue and Monk Hill drinking water treatment systems.

WORK IN PROGRESS IN FY 2017

NASA's ECR program includes cleanup activities at all NASA centers, with priority given to protecting human health and the environment in balance with Environmental Protection Agency and state regulatory agreements and requirements. NASA demonstrated this priority at the SSFL, where NASA is continuing its investigation of contaminated groundwater, completing treatability studies and preparing plans for remediation of soils, and demolition of facilities under the State of California consent order.

- SSFL continued demolition of structures in areas not associated with the Test Stands. Submit cleanup plans for soil and groundwater. Continue operations of groundwater treatment system and long-term monitoring of groundwater;
- GRC continued decontamination and decommission of the cyclotron building under NRC license termination;
  ARC began landfill remediation and final closure per Federal Facilities Agreement;
- MSFC completed soil cleanup at petroleum sites;
- MAF completed pilot scale remediation of groundwater at the former rinse water impoundments;
- WSTF continued to operate the plume front and mid-plume front treatment systems to capture and treat contaminated groundwater and continue source area investigations and closure activities of the sewage lagoon; and
- Continue operations of treatment systems and monitoring at AFRC, GSFC, LaRC, SSC, and WFF.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

Key projects and achievements in the FY 2018 request include:

- $9.2 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;

ENVIRONMENTAL COMPLIANCE AND RESTORATION

- $10.3 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;
- $10.2 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; and
- $44.0 million for demolition, cleanup of contaminated soils, continued operations of groundwater treatment systems, and continued long term monitoring of groundwater at SSFL in accordance with the State of California.

Program Elements

RESTORATION

Restoration projects address cleanup liabilities at all NASA centers and component facilities. As of the start of FY 2016, known liabilities totaled $1.2 billion with many of the individual cleanup projects estimated to take more than 30 years to complete. NASA policy is to address these liabilities using a “worst first” approach to ensure protection of human health and the environment and to facilitate mission readiness. Plans for FY 2018 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 expects that program priorities may change.

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, and supporting operational activities by ensuring that advances in chemical risk management are incorporated early in mission design phases. For example, NASA is working with the European Space Agency on an international agreement to investigate methods of increasing energy and water resiliency in critical space mission supporting infrastructure to increase the infrastructure reliability.

INSPECTOR GENERAL

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	**37.4**	**37.9**	**39.3**	**39.3**	**39.3**	**39.3**	**39.3**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

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INSPECTOR GENERAL

FY 2018 Budget

Budget Authority (in $ millions)	Actual FY 2016	Enacted FY 2017	Request FY 2018	Notional FY 2019	FY 2020	FY 2021	FY 2022
Total Budget	**37.4**	**37.9**	**39.3**	**39.3**	**39.3**	**39.3**	**39.3**
Change from FY 2017			**1.4**				
Percentage change from FY 2017			**3.7%**				

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FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

For FY 2018, the NASA Office of Inspector General (OIG) requests $39.3 million to support the work of 190 auditors, investigators, analysts, specialists, lawyers, and support staff located at NASA Headquarters in Washington, DC, and 12 other locations throughout the United States.

The OIG conducts audits, investigations, and reviews of NASA programs to prevent and detect fraud, waste, abuse, and mismanagement and to assist NASA management in promoting economy, efficiency, and effectiveness in its programs and operations. 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 annual audit of NASA's financial statements. In its work, OA targets high-risk areas and NASA's top management challenges. OIG audits provide independent assessments and actionable recommendations that help NASA achieve its space exploration, scientific, and aeronautics research missions.

OI pursues 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 management 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 79 percent of its budget on contracts and grants, OI targets its resources to maintaining the integrity of NASA's procurement process and the security of NASA's mission and information systems. In the procurement area, 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 2018

No major changes.

INSPECTOR GENERAL

ACHIEVEMENTS IN FY 2016

In FY 2016, the OIG issued 23 audit products and identified approximately $2.2 million in potential savings for NASA. Audit products included reports examining NASA's:

- Management of Health and Human Performance Risks for Space Exploration;
- Space Technology Portfolio;
- Capabilities, Benefits, and Challenges with International Partnerships;
- Response to SpaceX's June 2015 Cargo Resupply Launch Failure;
- Commercial Crew Program Development and Certification Efforts; and
- Oversight of the Orion Multi-Purpose Crew Vehicle Program.

In FY 2016, 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 $8.7 million in criminal, civil, and administrative penalties and settlements. Approximately $500,000 of these funds were returned directly to NASA. Overall, OI's efforts in FY 2016 resulted in 18 indictments, 24 convictions, 3 civil settlements, 32 administrative actions, and 24 suspensions or debarments.

Examples of OI's work over the past year include:

- An investigation of fraud committed by Educational Advancement Alliance, Inc., and its president ended in convictions of the president, former Pennsylvania Congressman Chaka Fattah, and an associate. The organization received a series of Federal grants, including a $1.8 million grant from NASA to promote science, technology, engineering, and mathematics education. The investigation revealed that Educational Advancement Alliance, Inc., improperly used $100,000 of NASA grant money to pay a campaign debt on Congressman Fattah's behalf. In June 2016, a Federal jury convicted the Congressman and his associates of taking part in a racketeering conspiracy intended to further their political and financial interests by misappropriating Federal, charitable, and campaign funds.

- A Woburn, Massachusetts, company and its president agreed to pay $2.25 million in a civil settlement to resolve allegations the company violated the False Claims Act through a fraudulent scheme that falsified labor costs under Federal contracts and grants, including several with NASA. The contractor received funds under 15 Federal contracts awarded through the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs.

- Through the combined investigative efforts of the OIG, the National Science Foundation, and the Defense Criminal Investigative Service (DCIS), a research professor who made false statements to Government officials to obtain 22 grants and contracts from NASA and other agencies valued at $6.4 million pled guilty to wire fraud and was sentenced to 3 years' probation, paid a $175,000 fine, forfeited $180,000 in funds he and his company improperly received, and was debarred from Government contracting for 3 years. In award proposals, the professor failed to disclose all of his and his corporation's current and pending grants and contracts, thereby overstating the time he and the corporation could devote to the project awards he was applying to receive. He disclosed only 3 months per year of work, when in fact he had already committed to more than 19 months per year of work to various Government agencies. The professor also falsely certified that he was primarily employed by his corporation, when he was employed full-time as a research professor at the University of California, San Diego. The investigation further revealed the professor received more than $1.9 million in salary from 2005 to 2013 from his corporation, due in part to the fraudulently obtained grants and contracts.

- A Lehigh University professor and his wife were sentenced for wire fraud stemming from misuse of a $600,000 SBIR contract with NASA. The professor was sentenced to 1 year imprisonment and fined $3,000 while his wife was sentenced to 3 months imprisonment. In addition, both were ordered to pay $72,000 in restitution to NASA. In their application for SBIR funding, the couple proposed the wife would oversee development of a sensor to help track climate change and supervise researchers in her husband's lab at Lehigh, to which no more than half the work would be subcontracted. An investigation by the OIG disclosed the couple had used their company as a front to funnel Federal money to themselves while the research was actually performed by students and others working in the university lab. NASA suspended the individuals and their company from receiving any Federal contracts.

- A former research professor and his corporation were sentenced to 3 years' probation and fined $175,000 after admitting to fraudulently obtaining millions of dollars in Government grants and contracts. A multi-agency investigation disclosed that the professor made false statements in award proposals to obtain numerous grants and contracts. The corporation entered a guilty plea to felony wire fraud, and the professor entered into a deferred prosecution agreement for his role in the fraud. Additionally, both jointly agreed to forfeit $180,000 that was improperly received as a result of the fraud.

- An Estonian national was sentenced for his role as ringleader in a cybercriminal scheme that infected millions of computer systems worldwide, including NASA systems. He was sentenced to 7 years and 3 months imprisonment and ordered to forfeit $2.5 million.

- A Romanian national was sentenced for conspiracy to commit computer intrusion and bank fraud. The violations stemmed from the spread of Gozi Malware, which infected numerous Government computer systems, including NASA systems. The subject was sentenced to 3 years and 1 month imprisonment and forfeited $6.9 million.

WORK IN PROGRESS IN FY 2017

In the first six months of FY 2017, the OIG has issued audit reports examining NASA's efforts to "right-size" its workforce, facilities, and other supporting assets; the security of industrial control systems within NASA's critical and supporting infrastructure; the security of its cloud computing services; and its management of the Mars 2020 Rover Project. During the remainder of the fiscal year, we will continue to conduct audits, reviews, and investigations of NASA programs and operations to prevent and detect fraud, waste, abuse, and mismanagement and to assist NASA in promoting economy, efficiency, and effectiveness. Projects on which our auditors are currently working include NASA's plans for human exploration beyond low Earth orbit; information technology governance; management of its security operations center, and management of its spare parts inventory.

Ongoing OI work includes proactive initiatives designed to identify a variety of acquisition and procurement fraud schemes. Additionally, representatives from both OI and OA are working together to use data analytics and information technology resources to help identify indicators of potential fraudulent activity.

KEY ACHIEVEMENTS PLANNED FOR FY 2018

Going forward, the OIG will continue to focus its audit work in the areas the OIG identifies as NASA's top management and performance challenges. In a November 2016 report, we listed those challenges as:

- Positioning NASA for Deep Space Exploration;
- Managing the International Space Station and the Commercial Cargo and Crew Programs;
- Managing NASA's Science Portfolio;
- Overhauling NASA's Information Technology Governance;
- Securing NASA's Information Technology Systems and Data;
- Addressing NASA's Aging Infrastructure and Facilities;
- Ensuring the Integrity of the Contracting and Grants Processes; and
- Ensuring the Continued Efficacy of the Space Communications Networks.

The OIG's FY 2018 request is $39.3 million, and includes the following:

- $33 million (84 percent) for 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 accounts, and Thrift Savings Plan accounts. Salaries include the required additional 25 percent law enforcement availability pay (LEAP) for criminal investigators;
- $1.1 million (3 percent) for travel, per diem, and related expenses;
- $2.4 million (6 percent) to fund the required annual audit of NASA's financial statements; and $2.8 million (7 percent) for equipment, training, government vehicles, special equipment for criminal investigators, transit subsidies, and IT equipment unique to the OIG.[1]

NASA OIG is requesting a change from $500,000 in two-year funding to all FY 2018 funding as two-year funding in order to coincide with NASA's appropriations and more efficiently and effectively conduct audits and investigation of NASA's programs and operations by streamlining financial, procurement, and other year-end processes in NASA's centralized systems and multi-year budget environment.

[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 CIGI.*

Supporting Data

FUNDS DISTRIBUTION BY INSTALLATION

FUNDS BY MISSION BY NASA CENTER

Budget Authority ($ millions)	**FY 2018***
Science	197.4
Aeronautics	112.9
Space Technology	42.5
Exploration	36.7
Space Operations	34.0
Education	0.0
Safety, Security, and Mission Services	204.6
Construction and Environmental Compliance and Restoration	28.0
Ames Research Center (ARC) Total	**656.1**
Science	53.7
Aeronautics	72.1
Space Technology	13.0
Exploration	17.6
Space Operations	0.1
Education	0.0
Safety, Security, and Mission Services	61.6
Construction and Environmental Compliance and Restoration	10.2
Armstrong Flight Research Center (AFRC) Total	**228.2**
Science	31.5
Aeronautics	145.6
Space Technology	76.4
Exploration	103.2
Space Operations	61.0
Education	0.0
Safety, Security, and Mission Services	213.3
Construction and Environmental Compliance and Restoration	46.5
Glenn Research Center (GRC) Total	**677.4**
Science	2,256.2
Aeronautics	0.0
Space Technology	80.3
Exploration	10.5
Space Operations	225.7
Education	0.0
Safety, Security, and Mission Services	409.3
Construction and Environmental Compliance and Restoration	54.6
Goddard Space Flight Center (GSFC) Total	**3,036.6**

FUNDS DISTRIBUTION BY INSTALLATION

Budget Authority ($ millions)	FY 2018*
Science	1,458.7
Space Technology	44.3
Exploration	1.4
Space Operations	169.6
Education	0.0
Safety, Security, and Mission Services	15.1
Construction and Environmental Compliance and Restoration	25.0
Jet Propulsion Laboratory (JPL) Total	**1,714.0**
Science	20.2
Aeronautics	0.0
Space Technology	13.9
Exploration	1,242.7
Space Operations	3,036.4
Education	0.0
Safety, Security, and Mission Services	355.7
Construction and Environmental Compliance and Restoration	29.9
Johnson Space Center (JSC) Total	**4,698.8**
Science	407.3
Space Technology	9.8
Exploration	478.7
Space Operations	859.4
Education	0.0
Safety, Security, and Mission Services	360.3
Construction and Environmental Compliance and Restoration	124.4
Kennedy Space Center (KSC) Total	**2,240.0**
Science	217.1
Aeronautics	235.3
Space Technology	35.3
Exploration	35.6
Space Operations	7.9
Education	0.0
Safety, Security, and Mission Services	276.4
Construction and Environmental Compliance and Restoration	14.1
Langley Research Center (LaRC) Total	**821.7**

FUNDS DISTRIBUTION BY INSTALLATION

Budget Authority ($ millions)	FY 2018*
Science	185.7
Space Technology	52.0
Exploration	1,759.6
Space Operations	199.8
Education	0.0
Safety, Security, and Mission Services	425.6
Construction and Environmental Compliance and Restoration	77.8
Marshall Space Flight Center (MSFC) Total	**2,700.5**
Science	883.0
Aeronautics	58.1
Space Technology	308.7
Exploration	186.7
Space Operations	111.5
Education	37.3
Safety, Security, and Mission Services	456.0
Construction and Environmental Compliance and Restoration	63.6
Office of Inspector General	39.3
NASA Headquarters (HQ) and Inspector General (IG) Total	**2,144.2**
Science	1.2
Space Technology	2.4
Exploration	61.4
Space Operations	35.4
Education	0.0
Safety, Security, and Mission Services	52.3
Construction and Environmental Compliance and Restoration	22.0
Stennis Space Center (SSC) Total	**174.7**
Total	**19,092.2**

** 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 2018 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 benefit society, address contemporary environmental and social issues, lead or participate in emerging technology opportunities, collaborate and strengthen the capabilities of commercial partners, and communicate the challenges and results of Agency programs and activities. The civil service staffing levels proposed in the FY 2018 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. However, the mix of skills and distribution of workforce across the Agency is necessarily changing.

NASA continues to adjust its workforce size and mix of skills to address changing mission priorities, with an emphasis on industry and academic partnerships, transferring work in-house from on- and near-site support contracts, and operating in a leaner fiscal environment. A civil service workforce is critical for conducting mission-essential work in research and technology. As NASA continues to seek to have the right workforce to meet its requirements, some reduction to workforce levels is necessary. NASA will make modest reductions to the size of the civil service workforce with a decrease of approximately 30 full-time equivalents from FY 2017 to FY 2018, bringing the civil service workforce to approximately 17,116 full-time equivalents (FTEs). In addition, approximately 33,100 non-civil service work-year equivalents support NASA.

NASA will continue to explore opportunities across the Agency to insource work and 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 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

	Actual	Estimate	Request	Notional			
	FY 2016	**FY 2017**	**FY 2018**	**FY 2019**	**FY 2020**	**FY 2021**	**FY 2022**
ARC	1,125	1,179	1,176	1,173	1,173	1,173	1,173
AFRC	532	537	535	533	533	533	533
GRC	1,514	1,537	1,538	1,534	1,534	1,534	1,534
GSFC	3,156	3,250	3,245	3,243	3,243	3,243	3,243
JSC	2,951	2,962	2,960	2,956	2,956	2,956	2,956
KSC	1,969	1,967	1,954	1,950	1,950	1,950	1,950
LaRC	1,793	1,809	1,805	1,801	1,801	1,801	1,801
MSFC	2,290	2,325	2,326	2,322	2,322	2,322	2,322
SSC	302	304	302	300	300	300	300
HQ	1,122	1,119	1,119	1,129	1,139	1,139	1,139
NSSC	131	156	156	156	156	156	156
NASA Total*	**16,884**	**17,145**	**17,116**	**17,096**	**17,106**	**17,106**	**17,106**
OIG	191	213	213	213	213	213	213

**Totals may not add due to rounding. All actuals and estimates include direct-funded and reimbursable FTE.*
NOTE: Funds will not be fully distributed to Centers until after final acquisition decisions are made. Thus, Center FY 2018 allocations should not be considered final or directly comparable to prior year allocations.

CIVIL SERVICE FULL-TIME EQUIVALENT DISTRIBUTION

FY 2018 FTE DISTRIBUTION BY ACCOUNT BY CENTER

	Science	Aeronautics	Space Technology	Exploration	Space Operations	Education	Safety, Security, and Mission Services	Reimbursable / Working Capital Fund**	OIG	NASA-Funded Total	Agency TOTAL
ARC	136	251	96	99	30	3	542	19		1,157	1,176
AFRC	102	174	16	15	0	3	213	12		523	535
GRC	79	381	135	201	135	4	601	3		1,535	1,538
GSFC	1,205	-	138	16	133	4	1,549	200		3,045	3,245
JSC	31	-	64	718	1,287	4	857	-		2,960	2,960
KSC	1	-	50	554	489	4	856	1		1,953	1,954
LaRC	184	539	117	130	6	4	810	15		1,790	1,805
MSFC	130	-	97	856	229	4	1,010	-		2,326	2,326
SSC	7	-	6	62	40	2	168	19		284	302
HQ	12	-	7	-	-	-	1,100	-		1,119	1,119
NSSC	-	-	-	-	-	-	-	156		-	156
NASA Total*	**1,886**	**1,345**	**725**	**2,651**	**2,349**	**30**	**7,705**	**424**	**-**	**16,691**	**17,116**
OIG									213	213	213

**Totals may not add due to rounding*

***Includes 161 FTE funded by Working Capital Fund; and 263 FTE funded by reimbursable customers*

NOTE: Funds will not be fully distributed to Centers until after final acquisition decisions are made. Thus, Center FY 2018 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 by focusing on streamlining operations, measuring performance, and improving customer satisfaction.

NASA's WCF is comprised of four entities:

- NASA Shared Services Center (NSSC);
- Solutions for Enterprise-Wide Procurement (SEWP) Government-Wide Acquisition Contract;
- Information Technology (IT) Infrastructure Integration Program (I3P); and
- National Center for Critical Information Processing and Storage (NCCIPS).

WORKING CAPITAL FUNDS BUDGET SUMMARY

Spending Authority from Offsetting Collections ($ millions)	Actual FY 2016	Estimate FY 2017	Request FY 2018
NSSC	73	65	67
SEWP	11	17	19
I3P	330	390	386
NCCIPS	-	20	20
Total Spending Authority	**414**	**492**	**492**
Unobligated Brought Forward, Oct. 1	10	13	19
Recoveries of Prior Yr. Unpaid Obligations	4	5	0
Total Budgetary Resources	**428**	**510**	**511**
NSSC	73	69	69
SEWP	11	16	19
I3P	331	390	386
NCCIPS	-	16	24
Total Obligations	**415**	**491**	**498**
Unobligated Balance (end-of-year)*	**13**	**19**	**13**

Unobligated balance end-of-year is budgetary resources less obligations

NASA SHARED SERVICES CENTER (NSSC)

NSSC opened in March 2006 to provide centralized administrative processing services and customer contact center operations for support of human resources, procurement, financial management, Agency IT, and Agency business support services. NASA established NSSC, a function under the NASA Headquarters Mission Support Directorate, as a public/private partnership. NSSC has awarded its major business management and IT services contract to CSRA (Computer Sciences Corporation merged with SRA International). Typical expenditures are related to civil service workforce, support contractor, other direct procurements, and Agency training purchases.

NSSC is located on the grounds of Stennis Space Center (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 2018, NSSC will continue to offer similar services as in FY 2017 with no significant scope changes anticipated.

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 2017, SEWP quotes have a 15-percent savings for any Federal customer using SEWP contracts versus similar General Services Administration (GSA) contracts. In addition, SEWP offers a low surcharge to recover NASA's costs to operate the program with an average 0.39 percent fee as compared to the Government-wide standard of 0.75 percent. SEWP revenue is generated solely from the surcharge fees on all transactions processed. For FY 2017, the Federal Government is projected to save about $11.6 million in service fees, based on the difference between GSA and SEWP surcharge fees.

IT INFRASTRUCTURE INTEGRATION PROGRAM (I3P)

WCF operations supporting I3P began in early FY 2012. WCF enables I3P to improve the efficiency and economy in which contract services and management are provided to support NASA's IT strategic initiatives and to increase visibility into NASA's IT budget and expenditures. Under I3P, NASA has consolidated 19 separately managed contracts into five centrally managed contracts as described below:

- 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 streamlining budgeting, funding, and costing of I3P services; achieving transparency through 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 2018 anticipated funding level, the I3P WCF will continue to offer similar services as in FY 2017.

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 SSC. 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 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 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 (DOT), and Department of Housing and Urban Development (HUD). During FY 2018, NCCIPS will continue to offer similar services as in FY 2017 with no significant scope changes anticipated.

BUDGET BY OBJECT CLASS

Code	FY 2018 Estimated Direct Obligations ($ millions) Object Class	Science	Aeronautics	Space Technology	Exploration	Space Operations	Education	Safety, Security, and Mission Services	Construction & Environmental Compliance & Restoration	Office of Inspector General	NASA Total
11.1	Full-time permanent	255	170	94	337	308	4	993	0	24	2,185
11.3	Other than full-time permanent	4	3	1	2	2	0	20	0	0	33
11.5	Other personnel compensation	2	0	0	1	2	0	29	0	0	35
11.8	Special personal service payments	0	0	0	1	0	0	1	0	0	2
11.9	*Subtotal Personnel Compensation*	*261*	*174*	*95*	*341*	*312*	*4*	*1,044*	*0*	*24*	*2,255*
12.1	Civilian personnel benefits	80	53	30	109	98	1	314	0	10	695
13.0	Benefits to former personnel	0	0	0	0	0	0	1	0	0	2
Personnel Compensation & Benefits		**340**	**227**	**125**	**450**	**411**	**5**	**1,359**	**0**	**34**	**2,952**
21.0	Travel & transport. of persons	23	5	5	13	12	0	20	0	1	79
22.0	Transportation of things	5	0	4	25	1,487	0	3	0	0	1,524
23.1	Rental payments to GSA	0	0	0	0	0	0	14	0	0	14
23.2	Rental payments to others	6	0	0	0	3	0	13	0	0	22
23.3	Communications, utilities & misc.	4	4	0	6	4	0	58	1	0	77
24.0	Printing & reproduction	1	0	0	0	0	0	3	0	0	4
25.1	Advisory & assistance services	74	12	25	377	77	6	273	22	0	866
25.2	Other services	91	39	27	34	128	3	221	32	3	578
25.3	Other purchases of goods & services from Government accounts	222	6	9	34	26	0	45	51	1	394
25.4	Operation & maintenance. of facilities	10	17	3	95	37	0	217	84	0	463
25.5	Research & development contracts	4,063	214	409	2,627	2,228	1	155	20	0	9,716
25.6	Medical care	0	0	0	0	0	0	7	0	0	7
25.7	Operation & maintenance of equipment	99	33	14	134	260	1	354	7	0	902
26.0	Supplies & materials	29	11	7	19	19	0	14	1	0	100
31.0	Equipment	33	25	9	45	17	0	37	1	0	167
32.0	Land & structures	1	1	1	19	4	0	22	277	0	325
41.0	Grants, subsidies, & contributions	711	30	41	56	28	21	15	0	0	902
99.5	Below reporting threshold	0	0	0	0	0	0	0	0	0	0
Other Object Classes		**5,372**	**397**	**554**	**3,484**	**4,330**	**32**	**1,471**	**496**	**5**	**16,140**
NASA Total, Direct*		**5,712**	**624**	**679**	**3,934**	**4,741**	**37**	**2,830**	**496**	**39**	**19,092**

**Totals may not add due to rounding*

STATUS OF UNOBLIGATED FUNDS

The table below displays actual and estimated unobligated balances of direct discretionary budget authority in each NASA appropriation 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 2016 or FY 2017 amounts to make them comparable to the budget structure underlying the FY 2018 request.

UNOBLIGATED FUNDS SUMMARY BY APPROPRIATIONS ACCOUNT

Budget Authority ($ millions)	**Unobligated Balances Sep. 30, 2016**	**Estimated Unobligated Balances Sep. 30, 2017**	**Estimated Unobligated Balances Sep. 30, 2018**
Science	301	287	290
Aeronautics	12	21	19
Space Technology	71	34	45
Exploration	43	58	54
Space Operations	102	184	163
Education	11	24	21
Safety, Security, and Mission Services	24	21	23
Construction and Environmental Compliance and Restoration	130	98	118
Science, Exploration, & Aeronautics	0	0	0
Office of Inspector General	1	1	1
NASA Total*	**695**	**728**	**734**

**Totals may not add due to rounding*

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 2017 to FY 2018 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 each individual program offices: Aeronautics, Exploration, Space Operations, Science, Space Technology, and Education at the NASA centers under Safety, Security, Mission Services (SSMS) fund appropriation for reimbursable agreement authorities: Space Act, Economy Act, Commercial Space Launch Act, and Commercial Space Competitiveness Act. Supporting data for Enhanced Use Leasing (EUL) and National Historic Preservation Act (NHPA) is provided in the respective sections below.

REIMBURSABLE ESTIMATES BY APPROPRIATIONS ACCOUNT

Spending Authority from Offsetting Collections	Actual	Estimate	Request
($ millions)	**FY 2016**	**FY 2017**	**FY 2018**
Safety, Security, and Mission Services (non-EUL)	2,579.5	2,691.8	2,515.3
Aeronautics	*94.3*		
Safety, Security, Mission Svcs.	*89.0*		
Exploration	*118.5*		
Space Operations	*245.5*		
Science	*2,028.8*		
Space Technology	*1.5*		
Education	*1.9*		
Safety, Security, and Mission Services (EUL)	15.0	16.8	14.4
Safety, Security, and Mission Services (NHPA)	17.8	17.3	18.2
Office of Inspector General	0.9	1.4	1.1
Total	**2,613.2**	**2,727.3**	**2,549.0**

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 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 2018 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 FY 2018 EUL ACTIVITY

FY2018 EUL Expenses and Revenues ($ Thousands)	ARC	GSFC	JPL(NMO)	KSC	MSFC	SSC	Agency	Total
Base Rent	7,453.8	54.6	99.3	123.0	269.8	80.5	288.9	8,369.9
Institutional Support Income	821.8	7.4	-	14.0	-	7.7		850.9
Additional Reimbursable Demand Services Requested by Lessees (including overhead)	5,142.4	-	-	58.0	-	15.0	-	5,215.4
Total Lease Income	**13,418.0**	**62.0**	**99.3**	**195.0**	**269.8**	**103.2**	**288.9**	**14,436.2**
Institutional Support Costs	(821.8)	(7.4)	-	(14.0)	-	(0.3)	-	(843.5)
Lease Management and Administration	(851.5)	-	-	-	(6.6)	(1.4)	-	(859.5)
Tenant Building Maintenance and Repair	(1,064.9)	-	-	-	(128.4)	(6.0)	-	(1,199.3)
Cost to Fulfill Reimbursable Demand Services (including overhead)	(5,142.4)	-	-	(58.0)	-	(15.0)	-	(5,215.4)
Total Cost Associated with Leases	**(7,880.6)**	**(7.4)**	**-**	**(72.0)**	**(135.0)**	**(22.7)**	**-**	**(8,117.7)**
Net Revenue from Lease Activity	**5,537.4**	**54.6**	**99.3**	**123.0**	**134.8**	**80.5**	**288.9**	**6,318.5**
Beginning Balance, Capital Asset Account	**256.5**	**-**	**183.8**	**185.5**	**-**	**47.5**	**2,478.5**	**3,151.8**
Net Revenue from Lease Activity Retained at Center	**3,599.3**	**35.5**	**64.5**	**80.0**	**87.6**	**52.3**	**2,399.3**	**6,318.5**
Total Available, Capital Assest Account	**3,855.8**	**35.5**	**248.3**	**265.5**	**87.6**	**99.8**	**4,877.8**	**9,470.3**
Planned Maintenance, Various Buildings	(2,035.8)	-	-	-	(17.6)	-	-	(2,053.4)
Replace Roofs on Varous Buildings	(1,520.1)	-	-	-	(50.0)	-	-	(1,570.1)
Misc. Renewable Solar Energy Expansion	-	-	-	(132.5)	-	-	-	-
Replace Bldg 1 main steam condensate piping	-	(35.5)	-	-	-	-	-	(35.5)
Upgrade Lighting Systems (Green Project)	-	-	-	-	(20.0)	-	-	(20.0)
Energy and Sustainability Upgrades, Various Buildings (Various Centers)	-	-	-	-	-	(47.5)	(3,000.0)	(3,047.5)
Capital Asset Account Expenditures	**(3,555.9)**	**(35.5)**	**-**	**(132.5)**	**(87.6)**	**(47.5)**	**(3,000.0)**	**(6,859.0)**
Capital Asset Account Ending Balance	**299.9**	**-**	**248.3**	**133.0**	**-**	**52.3**	**1,877.8**	**2,611.3**
In Kind Activity	**131.5**	**-**	**-**	**-**	**-**	**-**	**-**	**131.5**

ENHANCED USE LEASING

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 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 2018. NASA currently expects total rental income of $18.2 million. Of the total rental income of $18.2 million, $9.5 million represents net revenue from lease activities. The net revenue amount of $9.5 million will be used for historic building maintenance and repairs for historic properties at ARC, as well as for other properties throughout the Agency.

FY2018 NHPA Expenses and Revenues ($ thousands)	**ARC**
Base Rent	15,500.0
Institutional Support Income	2,707.4
Total Rental Income	**18,207.4**
Institutional Support Costs	(8,296.0)
Lease Management and Administration	(400.3)
Total Cost Associated with Leases	**(8,696.3)**
Net Revenue from Lease Activity	**9,511.1**
Deferred Maintenance for Building 19 Lodge	(3,067.5)
Deferred Maintenance & Preservation Repair for Building 2, Core and Shell	(2,868.0)
Deferred Maintenance & Preservation Repair for Unitary Plan Wind Tunnel	(2,833.6)
Develop Facilities Requirements Document for Historic Preservation for Building N243	(315.0)
Capital Asset Account Expenditures	**(9,084.1)**
Capital Asset Account Ending Balance	**427.0**
Reimbursable Demand Services Requested by Lessees	2,526.4
Cost to Fulfill Reimbursable Demand Services	(2,526.4)
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 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.

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:

	Actual	Estimate	Request		Notional		
Budget Authority ($ millions)	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Exploration ISS Research	171	163	173	178	196	194	194
Non-Exploration ISS Research	198	194	181	197	232	238	238
Total	**368**	**357**	**354**	**375**	**428**	**433**	**433**
Percent of Non-Exploration to Total	54	54	51	52	54	55	55

The amounts included for FY 2016 reflect actuals, FY 2017 through FY 2022 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 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), the Alpha Magnetic Spectrometer (AMS) and the applicable MUSS funding. CASIS is the organization selected by NASA to manage non-NASA use of the ISS National Laboratory. AMS is a particle physics and astrophysics experiment on ISS which is searching for dark matter, anti-matter, and strange matter.

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	Notional			
Budget Authority ($ millions)	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Safety and Mission Assurance (AMO)	49.7	49.6	49.8	49.8	49.8	49.8	49.8
Institutional Operational Safety (CMO)	32.2	37.4	38.8	39.6	39.6	39.6	39.6
SMA Technical Authority (CMO)	48.7	49.5	51.1	52.4	52.4	52.4	52.4
Agency-wide Safety Oversight	**130.6**	**136.5**	**139.7**	**141.8**	**141.8**	**141.8**	**141.8**
Program Specific*	**300**	**300**	**300**	**300**	**300**	**300**	**300**
NASA Total, Safety	**430.6**	**436.5**	**439.7**	**441.8**	**441.8**	**441.8**	**441.8**

* 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 participates in forums that provide advice to the Administrator, Mission Directorates, Program Managers and Center Directors who are ultimately accountable for the safety and mission success of all NASA programs, projects, and operations. Specific program responsibility includes, 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 8715.1, NASA Safety and Health Handbook Occupational Safety and Health Programs, NPR 8715.3, 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 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

The Physicians' Comparability Program permits agencies to provide allowances to certain Federal physicians who enter into service agreements with their agencies to address recruitment and retention problems. Physicians' comparability allowances (PCAs) are critical to NASA's ability to retain flight surgeons and physicians, as well as support NASA's goal of maintaining a stable, high quality physician workforce. NASA's physicians are required to acquire and maintain specialized experience vital to supporting the Agency's missions on the ISS. JSC, NASA's primary user of PCAs is located in Houston, Texas and competes with some of the best medical facilities in the country. The following report summarizes NASA's use of this authority.

PCA DATA SUMMARY

		Actual	Estimate	Request
		FY 2016	**FY 2017**	**FY 2018***
1) Number of Physicians Receiving PCAs		25	24	25
2) Number of Physicians with One-Year PCA Agreements		25	24	25
3) Number of Physicians with Multi-Year PCA Agreements		0	0	0
4) Average Annual PCA Physician Pay (without PCA payment)		$160,476	$157,077**	$166,425***
5) Average Annual PCA Payment		$19,194	$20,992	$19,352
6) Number of Physicians Receiving PCAs by Category (non-add)	Category I Clinical Position	22	23	24
	Category II Research Position	0	0	0
	Category III Occupational Health	1	1	1
	Category IV-A Disability Evaluation	0	0	0
	Category IV-B Health and Medical Admin.	2	0	0

**FY 2018 data will be approved during the FY 2019 Budget cycle.*

***Based on estimated 1.6% pay increase in 2017*

****Based on estimated 1.6% pay increase in 2018*

MAXIMUM ANNUAL PCA AMOUNT PAID TO EACH CATEGORY OF PHYSICIAN

The allowance amount authorized will be the minimum amount necessary to address the recruitment and retention problems, noted below, and will be determined by considering the factors listed in 5 CFR 595.105(a). Allowance amounts may not exceed:

- $14,000 per annum if the employee has served as a Government physician for 24 months or less;
- $24,000 per annum if the employee has served as a Government physician for 24-48 months; or
- $30,000 per annum if the employee has served as a Government physician for more than 48 months.

PHYSICIANS' COMPARABILITY ALLOWANCE

RECRUITMENT AND RETENTION ISSUES

Category I - Clinical Positions

NASA currently has 22 physicians in this category, all located at Johnson Space Center in Houston, TX. There are a number of recruitment and retention challenges at Johnson Space Center (JSC) in Houston, TX.

- 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.
- JSC's clinical resources continue to focus on support of the International Space Station crew (operating 24/7), support of the active astronaut corps and the operation of the Lifetime Surveillance of Astronaut Health program (which includes all retired astronauts). Physicians at JSC are also using their expertise in aerospace medicine to develop requirements for both the Commercial Crew Program and the Orion Spacecraft development program.
- 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. PCA plays a key part in retaining them.

PCA is an important tool in recruiting new physicians, as the General Schedule salary offered is consistently lower than salaries in the private sector. JSC is planning to hire 2-3 physicians in the next two years in order to meet the Agency's needs. Currently, 32% of JSC's physicians are retirement eligible and in the next five years, 50% will become eligible. JSC must continue to concentrate on retaining physicians and having the capability to fill positions that may become vacant due to resignations and/or retirements. Being able to offer PCA has become increasingly critical to NASA in competing with the private sector for the most qualified physicians.

Category III - Occupational Health

Goddard Space Flight Center (GSFC) in Greenbelt, MD hired one physician in this category in FY 2016. Recruiting and retaining physicians in the Maryland/Washington, DC metropolitan area has been a challenge. Physician compensation is commensurately high in this location and competition for qualified physicians is intense. NASA must compete with several major medical schools in the Washington, DC area, as well as other Federal agencies such as the National Institutes of Health, Department of Defense, Veterans Administration, Department of Homeland Security, and the Federal Aviation Administration. Additionally, attracting physicians from outside the area is difficult due to commuting challenges and the high cost of living.

PHYSICIANS' COMPARABILITY ALLOWANCE

A number of recruitment methods were used to fill this physician position including posting the vacancy on various physician websites and medical alumni job boards. This vacancy was advertised twice. Only seven applicants applied in total. The first selectee declined the offer because GSFC could not match the individual's current salary of over $200,000. The applicant who accepted the offer did so only after being approved to receive PCA.

Category IV-B – Health and Medical Administration

KSC in not currently experiencing retention issues requiring the use of PCA. KSC has been decreasing the PCA amounts each fiscal year and will completely phase out the use of PCA in FY 2017 without a negative impact on the income of the two physicians.

How PCA Alleviates Recruitment and Retention Problems

PCA remains a very effective tool for NASA in both recruiting and retaining physicians. It has been used successfully at JSC 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.

JSC had no vacancies in FY 2016 and was able to avoid physician resignations in part due to the use of PCA to compensate for the difference between federal and non-federal pay. According to the 2015 Medscape Physician Compensation Report, the average physician compensation in the South Central geographical area was $271,000. PCA is a way to lessen the gap with private sector compensation and allow NASA to continue attracting and retaining qualified physicians.

Offering PCA to the physician hired at Goddard Space Flight Center in FY 2016 was critical to hiring this individual, who would have otherwise declined the employment offer.

Additional Information

With decreasing procurement funds in FY 2017, 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.

The multi-year Federal pay freeze caused the gap between Federal and private physician salaries to widen and become more evident. The 2013 Federal Government furlough calls 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.

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	Notional			
Budget Authority ($ millions)	**FY 2016**	**FY 2017**	**FY 2018**	**FY 2019**	**FY 2020**	**FY 2021**	**FY 2022**
ARC	2.5	3.8	3.9	3.9	4.0	4.0	4.0
AFRC	1.2	1.3	1.4	1.4	1.5	1.5	1.5
GRC	2.6	2.8	2.9	3.0	3.0	3.1	3.2
GSFC	5.8	5.9	5.9	6.0	6.0	6.1	6.1
HQ	14.0	14.8	15.4	15.7	16.1	16.3	16.3
JSC	7.6	7.6	7.7	7.9	8.1	8.4	8.7
KSC	7.2	8.0	8.5	8.8	9.1	9.3	9.6
LaRC	2.9	3.4	3.4	3.4	3.5	3.5	3.6
MSFC	4.3	5.0	5.0	5.0	5.0	5.0	5.0
SSC	1.3	1.4	1.4	1.4	1.5	1.5	1.5
NASA Total	**49.4**	**54.0**	**55.5**	**56.5**	**57.8**	**58.7**	**59.5**

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	Estimate	Request
($ millions)	**FY 2016**	**FY 2017**	**FY 2018**
Number of Paid Experts and Consultants	27.0	27.0	27.0
Annual FTE Usage	6.1	6.1	6.1
Salaries	$0.7	$0.7	$0.7
Total Salary and Benefits Costs	$0.8	$0.8	$0.8
Travel Costs	$0.2	$0.2	$0.2
Total Costs	**$1.0**	**$1.0**	**$1.0**

FY 2016 are actual obligations. FY 2017 and FY 2018 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.

	Actual	Estimate	Request
($ millions)	**FY 2016**	**FY 2017**	**FY 2018**
Quality Control, Testing and Inspection Services	$33.0	$33.0	$33.0
Management and Professional Support Services	$669.5	$669.5	$669.5
Studies, Analysis, and Evaluations	$84.0	$84.0	$84.0
Engineering and Technical Services	$22.0	$22.0	$22.0
IT Services	$57.0	$57.0	$57.0
Total Costs, Advisory and Assistance Services	**$865.5**	**$865.5**	**$865.5**

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

CONSULTING SERVICES

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 2018 for each of the following E-Government initiatives:

Initiative ($)	2018 Contributions (Includes In-Kind)	2018 Service Fees*
E-Rulemaking	-	10,000
Grants.gov	146,187	-
E-Training	-	183,625
Recruitment One-Stop	-	109,711
Enterprise HR Integration	-	347,000
E-Payroll	-	3,950,075
E-Travel	-	89,520
Integrated Award Environment (IAE)	-	874,354
Financial Management LoB	124,236	-
Human Resources Management LoB	68,478	500,000
Geospatial LoB	225,000	-
Budget Formulation and Execution LoB**	110,000	-
Federal PKI Bridge	-	121,283
NASA Total	**673,901**	**6,185,568**

**Service fees are estimates as provided by the E-Government initiative managing partners. Final FY 2018 commitments have yet to be finalized by Managing Partners (OMB MAX).*

After submission of the budget, NASA will post FY 2018 Exhibit 300 IT business cases on the IT Dashboard, located at: https://myit-2017.itdashboard.gov/drupal/summary/026.

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 2018 are described below.

eRulemaking (Managing Partner EPA) FY 2018 Benefits

This initiative provides the public 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 and provide the public access to review and comment on these rulemakings. Through Regulations.gov, NASA retrieves 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 compared to alternative options that would provide similar services.

E-GOV INITIATIVES AND BENEFITS

Grants.gov (Managing Partner HHS) FY 2018 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 2018 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 and development of e-learning content and in the purchase 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. This centralized approach allows NASA to reduce and leverage training costs by eliminating unique systems, standardizing training processes, and providing an accurate historical record.

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 2018 Benefits

USAJOBS simplifies the Federal Job Search Process for Job Seekers and Agencies. The USAJOBS.gov 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.

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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 2018 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.

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 of 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 2018 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 2018 Benefits

NASA completed migration of its travel services to ETS2 - Concur Government Edition (CGE) (formerly HP Enterprise Services (FedTraveler)) in 2014. Completing this migration has allowed NASA to provide more efficient and effective travel management services. ETS2 is a streamlined, adaptable world-class travel management service that continually applies commercial best practices to realize travel efficiencies and deliver a transparent, accountable, and sustainable service that yields exceptional customer satisfaction.

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 2018 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.

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Integrated Award and Environment – Loans & Grants FY 2018 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.

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 the 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.

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.

[1] More information on the development of this Web site can be found at: https://myit-2017.itdashboard.gov/drupal/.

Federal PKI Bridge –FY 2018 Benefits

The Federal Public Key Infrastructure (FPKI) is the primary, secure mechanism that allows for electronic business transactions across government and between government and industry. It is the backbone and trust anchor for HSPD-12 and PIV Cards and is critical to enabling cyber security via identity management. The FPKI enables secure physical and logical access 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 2018 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 2018 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. 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 government-wide best practices on 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 2018 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.

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 2018 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

E-GOV INITIATIVES AND BENEFITS

Community site is commonly used for sharing information, collaboratively drafting documents (including the direct-editing of documents posted on the site).

FY 2016 Operating Plan Crosswalk to FY 2018 Budget Structure

Budget Authority ($ millions)

NASA Total	**19,285.0**	**19,285.0**
Science	5,584.1	5,584.1
Earth Science	1,926.6	1,926.6
Earth Science Research	477.7	477.7
Earth Systematic Missions	914.6	914.6
Ice, Cloud, and land Elevation Satellite (ICESat-2)	*117.4*	*117.4*
Soil Moisture Active and Passive	*5.9*	
GRACE-FO	*59.9*	*59.9*
Surface Water and Ocean Topography (SWOT)	*114.1*	*114.1*
NASA-ISRO Synthetic Aperture Radar (NISAR)		
Sentinel-6		***38.2***
Landsat 9		***56.0***
Other Missions and Data Analysis	*617.3*	*617.3*
Soil Moisture Active and Passive		***5.9***
Sentinel-6	***38.2***	
Landsat 9	***56.0***	
Earth System Science Pathfinder	233.6	233.6
Earth Science Multi-Mission Operations	192.4	192.4
Earth Science Technology	60.7	60.7
Applied Sciences	47.6	47.6
Planetary Science	1,628.0	1,628.0
Planetary Science Research	274.0	274.0
Discovery	189.0	189.0
New Frontiers	194.0	194.0
Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer (OSIRIS-REx)	***124.7***	
Other Missions and Data Analysis	*69.3*	*69.3*
Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer (OSIRIS-REx)		***124.7***
Mars Exploration	513.0	513.0
Outer Planets and Ocean Worlds	261.0	261.0
Technology	197.0	197.0
Astrophysics	762.4	762.4
James Webb Space Telescope	620.0	620.0
Heliophysics	647.2	647.2
Heliophysics Research	160.0	160.0
Living with a Star	337.1	337.1
Solar Terrestrial Probes	49.5	49.5
Magnetospheric Multiscale (MMS)	***30.1***	
Other Missions and Data Analysis	*19.4*	*19.4*
Magnetospheric Multiscale (MMS)		***30.1***
Heliophysics Explorer Program	100.6	100.6

COMPARABILITY ADJUSTMENT TABLES

Aeronautics	**633.8**	**633.8**
Space Technology	**686.4**	**686.4**
Space Technology	**686.4**	**686.4**
Agency Technology and Innovation	**31.5**	**31.5**
SBIR and STTR	**200.9**	**200.9**
Space Technology Research and Development	**454.0**	**454.0**
Laser Communications Relay Demonstration		*30.5*
Exploration	**4,013.7**	**4,013.7**
Space Operations	**5,014.8**	**5,014.8**
Education	**115.0**	**115.0**
Safety, Security, and Mission Services	**2,772.4**	**2,772.4**
Construction and Environmental Compliance and Restoration	**427.4**	**427.4**
Inspector General	**37.4**	**37.4**
NASA Total	**19,285.0**	**19,285.0**

NOTE: Chart represents changes in budget structure and does not reflect funding changes.

COMPARABILITY ADJUSTMENT TABLES

FY 2017 Budget Structure Crosswalk to FY 2018 Budget Structure

Budget Authority ($ millions)

NASA Total	**19,653.3**	**19,653.3**
Science	5,764.9	5,764.9
Earth Science		
Earth Science Research		
Earth Systematic Missions		
Ice, Cloud, and land Elevation Satellite (ICESat-2)		
GRACE-FO		
Surface Water and Ocean Topography (SWOT)		
NASA-ISRO Synthetic Aperture Radar (NISAR)		
Sentinel-6		*42.5*
Landsat 9		*198.7*
Other Missions and Data Analysis	*241.2*	
Earth System Science Pathfinder		
Earth Science Multi-Mission Operations		
Earth Science Technology		
Applied Sciences		
Planetary Science		
Planetary Science Research		
Discovery		
InSight		
Lucy		*54.5*
Psyche		*3.5*
Other Missions and Data Analysis	*58.0*	
New Frontiers		
Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer (OSIRIS-REx)	*44.0*	
Other Missions and Data Analysis		*44.0*
Mars Exploration		
Outer Planets and Ocean Worlds		
Technology		
Astrophysics		
James Webb Space Telescope	569.4	569.4
Heliophysics		
Aeronautics	660.0	660.0
Aeronautics		
Airspace Operations and Safety Program		
Advanced Air Vehicles Program		
Integrated Aviation Systems Program	36.7	
Low-Boom Flight Demonstrator		*36.7*
Transformative Aero Concepts Program		
Space Technology	686.5	686.5
Space Technology		
Agency Technology and Innovation		
SBIR and STTR		
Space Technology Research and Development	25.7	
Laser Communications Relay Demonstration		*25.7*
Exploration	4,324.0	4,324.0
Space Operations	4,950.7	4,950.7
Education	100.0	100.0
Safety, Security, and Mission Services	2,768.6	2,768.6
Construction and Environmental Compliance and Restoration	360.7	360.7
Inspector General	37.9	37.9
NASA Total	**19,653.3**	**19,653.3**

NOTE: Chart represents changes in budget structure and does not reflect funding changes.

REBASELINED PROJECTS

In accordance with NPR 7120.5, NASA rebaselined the estimated Life Cycle Costs for the following projects. The original baselines are shown for comparison.

Webb	Base Year	Prior	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	Budget to Complete	Total
Original Life Cycle Cost	2009	4,448	92	93	94	94	76	66	4,964
Rebaselined Life Cycle Cost	2012	5,990	622	571	540	305	198	610	8,835
Actual	N/A	5,991	620						

ICESat-2	Base Year	Prior	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	Budget to Complete	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						

Cost and Schedule Performance Summary

2017 MAJOR PROGRAM ANNUAL REPORT SUMMARY

The 2017 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 2017 MPAR consists of this summary and FY 2018 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 2017 NASA BUDGET ESTIMATES

There are five new projects with estimated lifecycle costs greater than $250 million that received authority to proceed into the development phase since NASA submitted its 2016 MPAR in the FY 2017 NASA Congressional Justification:

1) Laser Communications Relay Demonstration (LCRD) with a baseline development cost of $91.8 million at a joint confidence level of 70 percent. LCRD is managed within the Space Technology Mission Directorate but co-funded with the Human Exploration and Operations Mission Directorates/Space Communications and Navigation (SCaN);
2) Mars 2020 with a baseline development cost of $1,676.9 million (total Agency commitment from all sources) at a joint confidence level of 70 percent. The Mars 2020 program is managed within the Science Mission Directorate but also receives funding from the Space Technology and Human Exploration and Operations Mission Directorates;
3) NASA-ISRO Synthetic Aperture Radar (NISAR) with a baseline development cost of $661.0 million at a joint confidence level of 70 percent;
4) Sentinel-6 with a baseline development cost of $465.0 million at a joint confidence level of 70 percent;
5) Surface Water and Ocean Topography (SWOT) with a baseline development cost of $571.5 million at a joint confidence level of 70 percent.

The 2016 MPAR in the FY 2017 NASA Congressional Justification included one project Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx) that is no longer in MPAR reporting. NASA successfully launched the OSIRIS-REx spacecraft on September 8, 2016. The OSIRIS-REx spacecraft launched approximately -20% below the baseline development cost.

CHANGES IN DEVELOPMENT COST AND SCHEDULE ESTIMATES FROM THE 2016 MPAR

Seven projects had no changes in their development cost or schedule estimates over the last year. Additionally, SLS and EGS-GSDO are evaluating their EM-1 launch readiness dates. As of now there were changes to the development cost estimates for Orion (down -2%), OSIRIS-REx (down an additional -10%), SOC (down -15%), SPP (down -1%), and TESS (down -8%) projects. ICESat-2 experienced a 3 month adjustment to its schedule estimate.

The InSight project experienced both a cost increase (up 24%) and schedule change of 26 months. The Science Mission Directorate held a Directorate Program Management Council (DPMC) meeting on August 31, 2016 and approved a replan of the InSight project. The appropriate Congressional Committees were notified of these changes.

Cost and Schedule Performance Summary

MPAR SUMMARY TABLE

Figure 1 provides cost, schedule, and confidence level information for NASA projects currently in development with lifecycle cost estimates of $250 million or more. NASA records the estimated development cost and a key schedule milestone and then measures changes from them. NASA tracks one of several key milestones, listed below, for reporting purposes:

- Launch readiness date (LRD);
- Full operational capability (FOC);
- Initial operating capability (IOC); or
- Launch Readiness for 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-GSDO: The 80% JCL is inferred from analysis based on FY14 President's Budget Request (PBR) including FY14 Appropriation changes. JCL analysis was completed prior to the release of the FY15 PBR. The ABC is informed by the 80% JCL and adjusted to reflect the FY15 PBR budget reduction.
- The Space Launch System (SLS) and Exploration Ground Systems (EGS) – Ground Systems Development Office (GSDO) programs continue to evaluate the impact the following events will have on the EM-1 launch readiness date: 1) the integrated manufacturing, test, and processing schedules based on projection of the ESA service module delivery; 2) the impact of tornado damage recovery at Michoud Assembly Facility and 3) first time production issues for the SLS stages element. NASA will be providing updates to the launch readiness date in the near future.

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.

Cost and Schedule Performance Summary

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 2017			Baseline	FY 2017	
EGS-GSDO*	2015	80	1,843.5	TBD	TBD	LR for EM-1	Nov 2018	TBD	TBD
GRACE-FO	2015	70	264.0	263.4	0%	LRD	Feb 2018	Feb 2018	0
ICESat-2	2015	70	763.7	763.7	0%	LRD	Jun 2018	Sep 2018	3
ICON	2015	70	196.0	196.0	0%	LRD	Oct 2017	Oct 2017	0
InSight	2014	70	541.8	673.5	24%	LRD	Mar 2016	May 2018	26
LCRD	2017	70	91.8	91.8	0%	LRD	Nov 2019	Nov 2019	0
Mars 2020	2017	70	1,676.9	1,674.7	0%	LRD	Jul 2020	Jul 2020	0
NISAR	2017	70	661.0	661.0	0%	LRD	Sep 2022	Sep 2022	0
Orion**	2016	70	6,768.4	6,616.7	-2%	LR for EM-2	Apr 2023	Apr 2023	0
Sentinel-6	2017	70	465.0	465.0	0%	LRD	Nov 2021	Nov 2021	0
SLS	2015	70	7,021.4	TBD	TBD	LR for EM-1	Nov 2018	TBD	TBD
SOC	2014	N/A	376.9	320.0	-15%	LRD	Oct 2018	Oct 2018	0
SPP	2015	70	1,055.7	1,050.3	-1%	LRD	Aug 2018	Aug 2018	0
SWOT	2017	80	571.5	571.5	0%	LRD	Apr 2022	Apr 2022	0
TESS	2015	70	323.2	296.4	-8%	LRD	Jun 2018	Jun 2018	0
Webb	2012	66	6,197.9	6,188.8	0%	LRD	Oct 2018	Oct 2018	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.*

Launch Readiness (LR) *Launch Readiness Date (LRD)* *Exploration Mission (EM)*

*** This amount reflects a transfer of funding to formulation costs and does not represent a reduction in the life cycle cost estimates.*

National Aeronautics and Space Administration

Report Regarding

Basic Research for Fiscal Year 2018

Pursuant to

Section 1008(c) of the America Competes Act (P.L. 110-69)

BASIC RESEARCH

BACKGROUND

Section 1008(c) of the American COMPETES Act (P.L. 110-69) directs that each Executive agency shall submit to the Congress each year, together with documents in support of the budget of the President, a report that outlines agency funding for "*high-risk, high-reward*" basic research projects. Specifically, the report shall describe whether a funding goal has been established that: (1) meets fundamental technological or scientific challenges; (2) involves multidisciplinary work; and (3) involves a high degree of novelty. The Act further stipulates that basic research shall be defined in accordance with Office of Management and Budget (OMB) Circular A-11.

The information requested in section 1008(c) is provided herein.

OMB Circular A-11 defines basic research as systematic study directed toward fuller knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific application towards processes or products in mind. Basic research, however, may include activities with broad applications in mind.

REPORT

The total Fiscal Year (FY) 2018 NASA budget request is $19.1 billion. The NASA Research and Development (R&D) budget consists of 19 percent basic research, 13 percent applied research, and 21 percent development as defined by OMB circular A-11.

Because much of NASA's work revolves around the creation of one-of-a-kind missions, a relatively large portion of its R&D activities involve *high-risk, high-reward* research and development—from basic research through applications and technology development. In addition, NASA is a leader in using innovative research approaches, such as science competitions and prizes, as well as multidisciplinary approaches. However, since the majority of these activities do not fall within the OMB definition of basic research, they are excluded from this report.

NASA conducts basic research under three accounts: (1) Science Investments, (2) the International Space Station (ISS), and (3) Exploration Research.

Based on the FY 2018 budget request, NASA expects that 32 percent of its basic research in FY 2018 will be for *high-risk, high-reward* fundamental, technical, and scientific challenges that are novel and multidisciplinary. NASA is budgeting $1.178 billion for *high-risk, high-reward* basic research.

Description of Basic Research Activities

(1) Science Investments: NASA conducts basic research in four theme areas:

(a) Astrophysics: Study of the origin, evolution, and fate of the universe, and the search for exoplanets;

(b) Earth Science: Study of the Earth, its interior, oceans, atmosphere, and fundamental processes within and interactions among those areas, including long-term climate change;

(c) Heliophysics: Study of the Sun, its interior, corona, solar wind, and the heliosphere, specifically including interactions with planetary magnetospheres; and

(d) Planetary Science: Study of the planets, moons, comets, asteroids and other bodies within our own solar system, including their interiors, surfaces, atmospheres, magnetospheres, etc. and their interactions.

Many of NASA's missions are inherently risky when they are launched on rockets into space and perform missions in the airless, weightless, high-radiation environment of space or near or on the surface of other planets. In addition, like other high-risk research, the outcomes of the research are often far from clear. However, the rewards can also be great. The following are examples of *high-risk, high-reward* science projects:

Hurricane track forecasts have improved in accuracy by about 50 percent since 1990, but there has been essentially no improvement in the accuracy of hurricane intensity forecasts. In December 2016, NASA launched a new mission using a constellation of eight small satellites carried to low-Earth orbit on a single launch vehicle to make accurate measurements of ocean surface winds in and near the eye of the storm throughout the lifecycle of tropical cyclones, typhoons and hurricanes. The Cyclone Global Navigation Satellite System, or CYGNSS, will be the first to probe the inner core of hurricanes in detail to better understand their rapid intensification. CYGNSS will make accurate measurements of ocean surface winds throughout the life cycle of tropical storms and hurricanes, leading to better weather forecasting. CYGNSS's eight micro-satellite observatories receive both direct and reflected signals from GPS satellites. The direct GPS signals pinpoint CYGNSS observatory positions, while the reflected signals are indicative of ocean surface roughness. Scientists will use both measurements to derive the critical measurement of wind speed. High-risk aspects of this project include the launch of eight spacecraft on a single rocket and the novel use of reflected GPS signals to measure winds. At inception of the project in 2013, NASA classified it as a high-risk, low cost (Class D in NASA parlance) mission.

The Neutron Star Interior Composition Explorer (NICER) instrument, to be located on the external logistics carrier of the ISS, will perform high time resolution and spectroscopic observations of neutron stars to uncover the nature and probe the physics of ultra-dense matter in the core of neutron stars. NICER is currently (as of May 2, 2017) scheduled for launch in early June 2017. NICER will explore the exotic states of matter inside these stars where density and pressure are higher than in atomic nuclei. NICER will enable rotation-resolved spectroscopy of the thermal and non-thermal emissions of neutron stars in the soft X-ray band with unprecedented sensitivity, probing interior structure, the origins of dynamic phenomena, and the mechanisms that underlie the most powerful known cosmic particle accelerators. Like CYGNSS, NASA designated NICER as a high-risk Class D payload, enabling the possibility of significant scientific advancement at relatively low cost.(

(2) ISS: NASA's research goals for ISS are driven by the NASA Authorization Act of 2010 and recommendations from the National Research Council. These goals focus on the following areas: human health and exploration, technology development and demonstration, physical sciences research, biology and biotechnology research, earth and space science research, education, and enabling the development of market driven commercial research and applications in low Earth orbit. Basic research in these areas includes the potential for high-reward discoveries including self-assembling materials, improved efficiency in diesel engines, and a deeper understanding of how humans interact with the microbial environment in which they live and work. For more information, go to: http://www.nasa.gov/mission_pages/station/research/index.html.

(3) Exploration: NASA's Human Research Program (HRP) is dedicated to discovering the best methods and technologies to support safe, productive human space exploration. The major areas of HRP's

physiological research include bone health, muscle function, cardiovascular response, sensorimotor systems, immunology, behavioral health, biomedical technology, and space radiation effects. One example of HRP fostering *high-risk, high-reward* research is through a new public-private partnership, the Translational Research Institute (TRI) that will lead a national effort in translating cutting-edge emerging terrestrial biomedical research and technology development into applied space flight human risk mitigation strategies for exploration missions.

Summary

The NASA 2018 budget supports an extensive program of *high-risk, high-reward* basic research that is novel, multidisciplinary, and of fundamental scientific or technological interest. NASA expects 32 percent of its basic research to be *high-risk, high-reward*.

FY 2018 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, [$5,589,400,000]*$5,711,800,000*, to remain available until September 30, [2017] *2019*. *Note.—A full-year 2017 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Further Continuing Appropriations Act, 2017 (P.L. 114-254). The amounts included for 2017 reflect the annualized level provided by the continuing resolution. (Science Appropriations Act, 2016.)*

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, [$640,000,000] *$624,000,000* to remain available until September 30, [2017] *2019*. *Note.—A full-year 2017 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Further Continuing Appropriations Act, 2017 (P.L. 114-254). The amounts included for 2017 reflect the annualized level provided by the continuing resolution. (Science Appropriations Act, 2016.)*

Space Technology

For necessary expenses, not otherwise provided for, in the conduct and support of space technology 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, [$686,500,000] *$678,600,000*, to remain available until September 30, [2017] *2019*. *Note.—A full-year 2017 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Further Continuing Appropriations Act, 2017 (P.L. 114-254). The amounts included for 2017 reflect the annualized level provided by the continuing resolution. (Science Appropriations Act, 2016.)*

Exploration

For necessary expenses, not otherwise provided for, in the conduct and support of exploration 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, [$4,030,000,000] *$3,934,097,000*, to remain available until September 30, [2017] *2019*. *Note.—A full-year 2017 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the*

FY 2018 PROPOSED APPROPRIATIONS LANGUAGE

Further Continuing Appropriations Act, 2017 (P.L. 114-254). The amounts included for 2017 reflect the annualized level provided by the continuing resolution. (Science Appropriations Act, 2016.)

SPACE 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, [$5,029,200,000] *$4,740,803,000*, to remain available until September 30, [2017] *2019. Note.—A full-year 2017 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Further Continuing Appropriations Act, 2017 (P.L. 114-254). The amounts included for 2017 reflect the annualized level provided by the continuing resolution. (Science Appropriations Act, 2016.)*

EDUCATION

For necessary expenses, not otherwise provided for, in the conduct and support of aerospace and aeronautical education research and development activities, including research, development, operations, support, and services; 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; purchase, lease, charter, maintenance, and operation of mission and administrative aircraft; *and to carry out* closure of the NASA Office of *Education, including for making payments for awards granted prior to September 30, 2017,* [$115,000,000] *$37,300,000, to remain available until* September 30, [2017] *2019. Note.—A full-year 2017 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Further Continuing Appropriations Act, 2017 (P.L. 114-254). The amounts included for 2017 reflect the annualized level provided by the continuing resolution. (Science Appropriations Act, 2016.)*

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, [$2,768,600,000] *$2,830,200,000*, to remain available until September 30, [2017] *2019. Note.—A full-year 2017 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Further Continuing Appropriations Act, 2017 (P.L. 114-254). The amounts included for 2017 reflect the annualized level provided by the continuing resolution. (Science Appropriations Act, 2016.)*

FY 2018 PROPOSED APPROPRIATIONS LANGUAGE

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, [$388,900,000] *$496,100,000*, to remain available until September 30, [2021] *2023*: 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 [2016] *2018* in an amount not to exceed *$9,470,300*: *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 2017 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Further Continuing Appropriations Act, 2017 (P.L. 114-254). The amounts included for 2017 reflect the annualized level provided by the continuing resolution. (Science Appropriations Act, 2016.)*

INSPECTOR GENERAL

For necessary expenses of the Office of Inspector General in carrying out the Inspector General Act of 1978, [$37,400,000] *$39,300,000, to* remain available until September 30, [2017] *2019. Note.—A full-year 2017 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Further Continuing Appropriations Act, 2017 (P.L. 114-254). The amounts included for 2017 reflect the annualized level provided by the continuing resolution. (Science Appropriations Act, 2016.)*

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 5 percent of any appropriation made available for the current fiscal year for the National Aeronautics and Space Administration in this Act may be transferred between such appropriations, but no such appropriation, except as otherwise specifically provided, shall be increased by more than 10 percent by any such transfers. *Any 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 505 of this Act and shall not be available for obligation except in compliance with the procedures set forth in that section.

The spending plan required by this Act shall be provided by NASA at the theme *and* program level. The spending plan, as well as any subsequent change of an amount established in that spending plan that meets the notification requirements of section 505 of this Act, shall be treated as a reprogramming under section 505 of this Act and shall not be available for obligation or expenditure except in compliance with the procedures set forth in that section. *(Science Appropriations Act, 2016.)*

ACRONYMS AND ABBREVIATIONS

$K	Dollars in thousands
$M	Dollars in millions
21CSLC	21st Century Space Launch Complex
3U	3-unit
45SW	US Air Force 45th Space Wing
AANAPISI	Asian American and Native American Pacific Islander-Serving Institutions
AAV	Advanced Air Vehicles
ABC	Agency Baseline Commitment
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
ACTE	adaptive compliant trailing-edge technology
ADAP	Astrophysics Data Analysis Program
ADCAR	Astrophysics Data Curation and Archival Research
ADS-B	Automatic Dependent Surveillance-Broadcast
AEDL	Advanced Entry Descent and Landing
AES	Advanced Exploration Systems
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
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

ACRONYMS AND ABBREVIATIONS

ARMD	Aeronautics Research Mission Directorate
ARRA	American Recovery and Reinvestment Act
ARSET	Applied Remote SEnsing Training
ARTEMIS	Acceleration, Reconnection, Turbulence and Electrodynamics of the Moon's Interaction with the Sun
ASCENDS	Active Sensing of CO2 Emissions over Nights, Days, and Seasons
ASDM	Astrophysics Decadal Strategic Mission
ASI	Agenzia Spaziale Italiana
ASPERA	Analyzer of Space Plasmas and Energetic Atoms
ATCC	A-Complex Test Control Center
ATD	Air Traffic Management Technology Demonstration-1
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
BTC	budget to complete
BWG	Beam Wave Guide
CAL	Cold Atom Laboratory
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation
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
CBT	Computer-Based Training
CCAFS	Cape Canaveral Air Force Station
CCD	charge-coupled device
CCDev2	Commercial Crew Development Round 2
CCM	Camera Control Module
CCMC	Community Coordinated Modeling Center
CCP	Commercial Crew Program

ACRONYMS AND ABBREVIATIONS

CCtCap	Commercial Crew transportation Capabilities
CDC	Centers for Disease Control
CDI	Climate Data Initiative
CDM	Continuous Diagnostic Mitigation
CDR	Critical Design Reviews
CDTI	Center for the Development of Industrial Technology
CECR	Construction and Environmental Compliance and Restoration
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™
CHS	Crew Health and Safety
CIBER	Cosmic Infrared Background Experiment Rocket
CINDI	Coupled Ion Neutral Dynamic Investigation
CIRs	co-rotating interaction regions
CL	confidence level
CLARREO	Climate Absolute Radiance and Refractivity Observatory
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
COR	Cosmic Origins
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
CSL	Belgian Centre Spatial de Liège
CSO	Communications Services Office
CSTD	Crosscutting Space Technology Development

ACRONYMS AND ABBREVIATIONS

CYGNSS	Cyclone Global Navigation Satellite System
D&B	Dun and Bradstreet
DAAC	Distributed Active Archive Center
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
DLR	German Aerospace Center
DLS	deployable launch system
DNA	Deoxyribonucleic acid
DoD	Department of Defense
DOE	Department of Energy
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
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
DSOC	Deep Space Optical Communication
DSS	Deep Space Station
DUNS	Data Universal Numbering System
ECAST	Expert and Citizen Assessment of Science and Technology
ECOSTRESS	ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station
ECR	Environmental Compliance and Restoration
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
ELV	Expendable Launch Vehicle

ACRONYMS AND ABBREVIATIONS

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	Experimental Project To Stimulate Competitive Research
EQM	Engineering Qualification Model
ERA	Environmentally Responsible Aviation
ERBS	Earth Radiation Budget Science
ESA	European Space Agency
ESDN	Edison Demonstration of Smallsat Networks
ESM	Earth Systematic Missions
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
EVM	Earth Venture small Missions
EX	Explorers
FAA	Federal Aviation Administration
FDC	Flight Demonstrations and Capabilities
FDMS	Federal Docket Management System
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
FO	Follow-On
FOC	Full operational capability
FPB	Flight Planning Board
FPI	Fast Plasma Investigation
FPPS	Federal Personnel and Payroll System

ACRONYMS AND ABBREVIATIONS

FRR	Flight Readiness Review
FY	Fiscal Year
G-3	Gulfstream 3
GALEX	Galaxy Evolution Explorer
GCIS	Global Change Information System
GEDI	Global Ecosystem Dynamics Investigation Lidar
GEMS	Gravity and Extreme Magnetism
GEO-CAPE	GEOstationary Coastal and Air Pollution Events
GFZ	German Research Centre for Geosciences
GIS	Geographic Information System
GLOBE	Global Learning and Observations to Benefit the Environment
GMAO	Global Modeling and Assimilation Office
GNC	Guidance, Navigation, and Control
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
GSDO	Ground Systems Development and Operations Program Office
GSFC	Goddard Space Flight Center
GSRT	GSFC System Review Team
HAWC+	High-resolution Airborne Wideband Camera
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
HF	High Frequency
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
HMI	Helioseismic and Magnetic Imager
HMTA	Health and Medical Technical Authority

ACRONYMS AND ABBREVIATIONS

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
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
IDIQ	indefinite-delivery-indefinite-quantity
IDS	Intrusion Detection Systems
ILT	Instructor-Led Training
IMC	International Mission Contributions
InSight	Investigations, Geodesy and Heat Transport
INTA	National Institute of Aerospace Technology
InVEST	In-space Validation of Earth Science Technology
IOC	Initial operating capability
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

ACRONYMS AND ABBREVIATIONS

IT	information technology
I-trek	I turn research into empowerment and knowledge
ITSEC-EDW	IT Security Enterprise Data Warehouse
IV&V	Independent Verification and Validation
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
JSC	Johnson Space Center
JUICE	Jupiter Icy Moons Explorer
KaBOOM	Ka-Band Objects Observation and Monitoring
KaRIn	Ka-band Radar Interferometer
KBOs	Kuiper Belt objects
KDP	Key Decision Point
KOA	Keck Observatory Archive
KSC	Kennedy Space Center
LADEE	Lunar Atmosphere and Dust Environment Explorer
LaRC	Langley Research Center
LBTI	Large Binocular Telescope Interferometer
LC	Launch Complex
LCC	Life Cycle Cost
LCPSO	Land Cover Project Science Office
LDCM	Landsat Data Continuity Mission
LDSD	Low Density Supersonic Decelerator
LEARN	Leading Edge Aeronautics Research for NASA
LED	Light-Emitting Diode
LEED	Leadership in Energy and Environmental Design
LH2	Liquid Hydrogen
LIDAR	Light Detection and Ranging
LIS	Lightning Imaging Sensor
LISA	Laser Interferometer Space Antenna
LLCD	Lunar Laser Communication Demonstration
LMSSC	Lockheed Martin Space Systems Company
LoB	Lines of Business
LOX	liquid oxygen
LRA	Laser Retro-reflector Assembly
LRD	Launch Readiness Date

ACRONYMS AND ABBREVIATIONS

LRO	Lunar Reconnaissance Orbiter
LRR	Launch Readiness Review
LVC-DE	Live Virtual Constructive-Distributed Environment
LWS	Living With a Star
MAA	MUREP Aerospace Academy
MAF	Michoud Assembly Facility
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
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
MLCC	multi-layer ceramic capacitor
MLTI	mesosphere-lower 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
MOXIE	Mars Oxygen ISRU Experiment
MPAR	Major Program Annual Report
MPCV	Multi-Purpose Crew Vehicle
MPRAT	Mission Profile Risk Assessment Test
MRO	Mars Reconnaissance Orbiter

ACRONYMS AND ABBREVIATIONS

MSE	MUREP STEM Engagement
MSFC	Marshall Space Flight Center
MSI	Minority-Serving Institutions
MSL	Measurement Systems Laboratory
mths	months
MUREP	Minority University Research and Education Program
MUSES	Multi-User System for Earth Sensing
MUSS	Multi User Systems and Support
N/A	not applicable
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
NEACC	NASA Enterprise Applications Competency Center
NEN	Near Earth Network
NEO	near-Earth objects
NEOO	Near-Earth Object Observations
NESC	NASA Engineering and Safety Center
NextGen	Next Generation Air Transportation System
NHPA	National Historic Preservation Act
NIAC	NASA Innovative Advanced Concepts
NICER	Neutron star Interior Composition ExploreR
NIFS	NASA Internship, Fellowship, and Scholarship
NIH	National Institutes of Health
NIRCam	Near Infrared Camera
NIRISS	Near Infrared Imager and Slitless Spectrograph
NISAR	NASA-ISRO Synthetic Aperture Radar
NISN	NASA Integrated Services Network
NIST	National Institute of Standards and Technology
NLCs	noctilucent clouds
NLS	United 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

ACRONYMS AND ABBREVIATIONS

NSBRI	National Space Biomedical Research Institute
NSF	National Science Foundation
NSSC	NASA Shared Services Center
NSSDC	National Space Science Data Center
NSTP PPD	National Space Policy Launch Infrastructure and Modernization Plan
NuSTAR	Nuclear Spectroscopic Telescope Array
O&M	operations and maintenance
OA	Office of Audits
OCAMS	OSIRIS-REx Camera Suite
OCHMO	Office of Chief Health Medical Officer
OCO	Orbiting Carbon Observatory
OCSD	Optical Communications and Sensor Demonstration
OCT	Office of the Chief Technologist
OE	Office of Education
OI	Office of Investigations
OIG	Office of Inspector General
OLA	OSIRIS-REx Laser Altimeter
OLI	Operational Land Imager
OMB	Office of Management and Budget
OMDA	Other Missions and Data Analysis
OMI	Ozone Monitoring Instrument
OMPS	Ozone Mapping and Profiler Suite
ONERA	French Office National d’Etudes et Recherches Aérospatiales
OPM	Office of Personnel Management
Orb-#	Orbital Sciences Commercial Resupply Services #
ORR	Operational Readiness Review
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
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
PACE	Pre-Aerosol, Clouds, and ocean Ecosystem
PAMSS	Planetary Atmosphere Minor Species Sensor
Pan-STARRS	Panoramic Survey Telescope and Rapid Reporting System

ACRONYMS AND ABBREVIATIONS

PB	President's Budget
PCA	Physicians' comparability allowance
PCOS	Physics of the Cosmos
PDA	progressive damage analysis
PDR	preliminary design review
PDS	Planetary Data System
PEP	Particle Environment Package
PI	Principal Investigator
PIR	Program Implementation Review
PIV	Personal Identity Verification
P.L.	Public Law
POWER	Protecting Our Workers and Ensuring Reemployment
PSL	Propulsion Systems Laboratory
Pu	plutonium
PV	Planetary Ventures, LLC
QM-1	qualification motor 1
QuikSCAT	Quick Scatterometer
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
RBA	Reflector Boom Assembly
RBI	Radiation Budget Instrument
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
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
ROSES	Research Opportunities in Space and Earth Sciences
RPO	rendezvous and proximity operations
RPS	Radioisotope Power Systems
RPT	Rocket Propulsion Testing
RRM	Robotic Refueling Mission

ACRONYMS AND ABBREVIATIONS

RRS	Research Range Services
RS	Reflected Solar
RTCA	Radio Technical Commission for Aeronautics
RTG	Radioisotope Thermoelectric Generator
RVLT	Revolutionary Vertical Lift Technology
SAC-D	Satellite for Scientific Applications-D
SAFFIRE	Spacecraft Fire Experiment
SAGE	Stratospheric Aerosol and Gas Experiment
SAM	Sample Analysis at Mars (Planetary Science)
SAM I	Stratospheric Aerosol Measurement (Earth Science)
SAO	Smithsonian Astrophysical Observatory
SAR	Synthetic Aperture Radar
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
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
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

ACRONYMS AND ABBREVIATIONS

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
SNC	Sierra Nevada Corporation
SOC	Solar Orbiter Collaboration
SOFIA	Stratospheric Observatory for Infrared Astronomy
SOHO	Solar and Heliospheric Observatory
SoloHI	Solar Orbiter Heliospheric Imager
SORCE	Solar Radiation and Climate Experiment
SOST	Subcommittee on Ocean Science and Technology
SOT	Solar Optical Telescope
Space Grant	National Space Grant College and Fellowship Program
SpaceX	Space Exploration Technologies Company
SPB	Solar Pressure Balloon
SPDF	Space Physics Data Facility
SPHERES	Synchronized Position Hold, Engage, Reorient, and Experimental Satellites
SPOC	Science Processing and Operations Center
SPP	Solar Probe Plus
SpX-#	Space Exploration Technologies Company Commercial Resupply Services #
SR&T	Strategic Research and Technology
SRB	Strategic Review Board
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
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

ACRONYMS AND ABBREVIATIONS

STPH-5 LIS	Space Test Program Houston-5 Lightning Imaging System
STScI	Space Telescope Science Institute
STTR	Small Business Technology Transfer
SWEAP	Solar Wind Electrons Alphas and Protons
SWOT	Surface Water Ocean Topography
SwRI	Southwest Research Institute
SXS	Soft X-Ray Spectrometer
TAC	Transformative Aeronautics Concepts
TAGSAM	Touch and Go Sample Acquisition Mechanism
TASEAS	Technologies for Assuring Safe Energy and Attitude State
TBD	to be determined
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
TDT	Transonic Dynamics Tunnel
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
TMC	Technical and Management and Cost
TPS	Thermal Protection System
TR&T	Targeted Research & Testing
TRACT	Transport Rotorcraft Airframe Crash Testbed
TRL	Technology Readiness Level
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
UAS	Unmanned Aircraft Systems
UAV	unmanned aerial vehicle

ACRONYMS AND ABBREVIATIONS

UAVSAR	Uninhabited Aerial Vehicle Synthetic Aperture Radar
UHB	ultra-high bypass
UHF	ultra high frequency
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
USAF	United States Air Force
USAID	U.S. Agency for International Development
U.S.C.	United States Code
USGCRP	US Global Change Research Program
USGS	US Geological Survey
USRA	Universities Space Research Association
UTM	UAS Traffic Management
UVS	Ultraviolet Spectrograph
VAB	Vehicle Assembly Building
VAC	Vertical Assembly Center
VAFB	Vandenberg Air Force Base
VIIP	visual impairment/intra-cranial pressure
VIIRS	Visible Infrared Imaging Radiometer
VIL	Vehicle Integration and Launch
VSPT	Variable-Speed Power Turbine
WANs	Wide Area Networks
WASP	Web Application Security Program
WBS	work breakdown structure
WCF	Working Capital Fund
Webb	James Webb Space Telescope
WFA	Work from Anywhere
WFF	Wallops Flight Facility
WFIRST	Wide-Field Infrared Survey Telescope
WISE	Wide-field Infrared Survey Explorer
WISPR	Wide-field Imager for Solar PRobe
WSTF	White Sands Test Facility
XMM-Newton	X-ray Multi-Mirror Mission
ZBOT	Zero Boil-Off Tank