United States Government Accountability Office

Report to Congressional Committees

May 2018

NASA

Assessments of Major Projects

GAO-18-280SP

GAO Highlights

Highlights of GAO-18-280SP, a report to congressional committees

May 2018

NASA

Assessments of Major Projects

Why GAO Did This Study

This report provides GAO's annual snapshot for 2018 of how well NASA is planning and executing its major acquisition projects. In May 2017, GAO found that projects were continuing a generally positive trend of limiting cost and schedule growth, maturing technologies, and stabilizing designs. But, at the same time, GAO noted that many of these projects, including some of the most expensive ones, were approaching the phase in their life cycles when cost and schedule growth is most likely.

The explanatory statement of the House Committee on Appropriations accompanying the Omnibus Appropriations Act, 2009 included a provision for GAO to prepare status reports on selected large-scale NASA programs, projects, and activities. This is GAO's 10th annual assessment. This report describes the cost and schedule performance of NASA's portfolio of major projects, among other issues. This report also includes assessments of NASA's 26 major projects, each with a life-cycle cost of over $250 million. To conduct its review, GAO analyzed cost, schedule, technology maturity, design stability, and other data; reviewed monthly project status reports; and interviewed NASA officials.

What GAO Recommends

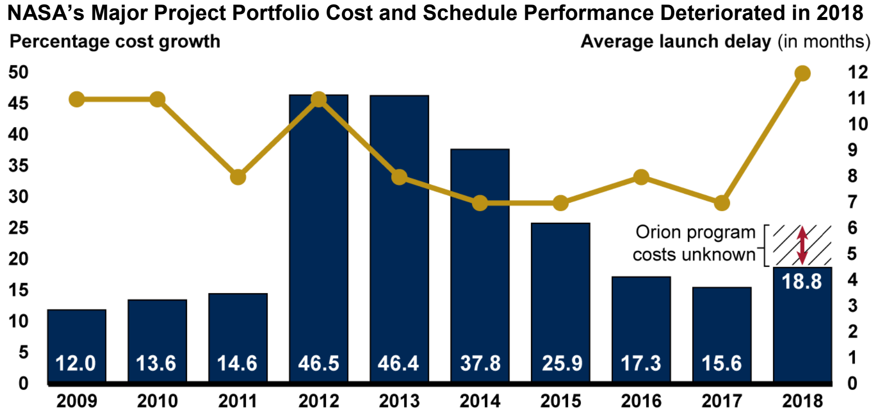
In prior reports, GAO has made related recommendations that NASA generally agreed with, but has not yet fully addressed. GAO continues to believe they should be fully addressed. NASA generally agreed with GAO's findings.

View GAO-18-280SP. For more information, contact Cristina Chaplain at (202) 512-4841 or chaplainc@gao.gov.

What GAO Found

The cost and schedule performance of the National Aeronautics and Space Administration's (NASA) portfolio of major projects has deteriorated, but the extent of cost performance deterioration is unknown. NASA expects cost growth for the Orion crew capsule—one of the largest projects in the portfolio—but does not have a current cost estimate. In addition, the average launch delay for the portfolio was 12 months, the highest delay GAO has reported in its 10 years of assessing major NASA projects (see figure below).

NASA's Major Project Portfolio Cost and Schedule Performance Deteriorated in 2018



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-18-280SP

The deterioration in portfolio performance was the result of 9 of the 17 projects in development experiencing cost or schedule growth.

- Four projects encountered technical issues that were compounded by risky program management decisions. For example, the Space Launch System and Exploration Ground Systems programs are large-scale, technically complex human spaceflight programs, and NASA managed them to aggressive schedules and with insufficient levels of cost and schedule reserves. This made it more difficult for the programs to operate within their committed baseline cost and schedule estimates.
- Two projects ran into technical challenges that resulted in delays in the integration and test phase. For example, in December 2017, GAO found that the James Webb Space Telescope project encountered delays primarily due to the integration of the various spacecraft elements taking longer than expected, as well as resolving technical issues during testing. GAO has previously found that integration and testing is when projects are most at risk of incurring cost and schedule growth.
- Three projects experienced cost growth or schedule delays due to factors outside of the projects' control, such as delays related to their launch vehicles.

NASA continues to face increased risk of cost and schedule growth in future years due to new, large and complex projects that will enter the portfolio and expensive projects remaining in the portfolio longer than expected.

Contents

Tables

Figures

Abbreviations

AIM	Asteroid Impact Monitor
ATLAS	Advanced Topographic Laser Altimeter System
CCP	Commercial Crew Program
CNES	Centre National d'Etudes Spatiales
DART	Double Asteroid Redirection Test
DCI	data collection instrument
DSOC	Deep Space Optical Communications
EGS	Exploration Ground Systems
EM-1	Exploration Mission 1
EM-2	Exploration Mission 2
ESM	European Service Module
ESA	European Space Agency
GFAS	Ground Flight Application Software
GFZ	German Research Centre for Geosciences
GN&C	Guidance, Navigation, and Control
GRACE-FO	Gravity Recovery and Climate Experiment Follow-On
GSLV	Geosynchronous Satellite Launch Vehicle
HP3	Heat Flow and Physical Properties Probe
HVPS	high voltage power supply
ICESat-2	Ice, Cloud, and Land Elevation Satellite-2
ICON	Ionospheric Connection Explorer
InSight	Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport
ISRO	Indian Space Research Organisation
ISS	International Space Station
JCL	joint cost and schedule confidence level
JPL	Jet Propulsion Laboratory
JPSS-2	Joint Polar Satellite System 2
JWST	James Webb Space Telescope
KaRIn	Ka-band Radar Interferometer
KDP	key decision point
LBFD	Low Boom Flight Demonstrator
LCRD	Laser Communications Relay Demonstration
LRI	Laser Ranging Interferometer
MAVEN	Mars Atmosphere and Volatile Evolution
NASA	National Aeronautics and Space Administration
NEXT-C	NASA's Evolutionary Xenon Thruster-Commercial
NISAR	NASA ISRO Synthetic Aperture Radar
NOAA	National Oceanic and Atmospheric Administration

NPR	NASA Procedural Requirements
OCI	Ocean Color Instrument
Orion	Orion Multi-Purpose Crew Vehicle
OSIRIS-REx	Origins-Spectral Interpretation-Resource Identification Security-Regolith Explorer
PSP	Parker Solar Probe
PACE	Plankton, Aerosol, Cloud, ocean Ecosystem
QueSST	Quiet Supersonic Technology
RBI	Radiation Budget Instrument
SCaN	Space Communication and Navigation
SCCS	Spaceport Command and Control System
SCS	Sampling and Caching System
SDO	Solar Dynamics Observatory
SEIS	Seismic Experiment for Interior Structure
SGSS	Space Network Ground Segment Sustainment
SLS	Space Launch System
SPC	Solar Probe Cup
SWOT	Surface Water and Ocean Topography
TESS	Transiting Exoplanet Survey Satellite
VBB	Very Broad Band
WFIRST	Wide-Field Infrared Survey Telescope
WICN	Workforce Information Cubes for NASA

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
441 G St. N.W.
Washington, DC 20548

May 1, 2018

Congressional Committees

The National Aeronautics and Space Administration (NASA) is planning to invest about $61 billion over the life cycle of its current portfolio of 26 major projects—those projects that have a life-cycle cost over $250 million. These projects aim to continue exploring Earth and the solar system and extend human presence beyond low Earth orbit, among other things. This report provides an overview of NASA's planning and execution of these major acquisitions—an area that has been on GAO's high risk list since 1990.[1] It includes assessments of NASA's key projects across mission areas, such as the Space Launch System for human exploration, Mars 2020 for planetary science, and Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2) for Earth science.

The explanatory statement of the House Committee on Appropriations accompanying the Omnibus Appropriations Act, 2009 includes a provision for us to prepare project status reports on selected large-scale NASA programs, projects, and activities.[2] This is our 10th annual report responding to that mandate. This report assesses (1) the cost and schedule performance of NASA's portfolio of major projects, (2) the maturity of critical technologies and stability of project designs at key points in the development process, and (3) the extent to which NASA is assessing future workforce capacity challenges that may affect its ability to manage its portfolio of projects. This report also includes individual assessments of 26 major NASA projects. When NASA determines that a project has an estimated life-cycle cost of over $250 million, we include that project in our annual review up through launch or completion.

To assess the cost and schedule performance, technology maturity, and design stability of NASA's major projects, we collected information on these areas from projects using a data collection instrument, analyzed projects' monthly status reports, interviewed NASA project and

[1]GAO, *High-Risk Series: Progress on Many High-Risk Areas, While Substantial Efforts Needed on Others*, GAO-17-317 (Washington, D.C.: Feb. 15, 2017).

[2]See Explanatory Statement, 155 Cong. Rec. H1653, 1824-25 (daily ed., Feb. 23, 2009), on H.R. 1105, the Omnibus Appropriations Act, 2009, which became Pub. L. No. 111-8. In this report, we refer to these projects as major projects rather than large-scale projects as this is the term used by NASA.

headquarters officials, and reviewed project documentation. There are 26 major projects in total, but the information available depends on where a project is in its life cycle.[3] For the 17 projects in the implementation phase, we compared cost and schedule estimates as of February 2018 to their original cost and schedule baselines, identified the number of technologies being developed, and assessed their technology maturity against GAO-identified acquisition best practices and NASA policy. We also compared the number of releasable design drawings at the critical design review against GAO-identified acquisition best practices and analyzed subsequent design drawings changes. We reviewed historical data on cost and schedule performance, technology maturity, and design stability for major projects from our prior reports and compared it to the performance of NASA's current portfolio of major projects.

To assess the extent to which NASA is assessing future workforce capacity, we reviewed NASA assessments of technical capabilities and business services, interviewed officials responsible for the assessments and implementing recommendations from the assessments, including officials within the Office of Human Capital Management, and analyzed workforce data found in a NASA database. We determined that the data were sufficiently reliable for our purpose by reviewing responses to data reliability questions from knowledgeable agency officials and the data for obvious errors.

Finally, to conduct our 26 project assessments, we analyzed monthly status reports and interviewed project officials to identify major sources of risk and the strategies that projects are using to mitigate them. Appendix I contains detailed information on our scope and methodology.

We conducted this performance audit from April 2017 to May 2018 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that

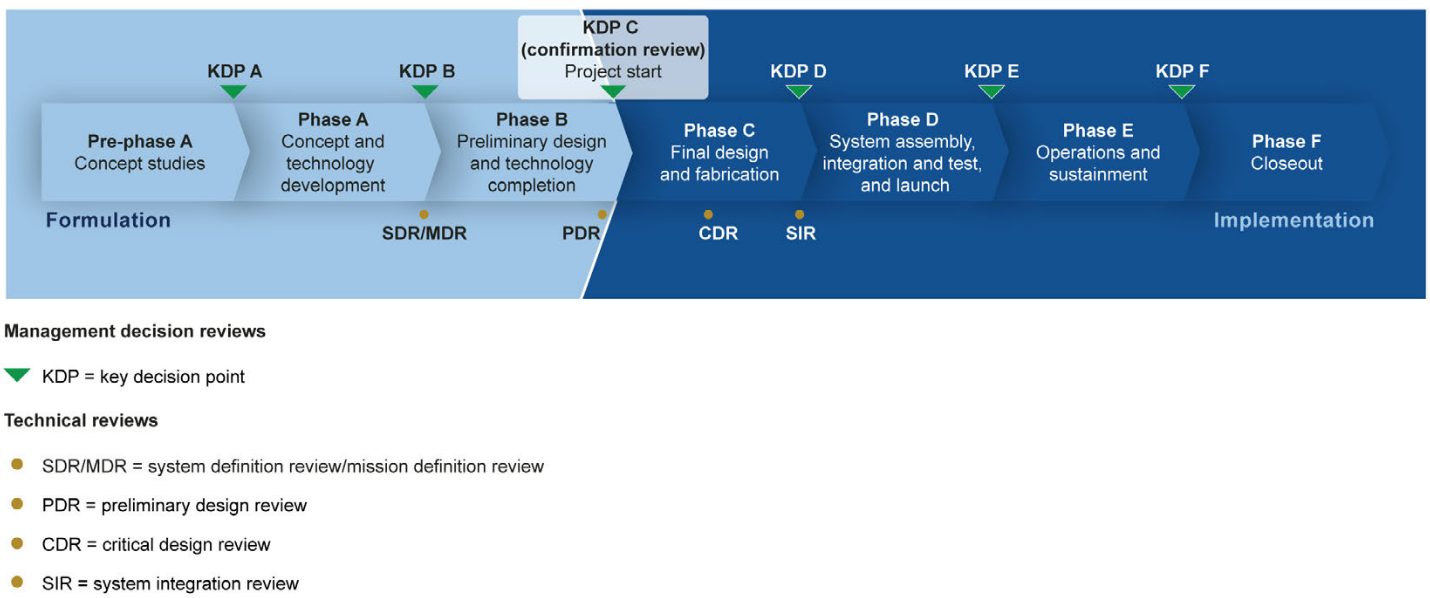
[3]Eight projects were in an early stage of development, called formulation, when there are still unknowns about requirements, technology, and design. For those projects, we reported preliminary cost ranges and schedule estimates. The Commercial Crew Program has a tailored project life cycle and project management requirements. As a result, it was excluded from our cost and schedule performance, technology maturity, and design stability analyses.

the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

The life cycle for NASA space flight projects consists of two phases—formulation, which takes a project from concept to preliminary design, and implementation, which includes building, launching, and operating the system, among other activities. NASA further divides formulation and implementation into phase A through phase F. Major projects must get approval from senior NASA officials at key decision points before they can enter each new phase. Figure 1 depicts NASA's life cycle for space flight projects.

Figure 1: NASA's Life Cycle for Space Flight Projects



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-18-280SP

Project formulation consists of phases A and B, during which the projects develop and define requirements, cost and schedule estimates, and the system's design for implementation. NASA Procedural Requirements 7120.5E, NASA Space Flight Program and Project Management Requirements, specifies that during formulation, the project must complete a formulation agreement to establish the technical and acquisition work that needs to be conducted during this phase and define the schedule and funding requirements for that work. The formulation agreement should identify new technologies and their planned development, the use of heritage technologies, risk mitigation plans, and testing plans to ensure that technologies will work as intended in a relevant environment. Prior to entering phase B, projects develop a range of the project's expected cost and schedule which is used to inform the budget planning for that project. During phase B, the project also develops programmatic measures and technical leading indicators, which track various project metrics such as requirement changes, staffing demands, and mass and power utilization. Near the end of formulation, leading up to the preliminary design review, the project team completes technology development and its preliminary design.

Formulation culminates in a review at key decision point C, known as project confirmation, where cost and schedule baselines are established and documented in a decision memorandum. The decision memorandum outlines the management agreement and the agency baseline commitment. The management agreement can be viewed as a contract between the agency and the project manager. The project manager has the authority to manage the project within the parameters outlined in the agreement. The agency baseline commitment includes the cost and schedule baselines against which the agency's performance on a project may be measured.

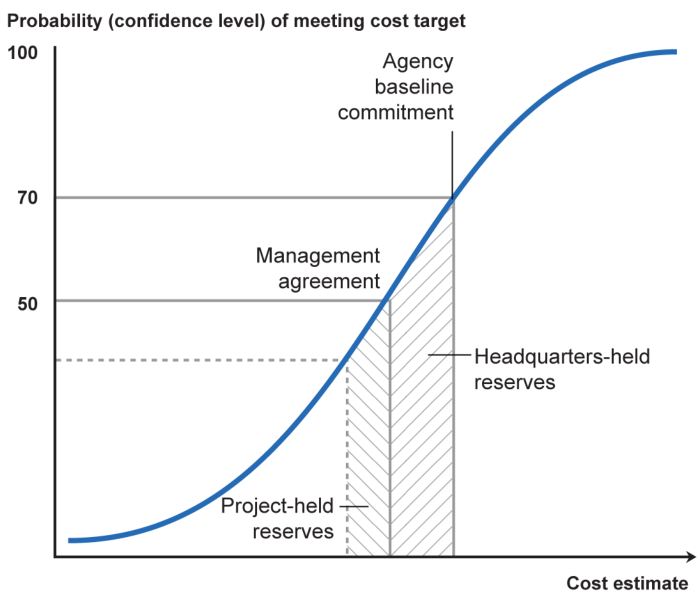
To inform the management agreement and the agency baseline commitment, each project with a life-cycle cost estimated to be greater than $250 million must also develop a joint cost and schedule confidence level (JCL). The JCL initiative, adopted in January 2009, produces a point-in-time estimate that includes, among other things, all cost and schedule elements in phases A through D, incorporates and quantifies known risks, assesses the impacts of cost and schedule to date, and addresses available annual resources. NASA policy requires that projects be baselined and budgeted at the 70 percent confidence level and funded at a level equivalent to at least the 50 percent confidence level.[4]

The management agreement and agency baseline commitment include cost and schedule reserves held at the project and NASA headquarters-

[4]NASA Procedural Requirements (NPR) 7120.5E, *NASA Space Flight Program and Project Management Requirements* paras 2.4.4 and 2.4.4.2 (Aug. 14, 2012) (hereinafter cited as NPR 7120.5E (Aug. 14, 2012)). The decision authority for a project can approve it to move forward at less than the 70 percent confidence level. That decision must be justified and documented.

level, respectively.[5] Cost reserves are for costs that are expected to be incurred—for instance, to address project risks—but are not yet allocated to a specific part of the project. Schedule reserves are extra time in project schedules that can be allocated to specific activities, elements, and major subsystems to mitigate delays or address unforeseen risks. Project-held cost and schedule reserves are within the project manager's control. If the project requires additional time or money beyond the management agreement—for example, if a project needs additional funds for an issue outside of the project's control—NASA headquarters may allocate headquarters-held reserves. Figure 2 notionally depicts how NASA would distribute cost reserves for a project that was baselined in accordance with its JCL policy.

Figure 2: Notional Distribution of Cost Reserves for a Project Budgeted at the 70 Percent Confidence Level



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-18-280SP

The total amount of cost and schedule reserves held at the project level varies based on where the project is in its life cycle. Seven NASA centers or laboratories are responsible for managing 25 NASA major projects. Of these, four centers or laboratories manage 20 of the 25 major projects

[5]NASA refers to cost reserves as unallocated future expenses.

and require or recommend that projects hold a certain level of cost and schedule reserves at key project milestones.[6] For example, at the Goddard Space Flight Center, projects are required to hold cost reserves equal to at least 25 percent of the estimated cost remaining at the project confirmation review, and 10 percent at the time of delivery to the launch site. Projects track their reserves between phases to help ensure they hold reserves consistent with these requirements. The 26th major project included in our review, the Low Boom Flight Demonstrator (LBFD), does not have a lead center because it is using a virtual project office model. Project officials said they have not yet determined which center cost and schedule guidelines the project will follow.

After a project is confirmed, it begins implementation, consisting of phases C, D, E, and F. In this report, we refer to projects in phase C and D as being in development. A critical design review is held during the latter half of phase C in order to determine if the design is mature enough to support proceeding with the final design and fabrication. After the critical design review and just prior to beginning phase D, the project completes a system integration review to evaluate the readiness of the project and associated supporting infrastructure to begin system assembly, integration and test. In phase D, the project performs system assembly, integration, test, and launch activities. Phases E and F consist of operations and sustainment and project closeout.

NASA Projects Reviewed in GAO's Annual Assessment

NASA's portfolio of major projects ranges from satellites equipped with advanced sensors to study the Earth to a rover that plans to collect soil or rock samples on Mars to telescopes intended to explore the universe to spacecraft to transport humans and cargo beyond low-Earth orbit. When NASA determines that a project will have an estimated life-cycle cost of more than $250 million, we include that project in our annual review. After

[6]Goddard Procedural Requirements 7120.7A, *Schedule and Budget Margins for Flight Projects* (Feb. 28, 2017); Marshall Procedural Requirements 7120.1, *Marshall Space Flight Center Engineering and Program/Project Management Requirements* (Aug. 26, 2014); Langley Research Center, *Space Flight Project Practices Handbook*, LPR 7120.5 B-1 (Mar. 17, 2014); and Jet Propulsion Laboratory, *Flight Project Practices*, *Rev. 8* (Oct. 6, 2010). The Kennedy Space Center and Johnson Space Center do not have center-specific guidance for reserves. The Johns Hopkins University Applied Physics Laboratory manages the Parker Solar Probe (PSP) and Double Asteroid Redirection Test (DART) projects and has guidelines for schedule reserves, but not for cost reserves. The Johns Hopkins University Applied Physics Laboratory SD-QP-012, Rev. b, *Space Exploration Sector (SES) Quality Procedure: Earned Value Management System (EVMS) Project Management Control System (PMCS)* (Apr. 4, 2017).

a project launches or reaches full operational capability, we no longer include an assessment of it in our annual report.

This report includes assessments of 26 major NASA projects (see table 1). Six projects are being assessed for the first time this year: Double Asteroid Redirection Test (DART), Laser Communications Relay Demonstration (LCRD), LBFD, Lucy, Psyche, and Restore-L. Prior to establishing its cost baseline, the LCRD project had an estimated life-cycle cost estimate of less than $250 million and therefore was not included in our previous reviews when the project was in formulation. For a list of the 26 projects and their current cost and schedule estimates, see appendix II. We did not complete an assessment for the Asteroid Redirect Robotic Mission project this year because, as of June 2017, the project closed out most project development activities at the direction of NASA headquarters. Appendix III includes a list of all the projects that we have reviewed from 2009 to 2017.

Table 1: Major NASA Projects Reviewed in GAO's 2018 Assessment by Phase

Projects in formulation	Double Asteroid Redirection Test (DART)
	Europa Clipper
	Low Boom Flight Demonstrator (LBFD)
	Lucy
	Plankton, Aerosol, Cloud, ocean Ecosystem (PACE)
	Psyche
	Restore-L
	Wide-Field Infrared Survey Telescope (WFIRST)
Projects in implementation	Commercial Crew Program (CCP)
	Exploration Ground Systems (EGS)
	Gravity Recovery and Climate Experiment Follow-On (GRACE-FO)
	Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2)
	Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport (InSight)
	Ionospheric Connection Explorer (ICON)
	James Webb Space Telescope (JWST)
	Landsat 9 (L9)
	Laser Communications Relay Demonstration (LCRD)
	Mars 2020
	NASA ISRO Synthetic Aperture Radar (NISAR)
	Orion Multi-Purpose Crew Vehicle (Orion)
	Parker Solar Probe (PSP) (formerly Solar Probe Plus)
	Radiation Budget Instrument (RBI)
	Space Launch System (SLS)
	Space Network Ground Segment Sustainment (SGSS)
	Surface Water and Ocean Topography (SWOT)
	Transiting Exoplanet Survey Satellite (TESS)

Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-18-280SP

Over the past 6 years, we have issued several reports assessing NASA's progress acquiring its largest projects and programs in more depth.[7] We found in July 2016 that all three human spaceflight programs—the Orion Multi-Purpose Crew Vehicle (Orion), the Space Launch System (SLS), and Exploration Ground Systems (EGS)—were making progress in resolving technical issues and maturing designs, but that pressure on the limited cost and schedule reserves put the schedule for their first combined mission, the uncrewed Exploration Mission-1 (EM-1), at risk.[8] Subsequently, in April 2017, we found that given the combined effects of ongoing technical challenges in conjunction with limited cost and schedule reserves, it was unlikely that these programs would achieve the planned November 2018 launch readiness date.[9] We recommended that NASA confirm whether this launch readiness date was achievable and, if warranted, propose a new, more realistic EM-1 date and report to Congress on the results of its schedule analysis. NASA agreed with both recommendations and stated that it was no longer in its best interest to pursue the November 2018 launch readiness date. In December 2017,

[7]GAO, *James Webb Space Telescope: Actions Needed to Improve Cost Estimate and Oversight of Test and Integration*, GAO-13-4 (Washington, D.C.: Dec. 3, 2012); *Space Launch System: Resources Need to be Matched to Requirements to Decrease Risk and Support Long Term Affordability*, GAO-14-631 (Washington, D.C.: July 23, 2014); *James Webb Space Telescope: Project Meeting Commitments but Current Technical, Cost, and Schedule Challenges Could Affect Continued Progress*, GAO-14-72 (Washington, D.C.: Jan. 8, 2014); *James Webb Space Telescope: Project Facing Increased Schedule Risk with Significant Work Remaining,* GAO-15-100 (Washington, D.C.: Dec. 15, 2014); *Space Launch System: Management Tools Should Better Track to Cost and Schedule Commitments to Adequately Monitor Increasing Risk,* GAO-15-596 (Washington, D.C.: July 16, 2015); *James Webb Space Telescope: Project on Track but May Benefit from Improved Contractor Data to Better Understand Costs,* GAO-16-112 (Washington, D.C.: Dec. 17, 2015);*NASA Human Space Exploration: Opportunity Nears to Reassess Launch Vehicle and Ground Systems Cost and Schedule,* GAO-16-612 (Washington, D.C.: July 27, 2016); *Orion Multi-Purpose Crew Vehicle: Action Needed to Improve Visibility into Cost, Schedule, and Capacity to Resolve Technical Challenges,* GAO-16-620 (Washington, D.C.: July 27, 2016); *NASA Commercial Crew Program: Schedule Pressure Increases as Contractors Delay Key Events,* GAO-17-137 (Washington, D.C.: Feb. 16, 2017); *NASA Human Space Exploration: Delay Likely for First Exploration Mission,* GAO-17-414 (Washington, D.C.: Apr. 27, 2017); *NASA Human Space Exploration: Integration Approach Presents Challenges to Oversight and Independence,* GAO-18-28 (Washington, D.C.: Oct 19, 2017); *NASA Commercial Crew Program: Continued Delays Pose Risks for Uninterrupted Access to the International Space Station,* GAO-18-317T (Washington, D.C.: Jan. 17, 2018); and *James Webb Space Telescope: Integration and Test Challenges Have Delayed Launch and Threated to Push Costs Over Cap,* GAO-18-273 (Washington, D.C.: Feb. 28, 2018).

[8]GAO-16-620 and GAO-16-612.

[9]GAO-17-414.

NASA approved a new EM-1 schedule of December 2019, with six months of schedule reserve available to extend the date to June 2020. In April 2018, NASA provided us with the letter the agency sent to Congress on its assessment of the EM-1 schedule. We are in the process of reviewing the letter to determine if it addresses our recommendation.

We have also reported for several years on the James Webb Space Telescope (JWST) project, which has experienced significant cost increases and schedule delays. Prior to being approved for development, cost estimates for JWST ranged from $1 billion to $3.5 billion, with expected launch dates ranging from 2007 to 2011. Before 2011, early technical and management challenges, contractor performance issues, low levels of cost reserves, and poorly phased funding levels caused JWST to delay work after confirmation, which contributed to significant cost and schedule overruns, including launch delays. Following an independent review that found JWST was executing well from a technical standpoint, but that the baseline cost estimate did not reflect the most probable cost with adequate reserves in each year of project execution, Congress placed an $8 billion cap on the formulation and development costs for the project in November 2011. NASA rebaselined JWST with a life-cycle cost estimate of $8.835 billion that included additional money for operations and a planned launch in October 2018.[10] In December 2017, we found that the JWST project continues to make progress towards launch, but the program is encountering technical challenges that require both time and money to fix and may lead to additional delays.[11]

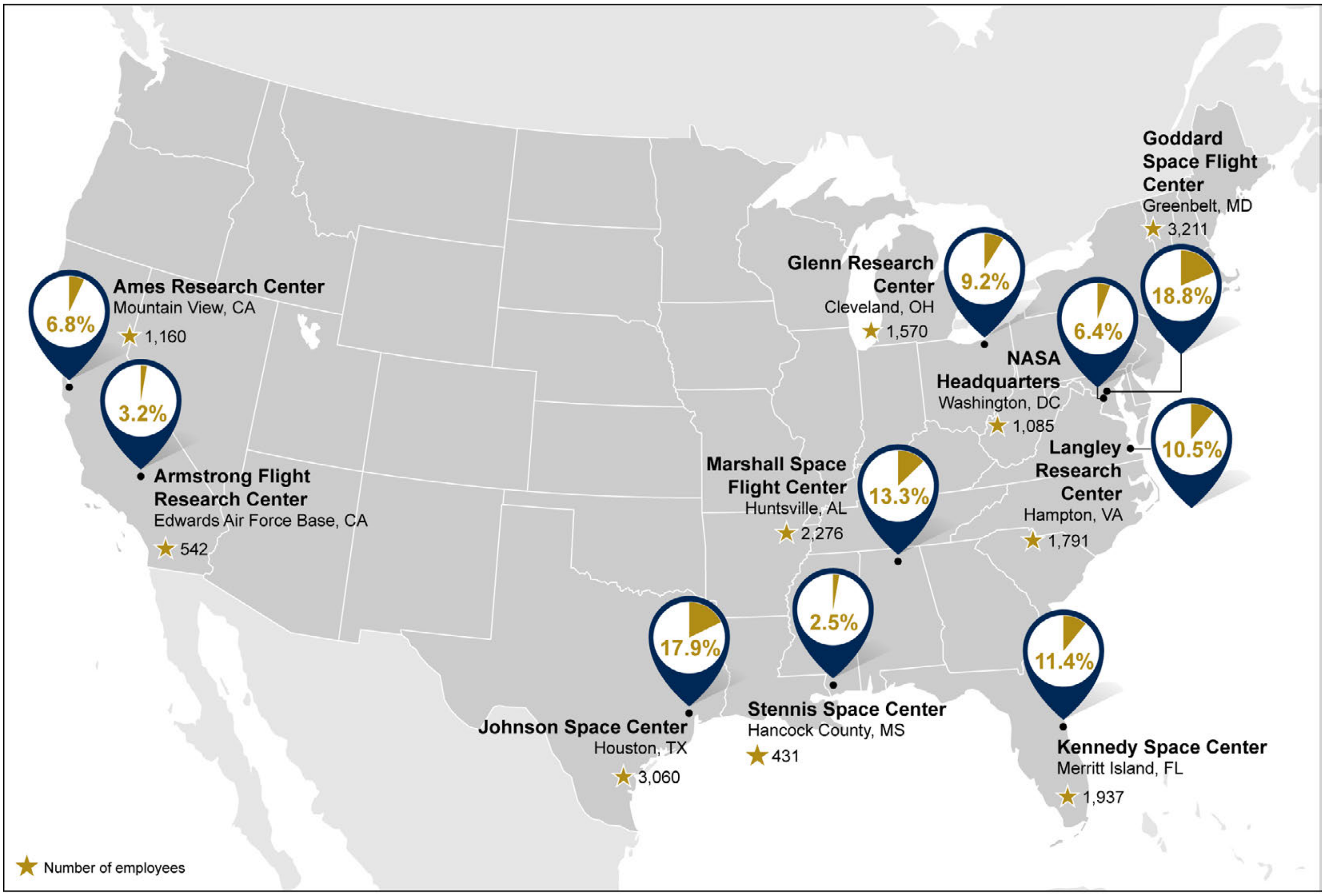
NASA's Workforce

In January 2018, NASA had a civil servant workforce of approximately 17,100 employees distributed among NASA Headquarters in Washington, D.C., and nine centers located around the country. Figure 3 shows the distribution of this workforce across NASA headquarters and the centers.

[10]A rebaseline is a process initiated if development costs increase by 30 percent or more and requires the NASA Administrator to transmit a report to the Committee on Science, Space, and Technology of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate.

[11]GAO, *NASA: Preliminary Observations on the Management of Space Telescopes*, GAO-18-277T (Washington, D.C.: Dec. 6, 2017).

Figure 3: NASA's Workforce Distribution at NASA Headquarters and Centers as of January 2018



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-18-280SP

Note: Civil servant staff within NASA's Shared Services Center are included in the total for the Stennis Space Center because the center is located there.

NASA also relies on a contractor workforce to accomplish its mission. NASA estimated that approximately 33,100 contractors would support NASA in 2018. The Jet Propulsion Laboratory is a federally funded research and development center under contract with NASA and is managed by the California Institute of Technology. It has about 5,500 employees, who primarily conduct NASA-related work. The Applied Physics Laboratory is a research center affiliated with Johns Hopkins

University and has about 6,300 employees, some of whom manage and support NASA projects.

Portfolio Cost and Schedule Deteriorated but Extent of Cost Growth Is Unknown

The cost and schedule performance of NASA's portfolio of major projects has deteriorated since last year, but the extent of cost performance deterioration is unknown. NASA lacks a current cost estimate for its Orion crew capsule—one of the largest programs in the portfolio—but expects the program will exceed its cost baseline when NASA updates the program's life-cycle cost estimate. Because the Orion program accounts for about 22 percent of all development costs, even a small percentage of cost growth for the Orion program could significantly affect cost performance. The known negative cost and schedule performance is largely driven by the cost and schedule growth of four projects—SLS, EGS, Space Network Ground Segment Sustainment (SGSS) and Mars 2020—that experienced technical problems compounded by programmatic challenges. Together, these projects experienced $638 million in cost growth and 59 months in aggregate schedule delays. Two projects—JWST and ICESat-2—experienced schedule delays due to technical challenges identified during integration and test. Another 3 projects—NASA ISRO Synthetic Aperture Radar (NISAR), Ionospheric Connection Explorer (ICON), and Gravity Recovery and Climate Experiment Follow-On (GRACE-FO)—experienced cost growth or delays largely due to factors outside of the projects' control, such as launch vehicle delays.

NASA is at risk of continued cost increases and schedule delays as newer, complex projects begin development and expensive projects linger in the portfolio longer than expected due to delays. Several projects that experienced schedule delays or cost increases will face further challenges completing integration and test—the phase of development that often reveals unforeseen challenges that can lead to cost and schedule growth—that could result in additional cost and schedule growth.

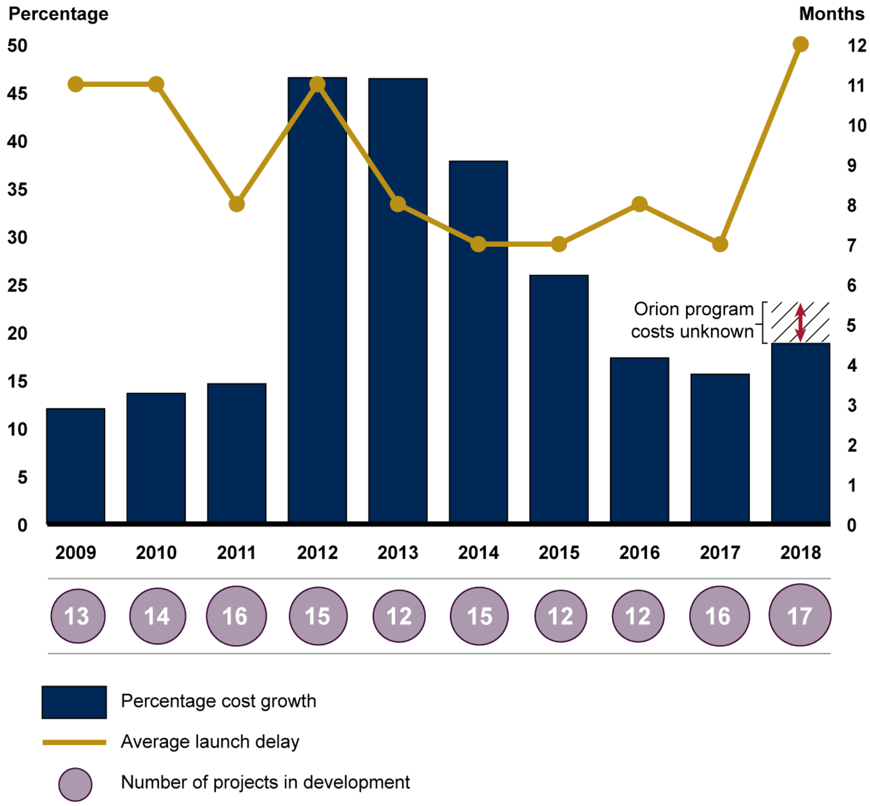
Portfolio Average Launch Delays Increased, but NASA Lacks a Current Orion Program Cost Estimate to Determine Extent of Cost Growth

Since we last reported in May 2017, the average launch delay increased to 12 months, up from 7 months in 2017—the highest schedule delay we have reported to date.[12] We are not able to determine the extent of portfolio cost growth this year because NASA does not have a current cost estimate for the Orion program—one of the largest programs in its portfolio—and officials expect the cost to increase. As of June 2017, the Orion program's development cost was about $6.6 billion and based on that estimate it accounts for 22 percent of the portfolio's estimated $30.1 billion of development costs. As a result, a small percentage of cost growth for the Orion program could significantly affect cost performance. Even without including Orion cost growth, the overall development cost growth for the portfolio of 17 development projects increased to 18.8 percent, up from 15.6 percent in 2017 (see figure 4).[13]

[12]GAO, *NASA: Assessments of Major Projects*, GAO-17-303SP (Washington, D.C: May 16, 2017).

[13]We have historically presented cost and schedule performance including and excluding the James Webb Space Telescope (JWST) because, prior to 2015, it had a development cost baseline significantly larger than other projects and the magnitude of its cost growth masked the performance of the remainder of the portfolio. Now that other projects in the portfolio, such as Orion and the Space Launch System, have large development cost baselines, we no longer present cost performance trends excluding JWST.

Figure 4: Development Cost Performance and Average Launch Delay for Major NASA Projects from 2009 to 2018



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-18-280SP

Note: The years in the figure are the year we issued our report. Cost and schedule performance is compared across each report period.

Senior-level NASA officials told us that they expect that the Human Exploration and Operations Mission Directorate and the Orion program will complete an updated life-cycle cost estimate in June 2018. This would be approximately 10 months after the program raised to senior-level officials' attention that the program expects cost growth over its cost baseline to the second combined mission, Exploration Mission 2 (EM-2), during an August 2017 briefing concerning potential cost increases related to the EM-1 launch delay.

Seven of 17 NASA major projects stayed within cost and schedule estimates since we last reported in May 2017, but 9 projects experienced cost growth or schedule delays and cost growth is expected for the Orion program. Table 2 provides data on the cost and schedule performance for the 17 major projects in development that have cost and schedule baselines since we last reported on the portfolio's performance in May 2017.[14]

Table 2: Development Cost and Schedule Performance of Selected Major NASA Projects Currently in Development

Overall performance	Project	Confirmation date	Changes since May 2017		Cumulative performance	
		Year	Cost (millions)	Schedule (months)	Cost (millions)	Schedule (months)
Lower than expected cost	PSP	2014	$0.0	0	-$5.4	0
	GRACE-FO	2014	-$1.6	3	-$2.2	3
	TESS	2014	-$13.1	-2	-$39.9	-2
Within baseline	ICON	2014	$0.0	8	$0.0	8
	SWOT	2016	$0.0	0	$0.0	0
	LCRD	2017	$0.0	0	$0.0	0
	Landsat 9	2017	$0.0	0	$0.0	0
Higher than expected cost	Mars 2020[a]	2016	$12.9	0	$10.7	0
	NISAR	2016	$22.0	0	$22.0	0
Replan[c]	InSight	2014	$0.0	0	$131.7	26
	EGS (EM-1)	2014	$417.8	19	$421.4	19
	SLS (EM-1)	2014	$147.8	19	$147.8	19
Rebaseline[c]	JWST	2008	$0.0	19	$3,607.7	71
	ICESat-2	2012	$1.4	4	$206.3	17
	SGSS[b]	2013	$59.5	21	$421.6	48
Canceled	RBI	2016	$0.0	0	$0.0	0
Under revision	Orion (EM-2)[d]	2015	$0.0	0	-$151.7	0
Total:			**$646.7**	**91**	**$4,770.0**	**209**

Legend: PSP: Parker Solar Probe; GRACE-FO: Gravity Recovery and Climate Experiment Follow-On; TESS: Transiting Exoplanet Survey Satellite; ICON: Ionospheric Connection Explorer; SWOT: Surface Water and Ocean Topography; NISAR: NASA Indian Space Research Organisation – Synthetic Aperture Radar; LCRD: Laser Communications Relay Demonstration; InSight: Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport; EGS: Exploration Ground Systems; SLS: Space Launch System; EM-1: Exploration Mission 1; JWST: James Webb Space Telescope; ICESat-2: Ice, Cloud, and Land Elevation Satellite-2; SGSS: Space Network Ground Segment Sustainment; RBI: Radiation Budget Instrument; Orion: Orion Multi-Purpose Crew Vehicle; EM-2: Exploration Mission 2.

Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-18-280SP

Note: Positive values indicate cost growth or launch delays. Negative values indicate cost decreases or earlier than planned launch dates.

[a]The Mars 2020 project used $2.2 million in funds originally budgeted for development for formulation activities. This partially offsets an increase of $12.9 million in development cost growth primarily due

[14]GAO-17-303SP.

to increased costs associated with a technology demonstration instrument and entry, descent, and landing instrument.

[b]The SGSS project reported cost growth up through its first operational readiness review, which is currently planned for the end of fiscal year 2019. However, the project expects that there could be additional cost and schedule growth beyond what is reported here.

[c]A replan is a process initiated if development costs increase by 15 percent or more. NASA replanned the SLS program even though development costs did not increase by 15 percent or more. A replan does not require a new project baseline to be established. A rebaseline is a process initiated if development costs increase by 30 percent or more. Both processes require NASA to submit a report to relevant congressional committees. In addition, if a project or program milestone is likely to be delayed by 6 months or more, this report is also required.

[d]NASA officials said they are revising the Orion program's life-cycle cost estimate and expect to complete a new estimate in June 2018. The new cost is expected to exceed the program's development cost baseline. The current costs in the table reflect the estimate provided in June 2017. The cumulative cost change reflects the program shifting $151.7 million of funding previously budgeted for the development phase to the formulation phase.

The deteriorating cost and schedule performance of the portfolio in 2018 is the result of

- four projects—SLS, EGS, SGSS, and Mars 2020—addressing technical challenges that were compounded by risky programmatic decisions;
- two projects—JWST and ICESat-2—experiencing delays due to technical challenges identified during integration and test; and
- three projects—NISAR, ICON, and GRACE-FO—experiencing cost growth or delays largely due to factors outside of the projects' control.

We elaborate on these three scenarios below.

Technical challenges compounded by risky programmatic decisions. Together, SLS, EGS, SGSS, and Mars 2020 experienced $638 million in cost growth and 59 months in aggregate schedule delays due to technical problems that were compounded by programmatic challenges since our May 2017 report.[15] The SLS and EGS programs experienced cost growth and schedule delays associated with EM-1, their first combined mission along with the Orion program. We have found for several years that the human spaceflight programs—Orion, SLS, and EGS—are making progress maturing designs and building hardware, but also are experiencing some significant engineering and manufacturing challenges. For example, the SLS program ran into numerous challenges

[15]GAO-17-303SP.

completing the welding of its core stage element in 2017. The program stopped welding on the core stage for months to identify and resolve low weld strength in the liquid oxygen and liquid hydrogen tanks due to low weld strength measurements found in the liquid oxygen tanks caused by a program and contractor decision to change the weld tool configuration during fabrication. The EGS program also experienced technical challenges, including with the design and installation of the ground support equipment and the 10 umbilicals that connect SLS and Orion to the Mobile Launcher—which supports the assembly, testing, and servicing of SLS and provides the platform on which SLS and Orion will launch.

Finally, although the Orion program has not yet reported cost growth, it also experienced technical challenges. These challenges included software delays and hardware delays, and at least 14 months of delays with the European Service Module—which provides air, water, power, and propulsion to Orion during in-space flight—since the element's critical design review in June 2016. In April 2017, we found that, according to program officials, the delays with the service module were largely due to NASA, the European Space Agency, and the European Space Agency contractor underestimating the time and effort necessary to address design issues for the first production service module and the availability of parts from suppliers and subcontractors. NASA expects the Orion program to experience cost growth over its cost baseline to the second combined mission, EM-2. However, the extent of the growth is unknown because, as noted above, NASA is currently revising its life-cycle cost estimate.

Technical challenges such as these are not unusual for large-scale programs, especially human exploration programs that are inherently complex and difficult. However, we have found that NASA has made programmatic decisions—including establishing low cost and schedule reserves, managing to aggressive schedules, and not following best practices for earned value management or creating reliable cost and schedule baselines—that have compounded the technical challenges (see table 3). As a result, the three human spaceflight programs have been at risk of cost and schedule growth since NASA approved their baselines.

Table 3: Examples of Risky Programmatic Decisions Made by NASA's Human Spaceflight Programs

Programmatic decision	Example(s)	Negative effect	GAO report(s)
NASA baselined the Exploration Ground Systems (EGS), Orion Multi-Purpose Crew Vehicle (Orion), and Space Launch System (SLS) programs with low cost and schedule reserves.	In July 2016, we found that NASA baselined the SLS program with cost reserves of less than 2 percent, even though guidance for Marshall Space Flight Center—the NASA center with responsibility for the SLS program—established standard cost reserve for launch vehicle programs of 20 percent when the baseline is approved.	Operating with low cost and schedule reserves limits a program's ability to address risks and unforeseen technical challenges.	GAO-17-414 and GAO-16-612
NASA managed the EGS, Orion, and SLS programs to an internal schedule for completing development production that was aggressive and could exacerbate delays and lead to cost overruns.	In July 2016, we found that the EGS program planned to conduct the mobile launcher's verification and validation concurrent with ground support equipment systems and umbilicals installation to support the program's internal schedule goal. We found this to be a risky practice because of uncertainties regarding how systems not yet installed may affect the systems already installed.	Working towards a more aggressive internal goal is not a bad practice; however, increasing cost and schedule risk to the program in order to pursue such a goal is not beneficial to programs in the long term.	GAO-16-620 and GAO-16-612
The SLS program did not follow best practices for using earned value management, which integrates the project scope of work with cost, schedule, and performance elements for optimum project planning and control.	In July 2016, we found that the SLS program had not positioned itself well to provide accurate assessments of progress with the core stage because it operated for several years without a performance measurement baseline that is necessary to support full earned value management reporting. The use of earned value management is advocated by both GAO's best practices for cost estimating and NASA's own guidance.	Programs that do not use earned value data are limited in their ability to have accurate assessments of project progress, produce early warning signs of impending schedule delays and cost overruns, and provide unbiased estimates of anticipated costs at completion.	GAO-16-612
The Orion and SLS programs established baselines that were not fully reliable.[a]	In July 2016, we found that the Orion program did not generally follow best practices in preparing its cost and schedule estimates, which were key inputs into the program's joint cost and schedule confidence level processes and baseline. In July 2015, we found that cost and schedule estimates for the SLS program substantially met five of six characteristics that GAO considers best practices for preparing reliable estimates, but could not be deemed fully reliable because they only partially met the sixth characteristic—credibility.	Without sound cost and schedule estimates, decision makers do not have a clear understanding of the cost and schedule risk inherent in the program or important information needed to make programmatic decisions.	GAO-16-620 and GAO-15-596

Source: GAO analysis of prior GAO reports. | GAO-18-280SP

[a]We did not assess EGS's cost and schedule estimates compared to best practices.

In December 2017, NASA announced the new internal launch readiness date for EM-1 is now December 2019, and has allocated 6 months of schedule reserve available to extend the date to June 2020 for possible manufacturing and production schedule risks. This represents a delay of 13-19 months for EM-1. It is too soon to know if NASA has addressed the programmatic challenges identified above but we will continue to follow up through future reviews.

Similarly, the SGSS project experienced new cost growth of $59.5 million and delayed its completion by 21 months. Project officials attributed the cost growth and delays to the contractor's incomplete understanding of its requirements, which led to poor contractor plans and late design changes. But project management has been a challenge as well.[16] The project has historically struggled to manage contractor performance and has faced both contractor and project staffing shortfalls, as we found in our prior reports starting in 2013.[17] For example, NASA managers noted concerns with contractor plans and staffing estimates in 2013 during project confirmation. In March 2015, we found that the project was being rebaselined due to the contractor's poor cost and schedule performance and limitations that NASA placed on the funding available to the contractor in fiscal years 2014 and 2015. The contractor was also operating with a limited number of staff at that time. In May 2017, we found that the project continued to experience contractor performance problems and had experienced cost growth and schedule delays over the 2015 rebaseline even as the project decreased its scope. In addition, the project experienced staff shortfalls in key areas, such as systems engineering and business management.

The Mars 2020 project experienced $12.9 million in development cost growth, but no schedule delays. The cost growth was primarily due to technical challenges on a technology demonstration instrument and

[16]In 2016, NASA announced it was reclassifying SGSS as a hybrid sustainment project for the Space Network. A hybrid sustainment effort is a sustainment effort that still includes development work. The SGSS project expects to experience additional cost growth and schedule delays, but the exact magnitude is unknown. The project was reevaluating its cost and schedules through its final acceptance review at the time of our review.

[17]GAO, *NASA: Assessments of Selected Large-Scale Projects*, GAO-13-276SP (Washington, D.C.: Apr. 17, 2013); *NASA: Assessments of Selected Large-Scale Projects*, GAO-14-338SP (Washington, D.C.: Apr. 15, 2014); *NASA: Assessments of Selected Large-Scale Projects*, GAO-15-320SP (Washington, D.C.: Mar. 24, 2015); *NASA: Assessments of Major Projects,* GAO-16-309SP (Washington, D.C.: Mar. 30, 2016); and GAO-17-303SP.

higher than anticipated integration costs for an entry, descent, and landing instrument. Both instruments are funded by the Human Exploration and Operations and Space Technology Mission Directorates. NASA officials attributed the cost growth of the technology demonstration instrument—which is designed to convert carbon dioxide to oxygen—to the complexity of the technology development for the effort. At the project's preliminary design review in February 2016, a critical technology for the technology demonstration instrument did not meet the recommended level of maturity, which we have found can increase risk for systems entering product development. The project had matured the technology to this recommended level by its critical design review in February 2017. However, as a result of the focus on maturing this particular technology, other components of the instrument fell behind the planned schedule. Project costs for Mars 2020 also increased for an entry, descent, and landing instrument, due, in part, to cost increases for integration and to add additional staff to the instrument team to maintain schedule.

Finally, the RBI project would have likely exceeded its cost baseline if NASA had not decided to cancel the project in January 2018. According to NASA's cancellation memorandum, the project was canceled because of continued cost growth, technical issues, and poor contractor performance. In 2017, we found that the project was working to an aggressive schedule, and the prime contractor continued to experience cost overruns even after NASA added a deputy project manager and increased site visits and meetings with the contractor.[18] Subsequently, the project—which was developing an instrument to be hosted on a National Oceanic and Atmospheric Administration satellite—determined that it would not be able to meet its delivery date for integration with the satellite without requiring additional funding in excess of the project's cost baseline if other technical issues arose. In its cancellation memorandum, NASA stated continuing to fund RBI from within the Earth Science Division budget would slow other important activities.

Technical challenges identified during integration and test. The JWST and ICESat-2 projects experienced technical challenges during integration and test that delayed their schedules. Both projects were previously rebaselined before entering system-level integration and testing, and the current schedule delays are beyond the new schedules

[18]GAO-17-303SP.

that NASA set for the projects in 2011 for JWST and in 2014 for ICESat-2.

- The JWST project delayed its launch readiness date by at least 19 months from October 2018 to May 2020. NASA announced two delays for the project since our last portfolio-wide review in May 2017.[19] First, as we found in February 2018, the project delayed its launch readiness date by up to 8 months primarily due to the integration of the various spacecraft elements taking longer than expected.[20] Specifically, execution of spacecraft integration and test tasks, due to complexity of work and cautious handling given the sensitivity of flight hardware, was slower than planned. In addition, before the delay, the project used all of its schedule reserves to its prior launch readiness date. This was the result of various contractor workmanship errors, particularly with respect to the spacecraft propulsion systems, as well as the resolution of various technical issues, including a test anomaly on the telescope and sunshield hardware challenges. Second, in March 2018, NASA announced that it had delayed the project's launch readiness date by an additional 11 months to approximately May 2020 and planned to establish an external independent review board to analyze the project's organizational and technical issues to inform a more specific launch time frame.

  The announcement also stated that after a new launch date is established, NASA would provide a new cost estimate that may exceed the $8 billion congressional cost cap that was established in 2011. NASA plans to finalize the project's cost and schedule in June 2018. Because the additional delays were announced while a draft of this report was with NASA for comment, we plan to follow up on the reasons for the additional delays and the results of the analysis in a future review.

- The ICESat-2 project delayed its launch readiness date by 4 months from June to October 2018 due to technical issues with its only instrument, the Advanced Topographic Laser Altimeter System. A key part in the instrument's lasers failed during instrument environmental testing, which delayed the project's system integration review—the start of system-level integration and test. The manufacturer determined the primary cause of the anomaly was a flaw in the design

[19] GAO-17-303SP.

[20] GAO-18-273.

of the mount that ensures a component of the optical module remains in a specific, precise position. The spare flight laser encountered the same problem during earlier testing, which indicated a systemic problem. The project redesigned and repaired the lasers and is proceeding through integration and test.

External factors. External factors—including responding to requests for additional data collection and delays due to launch-vehicle related issues—contributed to cost increases or schedule delays for the NISAR, ICON, and GRACE-FO projects.

- The NISAR project experienced cost growth as the result of an increase in the scope of data collection in response to additional data needs being identified by an interagency working group. The additional data includes soil moisture and natural hazard data that would be of value for other federal agencies and the science community. NASA officials said the additional funding for development would be used to upgrade the ground stations so that they can receive the additional data at a higher downlink data rate and volume.
- The ICON project missed its committed launch readiness date because of an accident involving its launch vehicle. In January 2017, two of the Pegasus launch vehicle's three stages were involved in a transport accident. The stages were subsequently returned to the launch vehicle contractor facility for inspection and testing, and no damage was found. The project had been on track to launch early. Subsequently, in September 2017, an anomaly found in testing of the launch vehicle bolt cutter assemblies resulted in additional delays, but the magnitude of these delays is not yet known; an investigation is underway.
- The GRACE-FO project delayed its launch readiness date from February to May 2018 due to issues with its planned launch vehicle and launch site. The launch vehicle is the responsibility of NASA's partner on the project—German Research Centre for Geosciences (GFZ). GRACE-FO had planned to launch at a Russian launch site. In February 2016, GFZ reported that it was notified by the Russian Federal Space Agency that the Dnepr launch vehicle was no longer available for GRACE-FO. GFZ, in June 2016, arranged to launch the two GRACE-FO spacecraft, along with commercial satellites, on a SpaceX Falcon 9.

In addition, the Commercial Crew Program also experienced delays, which are not included above because the program does not have a schedule baseline. Since the award of the current Commercial Crew contracts in September 2014, the program, Boeing, SpaceX, and multiple independent review bodies have all identified the contractors' delivery schedules as aggressive. In February 2017, we found that Boeing and SpaceX had determined that neither could meet their original 2017 dates for NASA to certify their systems for human spaceflight.[21] In January 2018, we found that both contractors had notified NASA that final certification dates have slipped again and are now in the first quarter of calendar year 2019.[22] The Commercial Crew Program's schedule analysis indicates that certification may be further delayed to December 2019 for SpaceX and February 2020 for Boeing.

NASA Is at Risk of Continued Cost Increases and Schedule Delays as Newer, Complex Projects Begin Development and Expensive Projects Linger

In 2016 and 2017, we found that projects appear most likely to rebaseline between their critical design review and system integration review—the riskiest point in the development cycle.[23] Of the 14 projects in NASA's current portfolio of major projects that have held a critical design review, 3 had to rebaseline before holding a system integration review. An additional 4 projects experienced cost growth after critical design review, but the cost growth did not require a rebaseline. Further, most of the projects that have experienced cost growth during this risky point in the development cycle are not small projects. All but one has a current life-cycle cost estimate of over $1 billion and include NASA's flagship missions, like JWST and Mars 2020. The total development cost growth for these 7 projects is about $4.9 billion to date, but additional cost growth could occur as the projects are not yet complete.

The composition of the portfolio in the coming years is expected to include similarly large and complex projects, putting NASA at risk of continued cost increases and schedule delays. Specifically, NASA plans to have complex projects enter the development portfolio in the next few years as they hold confirmation reviews and set cost and schedule baselines. This includes the Europa Clipper project and potentially the Wide-Field Infrared Survey Telescope (WFIRST) project. In February 2018, the President's 2019 Budget Request proposed canceling the WFIRST project due to the project's significant costs and higher priorities in the agency. However, the project may continue if funding is received.

[21] GAO-17-137.

[22] GAO-18-317T.

[23] GAO-16-309SP and GAO-17-303SP.

Together, preliminary estimates indicate that these two projects could cost as much as $7.8 billion. In addition, NASA expects to begin other large, complex projects like the Lunar Orbital Platform-Gateway—currently being discussed as a space station or outpost in lunar orbit—and a Europa Lander project in the coming years. A December 2017 space policy directive also instructed NASA to return astronauts to the moon for long-term exploration and to pursue human exploration of Mars and the broader solar system.

To its credit, NASA recently took steps to put a process in place to control the costs of two projects while in formulation, which may prove useful if properly executed.

- The Europa Clipper project implemented a process whereby cost growth threats would be offset by descoping instruments in whole or in part. For example, if an instrument exceeds its development cost by 20 percent, the project would propose a descope option to NASA that brings instrument cost below that threshold. NASA has not descoped any instruments to date.
- The WFIRST project is responding to findings from an independent review that was conducted to ensure the mission's scope and required resources are well understood and executable. The review found that the mission scope is understood, but not aligned with the resources provided and concluded that the mission is not executable without adjustments and/or additional resources. For example, the study team found that NASA's current forecasted funding profile for the WFIRST project would require the project to slow down activities starting in fiscal year 2020, which would result in an increase in development cost and schedule. NASA agreed with the study team's results and directed the project to reduce the cost and complexity of the design in order to maintain costs within the $3.2 billion preliminary cost target.

But even with these efforts, NASA's cost and schedule performance may be further tested in upcoming years as some expensive, complex projects linger in the portfolio longer than expected.

- As previously discussed, the Orion program expects cost growth and faces other schedule and technical risks as it moves through the integration and test phase for EM-1 into at least 2019 and then through 2023 for EM-2. As of August 2017, NASA officials expected that new hardware and addressing development challenges would be the factors contributing to increased cost for the program. For example, there was a cost impact when the program moved from a single-piece, or monolithic, heatshield design to one that employs blocks in order to improve its structural strength. Program officials said they are also assessing schedule delays for EM-2, and noted that the EM-2 launch date depends on the outcome of the EM-1 launch date.

- The SLS and EGS programs continue to face cost, schedule, and technical risks as they move through the integration and test phase into at least 2019. For example, SLS will have to complete a "green run" test which requires multiple first-time efforts. Specifically, the test is the culmination of the development effort and includes the core stage integration with its four main engines, fully fueling with cryogenic hydrogen and oxygen, and then firing all four engines for about 500 seconds. NASA currently has no schedule reserve to its target December 2019 launch readiness date for two key areas in the core stage schedule. First, there is no reserve between the end of core stage production and the delivery of the core stage to the test facility. Second, there is no reserve between the end of the testing and delivery to Kennedy Space Center for final integration and testing prior to launch.
- As previously discussed, the JWST project is at risk of exceeding its congressional cost cap, and faces schedule risks as it completes its remaining integration and test work. These activities have taken considerably longer than planned due to a variety of challenges, including reach and access limitations on the flight hardware. Additionally, the project faces significant work ahead. For example, the project must complete integration of spacecraft element hardware and conduct deployment and environmental tests of the integrated sunshield and spacecraft. Further, it must integrate the telescope element with the spacecraft element to form the JWST observatory, and complete another set of challenging environmental tests on the full integrated observatory. At the same time, the project will need to mitigate dozens of remaining hardware and software risks to acceptable levels and address the project's many potential single point failures to the extent possible.
- The SGSS project expects to experience additional cost growth through the final acceptance review because the full scope of the effort has not been included in the cost. NASA only approved its new cost estimate through the initial operational readiness review, currently planned for September 2019. A project official said NASA headquarters asked the project to determine if there are ways to reduce the cost between the operational readiness review and the

final acceptance review. NASA plans to conduct an independent review of the project in mid-2018 to inform a decision on whether to continue the project past the operational readiness review. If NASA decides to continue the project past this review, additional cost growth is expected for SGSS when NASA revisits project costs through future budget cycles.

NASA Generally Maintained Technology Maturity of Its Projects but Performance in Design Stability Measures Is Mixed

NASA has generally maintained the technology maturity and number of critical technologies of its major projects, but had mixed performance in design stability measures. Most of NASA's major projects in development matured their technologies to the level recommended by best practices by their preliminary design review—continuing a trend since 2015. Our best practices work has shown that reaching this level of maturity can minimize risks for projects entering development, which lowers the risk of subsequent cost growth and schedule delays. Of the three projects that held preliminary design review in 2017, one matured its technologies to the level recommended by GAO best practices. The average number of critical technologies decreased in 2018 because new projects in the portfolio reported one or no critical technologies. NASA has maintained the level of design stability at critical design review, but projects continued to experienced late design changes. Of the three projects that had held critical design review in 2017, one met the best practice of releasing 90 percent of engineering drawings by this review. In addition, the average percentage of released drawings for the portfolio—meaning the average of the percentage of drawings released for each project in the portfolio for each reporting period—has remained generally consistent with the past 5 years. We have previously found that releasing at least 90 percent of engineering drawings lowers the risk of projects experiencing design changes and manufacturing problems that can lead to cost and schedule growth.

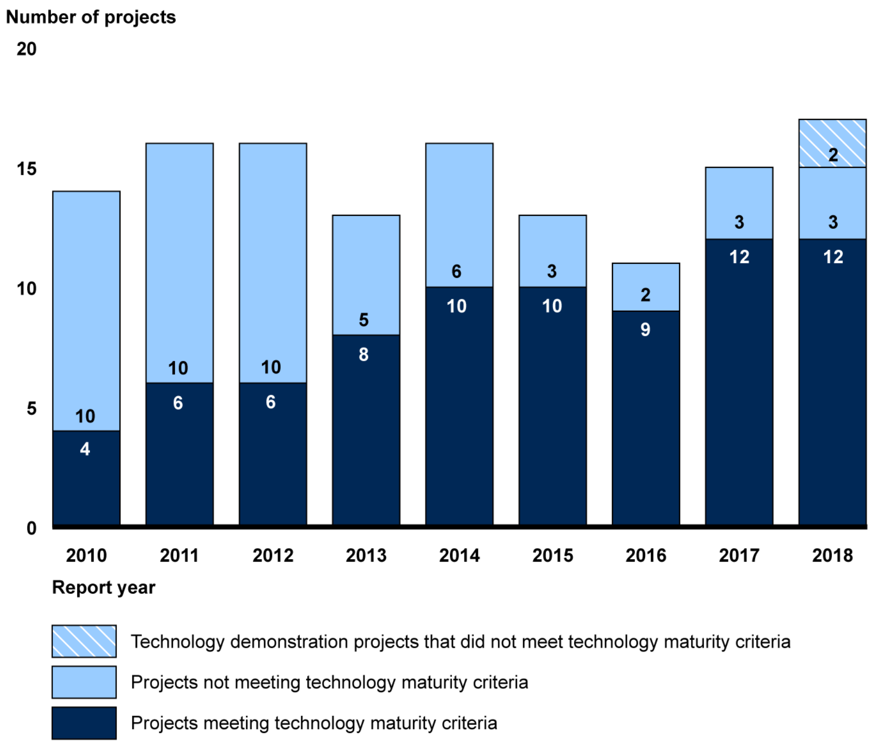
NASA Generally Maintained the Technology Maturity of Its Projects

Most of NASA's major projects in development—12 of 17 projects—met the best practice of maturing all technologies to a technology readiness level 6 by their preliminary design review, which is a generally consistent trend since 2015 (see figure 5).[24] Our best practices work has shown that reaching a technology readiness level 6—which includes demonstrating a representative prototype of the technology in a relevant environment that simulates the harsh conditions of space—by preliminary design review can minimize risks for the systems entering product development.[25] Projects falling short of this standard may experience subsequent technical problems, which can result in cost growth and schedule delays. Appendix IV provides a description of technology readiness levels, which are the metrics used to assess technology maturity.

[24]NASA distinguishes critical, or new, technologies from heritage technologies. Our product development best practices do not make this distinction. We describe critical technologies as those that are required for the project to successfully meet customer requirements, which can include both existing or heritage technology or new technology. Therefore, to assess overall technology maturity, we analyzed the maturity of heritage and critical technologies that NASA reported for projects in our data collection instrument. In other analyses, which focus on the number of new technologies being used by programs, we maintain NASA's distinction between critical and heritage technologies.

[25]Appendix V contains information about GAO's product development best practices and the project attributes and knowledge-based metrics that we assess projects against at each stage of a system's development.

Figure 5: Number of NASA's Major Projects Attaining Technology Maturity by Preliminary Design Review from 2010 to 2018



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-18-280SP

Note: Includes projects that completed preliminary design review and identified critical or heritage technologies. For example, for 2018, 17 of 26 NASA major projects had held this review and identified critical or heritage technologies.

This year, we removed one project—Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer (OSIRIS-REx)—from our analysis of technology maturity because it launched in September 2016. We added three projects—Landsat 9, LCRD, and Restore-L—which held their preliminary design review before February 2018. Of the three projects that were added, only one—Landsat 9—matured its technologies to a technology readiness level 6. The other two projects—Restore-L and LCRD—did not meet our technology maturity best practice.

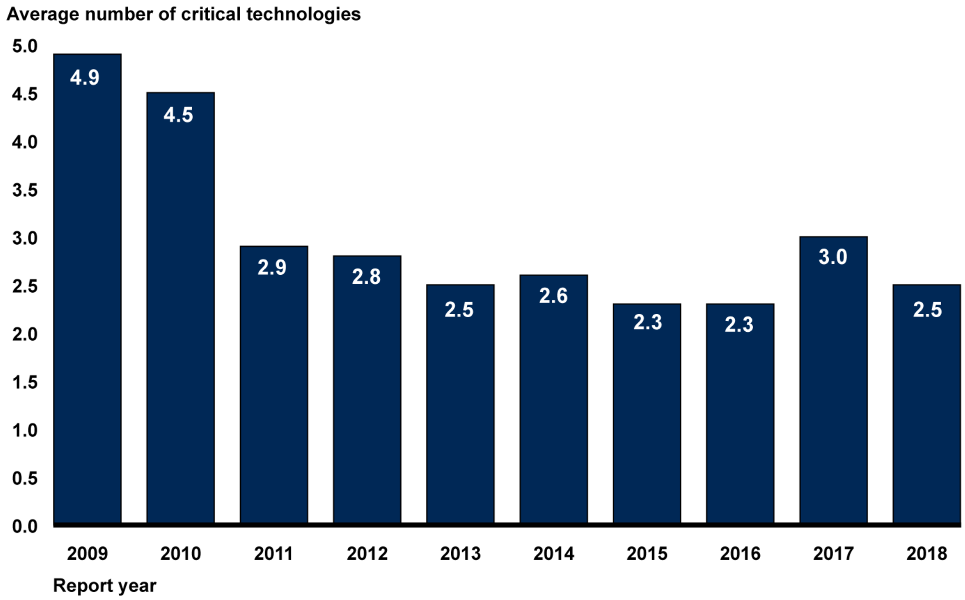
The LCRD and Restore-L projects are technology demonstrations managed by the Goddard Space Flight Center, and the center's policy does not require technology demonstrations to mature all of their technologies to technology readiness level 6 by preliminary design review.[26] NASA officials explained that this is because the purpose of some technology demonstration projects is to mature new technologies to technology readiness level 6 or higher by the end of the demonstration, making it not feasible for these projects to achieve this level by the preliminary design review. However, we included LCRD and Restore-L in our analysis because both planned to mature their technologies prior to launching. Therefore, the same risks of subsequent technical problems that can result in cost growth and schedule delays identified in our best practices work applies to these projects. The LCRD project matured its technologies to technology readiness level 5 by its preliminary design review and to a technology readiness level 6 by its critical design review. The Restore-L project matured all but one of its technologies. The project changed its vision navigation system shortly before its preliminary design review because its prior vision navigation system did not meet requirements and the contractor was unable to resolve the issue. Restore-L project officials stated that they have a plan in place to mature the new system to a technology readiness level 6 by summer 2018, prior to the project's planned critical design review in January 2019.

NASA's major projects continue to report low numbers of critical technologies.[27] The average number of critical technologies for the projects in development declined to 2.5 compared to last year's average of 3 critical technologies; however, the average is consistent with the last several years (see figure 6). The decrease in critical technologies was driven by the addition of three projects—Landsat 9, LCRD, and Restore-L—that reported one or no critical technologies and the exclusion of OSIRIS-REx, which had 3 critical technologies.

[26]NASA's technology demonstration missions program, which began in 2010, aims to mature new technologies from a technology readiness level 5 to technology readiness level 7 or greater. After the technologies are matured, they are to be transferred or infused into other NASA, partner, or commercial projects.

[27]Projects self-report the number of their critical technologies.

Figure 6: Average Number of Critical Technologies Reported by NASA's Major Projects in Development from 2009 to 2018



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-18-280SP

NASA's most recent Discovery project selections—Lucy and Psyche—continue its trend of low reported critical technologies, but are not yet included in our analysis because they have not held preliminary design review. These projects reported no critical technologies and plan to use a design that is based heavily on heritage technologies with modifications. Both projects reported that their heritage technologies are mature, but plan to modify some technologies. We have previously found that mature technologies must be demonstrated in a relevant environment and should be very close to form, fit, and function. Therefore, these two projects will likely have developmental work despite using high-heritage, mature technologies in their designs.

GAO's best practices criteria do not focus on the number of new technologies, but rather their maturity, when considering their effect on cost and schedule risk. Therefore, the issue is not whether to push innovation through technology development, but rather the steps projects take to increase the likelihood of mission success by maturing these technologies to a high level prior to entering the implementation phase.

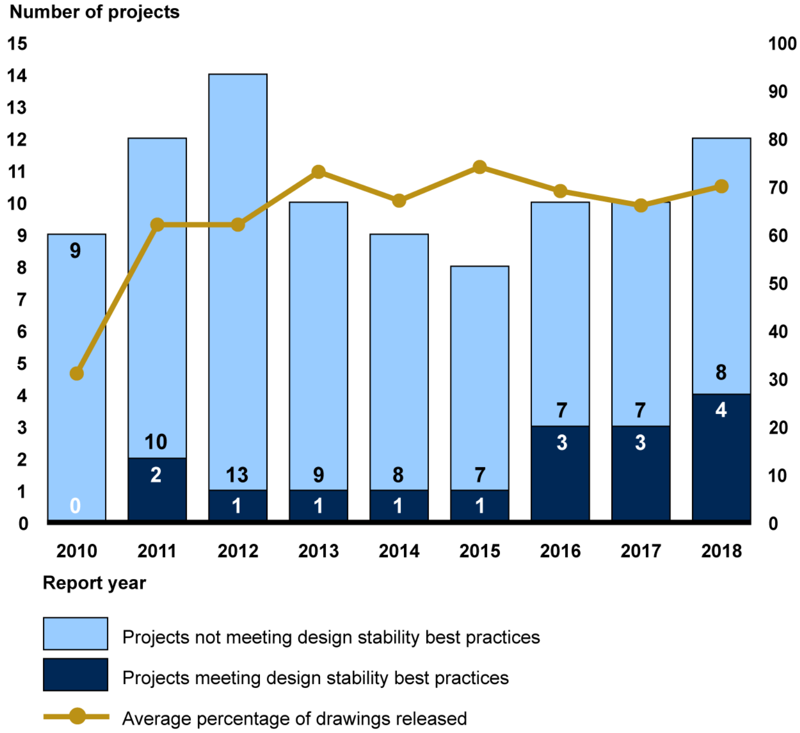
NASA Has Maintained the Level of Design Stability at Key Design Review, but Late Design Changes Still Occurred

NASA has maintained the number of projects with stable designs at critical design review. The critical design review is the time in the project's life cycle when the integrity of the project design and its ability to meet mission requirements is assessed. Our work on product development best practices shows that at least 90 percent of engineering drawings should be releasable by this review to lower the risk of subsequent cost and schedule growth. Engineering drawings are considered to be a good measure of the demonstrated stability of a product's design because the drawings represent the language used by engineers to communicate to the manufacturers the details of a new product design—what it looks like, how its components interface, how it functions, how to build it, and what critical materials and processes are required to fabricate and test it. Once the design of a product is finalized, the drawing is "releasable."

Of the 12 projects that have held a critical design review, four released at least 90 percent of their current projected engineering drawings (see figure 7).[28] In addition, the average percentage of released drawings for the portfolio has remained generally consistent with the past 5 years.

[28] We used the number of drawings released at the critical design review as a fraction of the total number of drawings currently projected. Therefore, the denominator in the calculation may have been larger than what was projected at the critical design review. We believe this calculation more accurately reflects the design stability of the project.

Figure 7: Number of NASA Major Projects That Released at least 90 Percent of Drawings by Critical Design Review and Average Percentage of Released Drawings from 2010 to 2018



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-18-280SP

Note: Includes projects that completed critical design review and had engineering drawings. For example, for 2018, 12 of 26 NASA major projects had held this review and had engineering drawings.

This year, in analyzing the number of projects that met the best practice, we added 3 projects and removed 1 project. One of the 3 projects that were added to the analysis this year—RBI—met the best practice. The other two projects, LCRD and Mars 2020, did not meet the best practice. The LCRD project released over 90 percent of its design drawings in December 2016 at its critical design review, but reported design drawing growth in January 2018. As a result of the drawing growth, the metric of drawings released at this review decreased to 78 percent, which is below the best practice. The Mars 2020 project held its critical design review before it had a stable design, at which point it had released about 72 percent of its expected design drawings. Project officials stated that they held the design review earlier than normal to avoid delaying the development of heritage technologies, which make up a large percentage of the Mars 2020 rover. As a result of holding the review early, new and highly complex developments were not stable at the time of the design review.

Our analysis of design drawings dropped one project—OSIRIS-REx—in 2018 and removed the EGS program from prior years' analyses. We excluded EGS from prior years because program officials told us that the prior data submissions were not inclusive of all subsystems and they did not have a way to replicate previous data submissions to include all of the subsystems. Further, EGS program officials stated they do not use design drawings as a management tool. EGS program officials said that the program used a different approach for tracking design maturity because the program contains several major construction and facilities efforts. This approach included tracking requirements stability, internal and cross-program technical assessments, interface control document maturation, and closure of open work. However, because some of these efforts required new development work, tracking the release of and changes to engineering design drawings at the program level would have been a valuable metric for the program to monitor. We will follow up on this issue in a future review.

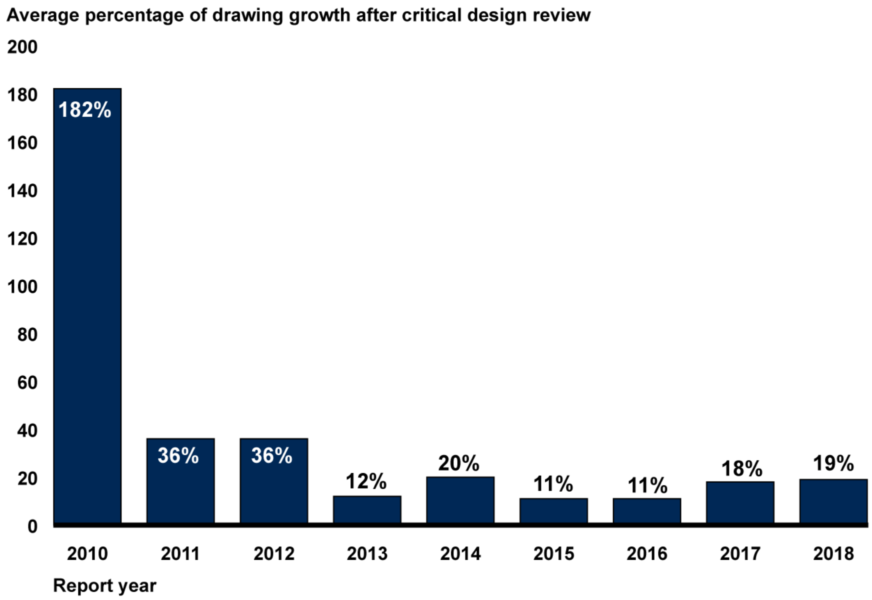
Despite an increase in the number of projects meeting GAO's best practice, some of the 8 projects that did not meet the best practice released a low percentage of their drawings by the critical design review. Five of the 8 projects that did not meet the best practice released fewer than 60 percent of their projected engineering drawings. For example, in 2016 we found that the Parker Solar Probe project held its critical design review with only 34 percent of its design drawings released, significantly lower than the best practice of 90 percent.[29] The project demonstrated it had a stable design at its system integration review in May 2016—over one year after its critical design review, the point at which product development best practices recommend having a stable design.

In addition to maintaining the level of design stability at critical design review, NASA major projects also experienced design changes at a similar level as last year. The average percentage of drawing growth for the entire portfolio slightly increased from 18 percent to 19 percent (see figure 8). Of the 12 projects included in this year's analysis, 11 experienced drawing growth after their critical design review, ranging from 2 to 52 percent. If a project experiences a large amount of engineering

[29] GAO-16-309SP.

drawing growth after this review, it may be an indicator of instability in the project design late in the development cycle. Design changes at this point can be costly to the project in terms of time and funding because hardware may need to be reengineered or reworked as a result. This analysis dropped OSIRIS-REx in 2018 and the EGS program in prior years for reasons discussed above.

Figure 8: Average Percentage of Engineering Drawing Growth after Critical Design Review for NASA Major Projects from 2010 to 2018



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-18-280SP

Note: Drawing growth in 2010 was primarily attributed to the Solar Dynamics Observatory (SDO) because it did not have a stable design at its critical design review and drawings for SDO's instruments were not included in this review. The project launched in 2010 and exited the portfolio.

NASA projects have continued to perform well against other design stability measures, such as maintaining center-specified mass and power margins, and completing a validation and verification plan.[30] Most projects for which mass and power requirements were applicable met these

[30]Validation is defined as the continuous process of ensuring that requirements are well-formed (clear and unambiguous), complete (agrees with customer and stakeholder needs and expectations), consistent (conflict free), and individually verifiable and traceable to a higher level requirement or goal. Verification is defined as proof of compliance with requirements and specifications.

requirements at their critical design reviews and have continued to maintain the required levels of margin.[31] Further, all projects that were required to complete a validation and verification plan by their critical design review met the requirement. NASA requires that projects complete a validation and verification plan by this review to ensure that projects have a plan in place to track the completion of verification and validation events and activities.

Too Early to Determine Outcome of NASA's Efforts to Address Workforce Challenges

Several projects covered in our review were experiencing workforce challenges, such as not having enough staff or staff with the right skills. While it is difficult to tie these workforce challenges to increases in cost, there have been instances where projects have reported schedule delays or late design changes as a result of workforce shortages. Our work has generally found that the shortage of trained acquisition personnel hinders agencies from managing and overseeing acquisition programs and contracts that have become more expensive and increasingly complex.[32] Moreover, NASA's own assessments indicate that there are broader workforce-related challenges that can have a negative impact on programs over the long run, if not addressed in a strategic manner. NASA is taking steps to address its findings, but it is too early to determine the outcomes. One is focused on developing a strategic workforce plan, including determining what mix of skills and capabilities are needed in the future, and the other is focused on leveraging skills across NASA's centers. We will be tracking NASA's progress in this area in future reviews as capacity—having the right people and resources to resolve risk—is one of two criteria that NASA has not yet met for removal from our high-risk list.[33]

[31] Mass is a measurement of how much matter is in an object. It is related to an object's weight, which is mathematically equal to mass multiplied by acceleration due to gravity. Margin is the spare amount of mass or power allowed or given for contingencies or special situations. Some centers provide guidance on the percentage of mass margin required at various points in project development, with required margins ranging from 30 to 0 percent, depending on where a project is in the development cycle.

[32] GAO, *Acquisition Workforce: Federal Agencies Obtain Training to Meet Requirements, but Have Limited Insight into Costs and Benefits of Training Investment,* GAO-13-231 (Washington, D.C.: Mar. 28, 2013).

[33] GAO-17-317.

NASA Has Experienced Workforce Challenges on Major Projects

During the course of our review, we found that several major projects identified workforce challenges, including not having enough staff or staff with the right skills. To accomplish its scientific and space exploration missions, NASA relies on having a skilled civil servant and contractor workforce. While it is difficult to tie these workforce challenges to increases in cost, there have been instances where projects have reported schedule delays or late design changes as a result of workforce shortages. Further, our work has generally found that the shortage of trained acquisition personnel hinders agencies from managing and overseeing acquisition programs and contracts that have become more expensive and increasingly complex.[34] Examples of workforce challenges identified by projects include:

- The Mars 2020 project, which is managed by the Jet Propulsion Laboratory, experienced workforce shortages in several key areas such as flight software and for the development of a sampling and caching system that will collect and cache Martian soil and rock samples. Project officials said not having staff with the right level of experience within its sampling and caching system development contributed to the project being behind in releasing its engineering drawings. As of June 2017, project officials said the Jet Propulsion Laboratory has been able to address these workforce challenges largely because laboratory management prioritized staffing for the project over other projects.
- The Europa Clipper project, which is managed by the Jet Propulsion Laboratory, experienced workforce shortages in several key areas, including avionics, since October 2016. The project has revised staffing plans several times, but continues to face workforce shortages even with NASA headquarters involvement. Project officials said these shortages have delayed development in some areas and have led the project to outsource some work to contractors. As of January 2018, project officials reported that they have seen improvements in addressing workforce shortages.
- The SGSS project, managed by the Goddard Space Flight Center, faced staffing shortfalls in key areas, such as systems engineering and business management, which contributed to late design changes. For example, a project official said the systems engineering was not done correctly before, which led to the software not being coded to

[34] GAO-13-231.

the right requirements. As of January 2018, NASA officials stated that these workforce issues had largely been resolved because some positions were filled by reassigning staff to these areas and others are no longer needed.

- The EGS program, which is managed by Kennedy Space Center, is working with its contractors to increase its software development staff retention rate, which has been a challenge. Program officials said the current retention rate is about 70 percent, but the program would like that to be higher in order to avoid additional delays in its software development efforts due to losing staff. The officials attributed the contractor workforce challenges to competition in the space industry near the center in Florida.

Further, in January 2018, the NASA Office of Inspector General found that the SWOT project, which is managed by the Jet Propulsion Laboratory, experienced workforce shortages in key fields to design and develop its instruments.[35] The report stated that the staffing problems were driven by conflicting priorities among several other Jet Propulsion Laboratory projects, including Mars 2020, that also needed those skills. The Office of Inspector General recommended that the Jet Propulsion Laboratory director evaluate current and future critical technical staffing requirements and make adjustments as necessary to ensure that the laboratory has the technical support needed for their missions. The director plans to address the recommendation through its existing processes and forums for assessing and addressing staffing resources at the laboratory.

NASA's Assessments Indicate Broader Workforce Challenges

NASA's own assessments indicate that there are broader workforce challenges in disciplines that are necessary to effectively manage its major projects. Since 2012, NASA has been conducting capability assessments of its technical disciplines and business services to assist in establishing a more efficient operating model that maintains critical capabilities and meets current and future mission needs. Through these efforts, NASA identified capacity gaps in the following areas:

- **Guidance, Navigation, and Control (GN&C) disciplines.** An assessment of technical capabilities conducted in 2016 identified

[35]NASA Office of Inspector General, *NASA's Surface Water and Ocean Topography Mission*, IG-18-011 (Washington, D.C.: Jan. 17, 2018).

GN&C research and technology development as a discipline area that was inadequately positioned to meet mission requirements. In a follow-up assessment in 2017, NASA determined there have been no significant changes to the GN&C workforce since 2015. The assessment found, though, that the risk is stabilizing due, in part, to adding more early career hires. These assessments determined the GN&C workforce needs to be reshaped over the next decade to build future workforce skills.

- **Scheduling, earned value management, and cost estimating.** A budget business services assessment conducted in 2016 recommended that the agency work with centers to regionalize access to these specialty capabilities and to leverage access to these skills across centers. Officials from the Office of the Chief Financial Officer said they have made some progress in filling gaps in cost estimating and earned value management capabilities, but scheduling expertise remains a major challenge. As a result, officials said they have a scheduling effort underway to build the capability in-house by improving training and tools.
- **Cost and pricing analyst workforce.** A procurement business services assessment conducted in 2015 identified capability gaps in the cost and pricing analyst workforce. As part of assessing options to strengthen expertise associated with source evaluation boards for contract awards, NASA found that the agency had an inadequate supply of cost and pricing analysts across centers. In response to this finding, NASA plans to form a centralized team of cost and pricing professionals to support acquisition efforts across centers. In addition, NASA established a pricing community of practice to develop and share best practices in this area, developed training courses, and, in some instances, centers are hiring cost and pricing analysts as a part of efforts to rebuild this skill set across the agency.

We have also found that other agencies have experienced challenges related to their earned value management, cost estimating, and cost and pricing analysis workforces.[36] For example, in June 2008, we found that the Coast Guard faced challenges in recruiting and retaining a sufficient

[36]For example, GAO, *Coast Guard: Change in Course Improves Deepwater Management and Oversight, but Outcome Still Uncertain,* GAO-08-745 (Washington, D.C.: June 24, 2008); *Defense Contract Management Agency: Amid Ongoing Efforts to Rebuild Capacity, Several Factors Present Challenges in Meeting Its Missions,* GAO-12-83 (Washington, D.C.: Nov. 3, 2011); and *Defense Acquisition Workforce: Actions Needed to Guide Planning Efforts and Improve Workforce Capability*, GAO-16-80 (Washington, D.C: Dec. 14, 2015).

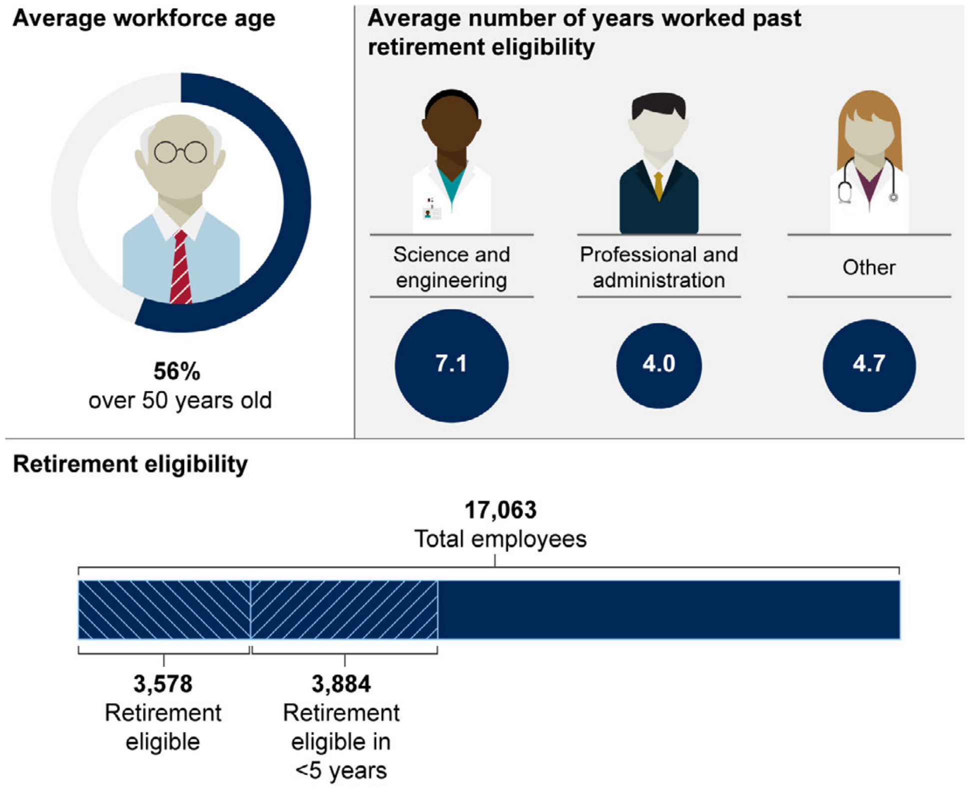
number of government employees in acquisition positions such as contract specialists and cost estimators, among other areas.[37] In addition, in December 2015, we found that the Department of Defense did not meet its workforce growth goals in 3 priority career growth areas—contracting, business, which includes cost estimating and analysis, and engineering.[38]

Another trend, the aging of NASA's workforce, has both negative and positive effects. About 56 percent of NASA's workforce is 50 years old and over, an increase of about 7 percentage points over the past 5 years. Officials said that NASA's workforce is aging because NASA has a low attrition rate—about 4 percent annually—and high numbers of staff stay several years past retirement. We also found that, as of the beginning of 2018, 21 percent of the workforce is retirement eligible, about another 23 percent will become eligible in less than 5 years, and the average number of years staff that stay past initial retirement eligibility varied by occupation (see figure 9). On average, individuals remain at NASA between 4-7 years past their initial retirement eligibility date, but staff in the engineering and science occupations stay on longer than other occupations, such as professional and administrative.

[37]GAO-08-745.

[38]GAO-16-80.

Figure 9: NASA's Workforce Average Age, Retirement Eligibility, and Average Number of Years Worked Past Retirement Eligibility as of January 2018



Source: GAO analysis of National Aeronautics and Space Administration workforce data. | GAO-18-280SP

Note: The other category includes clerical, technicians, medical and other miscellaneous occupations.

Officials said there are both advantages and disadvantages to having an aging workforce. For example, human capital officials noted that having an aging workforce is good for maintaining institutional knowledge due to experienced staff staying longer, but that having a low attrition rate makes it more difficult for the agency to make changes to its workforce skill mix as needed. Officials within the Office of the Chief Engineer and Mission Support Directorate said that they were looking at ways to be more strategic in hiring or using existing capabilities to meet their skills needs.

Outcome of NASA's Strategic Workforce and Cross-Center Planning Efforts Not Yet Known

In our review of selected agency-wide assessments and through discussions with knowledgeable NASA officials, we found that NASA has two efforts underway that may help to address some workforce challenges: strategic workforce planning and cross-center collaboration. We will be tracking the progress of these efforts in future reviews, as it is too early to determine the outcomes.

Strategic Workforce Planning: In 2016, NASA completed a human capital assessment that identified a lack of agency-wide strategic workforce planning as a high-risk area under the agency's current operating model. It stated that the lack of agency-wide strategic workforce planning was at the root of many of the other findings in the assessment, such as the need for better coordination and collaboration across the centers, created uncertainty and was driving centers to think locally instead of agency-wide. To address this concern, the Office of Human Capital Management has an effort underway to begin to develop NASA's first agency-level strategic workforce plan in 2018. NASA defines strategic workforce planning as the discipline of determining the size and composition of a future workforce that is able to perform the organization's most important functions, maintain capabilities, and fulfill key business goals while maintaining agility in a dynamic environment. Human capital officials said they plan to update NASA's policy on strategic workforce planning after they have established their framework for strategic workforce planning.[39] As part of the new process, human capital officials said their office will provide guidance to the centers to develop center master plans, which are to have a 10- to15-year outlook on capabilities. Human capital officials said they will ask the centers to develop their first master plans by October 2018, and the Office of Human Capital Management is to use them to create NASA's first agency-level strategic workforce plan.

Cross-Center Collaboration: The 2016 human capital assessment also identified the need to increase cross-center collaboration to improve workforce utilization. NASA plans to develop a process to better understand where skills are needed across the centers and then use employees with those skills at any center to meet those needs. According to human capital officials, the Office of Human Capital Management was not the right organization to address this concern because they felt that it

[39]NASA Policy Directive 3010.1A, *Strategic Workforce Planning* (Jan. 15, 2009).

would require leadership at a higher level than their office to implement it. They noted that an effort such as this would require the agency to overcome the cultural barrier of NASA being a decentralized agency, with most of its work completed at the center level. This barrier has proven difficult for the agency in the past and has resulted in NASA having different approaches to implementing policies and guidance at the centers. For example, in April 2014, we found that when NASA policy gave centers wide latitude in implementing export control procedures, implementation across centers was inconsistent.[40]

NASA has taken other steps to improve cross-center collaboration by sharing mission support capabilities across the centers. For example, NASA plans to coordinate the center-level human capital and financial staff and activities through the headquarters offices, rather than at each center. NASA plans to complete this transition by the end of September 2019.[41] Other business services areas, such as procurement, also plan to move to this operational model, but have not yet started the transition. Officials within the Office of the Chief Financial Officer said the purpose of this change is for the mission support areas to become more effective and efficient, and deliver a consistent set of services across the agency.

As NASA develops its first strategic workforce plan and considers taking additional steps towards a new operating model with more cross-center collaboration, it will be vital to have senior leadership's commitment to these efforts. Capacity—having the right people and resources to resolve risk—is one of two criteria that NASA has not yet met for removal from our high-risk list; the other being demonstrating progress. We first designated acquisition management at NASA as a high-risk area in 1990 in view of NASA's history of persistent cost growth and schedule slippage in the majority of its major systems. Capacity is central to managing the complex and difficult work that NASA takes on. We have found that an effective organization includes a senior leadership team committed to

[40]GAO, *Export Controls: NASA Management Action and Improved Oversight Needed to Reduce the Risk of Unauthorized Access to Its Technologies,* GAO-14-315 (Washington, D.C.: Apr. 15, 2014).

[41]The Office of the Chief Financial Officer capabilities that are not realigned under the new model before October 2019 will be handled as part of a separate effort.

developing more effective ways of doing business, accomplishing results, and investing in human capital.[42]

Project Assessments

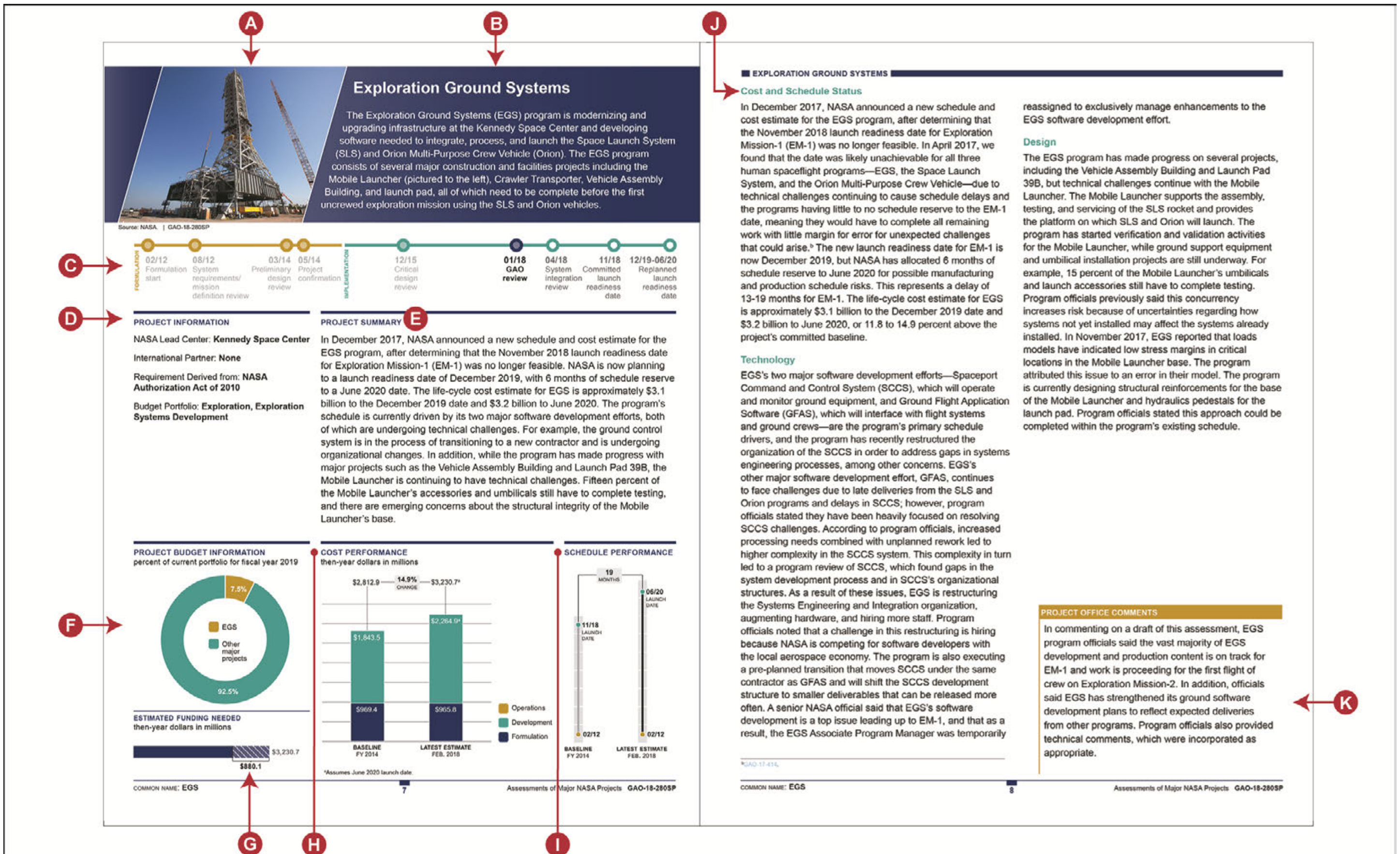
The individual assessments of the 26 projects we reviewed provide a two-page profile of each project. Each assessment includes a description of the project's objectives, information about the NASA centers and international partners involved in the project, the project's cost and schedule performance, a timeline identifying key project dates, budget information, and a brief narrative describing the current status of the project.[43] The budget information is based on NASA's fiscal year 2019 budget request. On the first page, the project profile presents the standard information listed above. On the second page of the assessment, we provide an analysis of the project challenges, and outline the extent to which each project faces cost, schedule, or performance risks because of these challenges, if applicable. NASA project offices were provided an opportunity to review drafts of the assessments prior to their inclusion in the final product, and the projects provided both technical corrections and more general comments. We integrated the technical corrections as appropriate and summarized the general comments at the end of each project assessment.

See figure 10 for an illustration of a sample assessment layout.

[42]GAO, *Exposure Draft: A Model of Strategic Human Capital Management,* GAO-02-373SP (Washington, D.C.: Mar. 15, 2002).

[43]The manifested launch date is the launch date which the project is working toward, and when a launch vehicle is available to launch the project. This date is only a goal launch date for the project, not a commitment that they will launch on this date. The committed launch readiness date is determined through a launch readiness review that verifies that the launch system and spacecraft/payloads are ready for launch.

Figure 10: Illustration of a Sample Project Assessment



- **A** Illustration of the spacecraft, instrument, aircraft, launch vehicle, or ground system.
- **B** General description of the mission's objectives.
- **C** Timeline identifying key dates for the project including when the project began formulation, held major design reviews, began implementation, and launched or fielded an operating capability.
- **D** **Project Information:** Information on the responsible NASA center, international partners, launch plans, mission duration, the source of mission's requirements, and budget portfolio.
- **E** **Project Summary:** Brief narrative describing the current status of the project.
- **F** **Project Budget Information:** The percentage of NASA's fiscal year 2019 budget for all major projects in the current portfolio that the project represents.
- **G** **Project Funding:** For projects in formulation, the total funding appropriated to the project since formulation start. For projects in implementation, the funding needed to be allocated for project completion as of the latest life-cycle cost estimate.
- **H** **Cost:** For projects in formulation, the preliminary cost estimate. For projects in implementation, the approved cost baseline and latest estimate.
- **I** **Schedule:** For projects in formulation, the preliminary launch readiness target date or range of dates. For projects in implementation, the approved schedule baseline and latest estimate.
- **J** The second page of the assessment is an analysis of the project challenges and the extent to which each project faces cost, schedule, or performance risks because of these challenges.
- **K** **Project Office Comments:** General comments provided by the cognizant project office.

Source: GAO analysis. | GAO-18-280SP

Commercial Crew Program

The Commercial Crew Program facilitates and oversees the development of safe, reliable, and cost-effective crew transportation systems by commercial companies to carry NASA astronauts to and from the International Space Station (ISS). The program is a multi-phase effort that started in 2010. During the current phase, the program is working with two contractors—Boeing and SpaceX—that will design, develop, test, and operate the crew transportation systems. Once NASA determines the systems meet its standards for human spaceflight—a process called certification—the companies will fly up to six crewed missions to ISS.

Source: NASA. | GAO-18-280SP

PROJECT INFORMATION

NASA Lead Center: **Kennedy Space Center**

Commercial Partners: **Boeing, SpaceX, Blue Origin,[a] Sierra Nevada Corporation[a]**

Launch Location: **Boeing-Cape Canaveral Air Force Station, FL; SpaceX-Kennedy Space Center, FL**

Launch Vehicle: **Boeing-Atlas V; SpaceX-Falcon 9**

Requirement Derived from: **NASA Strategic Plan**

Budget Portfolio: **Space Operations, Space Transportation**

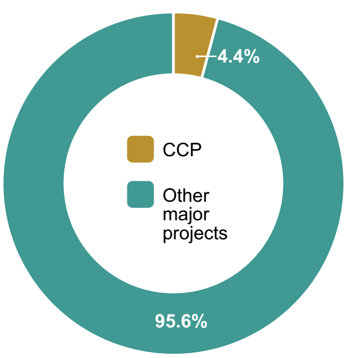
[a]Blue Origin and Sierra Nevada Corporation do not have contracts for the current phase and therefore were not included in this assessment.

PROJECT SUMMARY

Both of the Commercial Crew Program's contractors have made progress developing their crew transportation systems, but continue to have aggressive development schedules. All test flights have slipped to 2018 and the final certification reviews have slipped to early 2019. Both contractors continue to work through design issues for their crew transportation systems. SpaceX is finalizing the design for its launch vehicle, Falcon 9, which will be needed to support crewed flights. Boeing is analyzing the design of the forward heat shield to determine if its expected performance may damage the spacecraft during re-entry. The Commercial Crew Program is the first NASA program that the agency will evaluate against a loss of crew requirement, a key safety metric. Program officials said that if the contractors cannot meet the loss of crew requirement specified in the contracts, NASA could still certify their systems by employing operational mitigations.

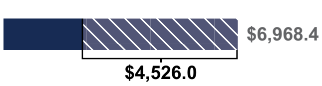
PROJECT BUDGET INFORMATION

percent of current portfolio for fiscal year 2019



ESTIMATED FUNDING NEEDED[b]

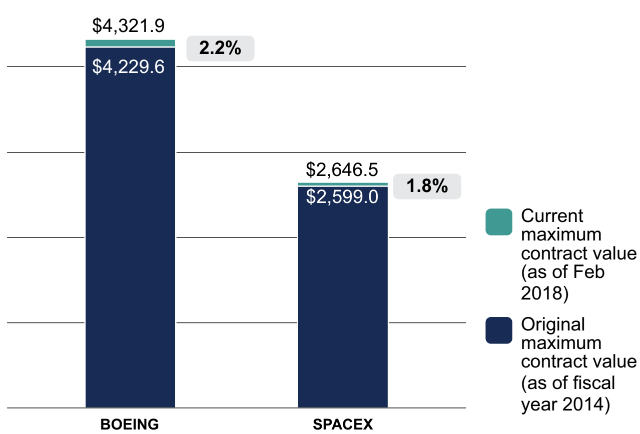
then-year dollars in millions



[b]Includes costs to fund the contracts.

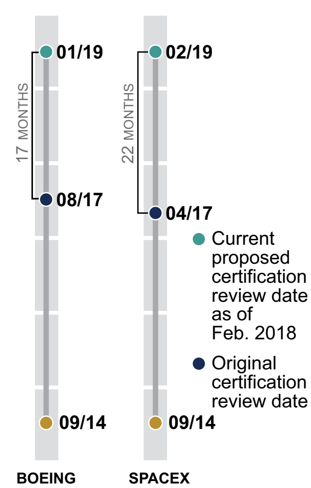
COST PERFORMANCE[c]

then-year dollars in millions



[c]Includes contract costs for development, operations, and special studies.

SCHEDULE PERFORMANCE



Cost and Schedule Status

Both of the Commercial Crew Program's contractors have made progress developing their crew transportation systems, but delays persist as the contractors have had difficulty executing aggressive schedules. The contractors were originally required to provide NASA all the evidence it needed to certify that their systems met its requirements by 2017. In January 2018, we found the contractors' test flights have slipped to 2018 and the final certification reviews have slipped to early 2019.[d] This represents a delay of 17 months for Boeing and 22 months for SpaceX from initial schedules. The Commercial Crew Program is tracking risks that both contractors could experience additional schedule delays and its schedule risk analysis indicates that certification is likely to slip until late 2019 for SpaceX and early 2020 for Boeing.

Design

SpaceX must close several of the program's top risks related to its upgraded launch vehicle design, the Falcon 9 Block 5, before it can be certified for human spaceflight. This includes SpaceX's redesign of the composite overwrap pressure vessel. SpaceX officials stated the new design aims to eliminate risks identified in the older design, which was involved in an anomaly that caused a mishap in September 2016. Separately, SpaceX officials told us that the Block 5 design also includes design changes to address cracks in the turbine of its engine identified during development testing. NASA program officials told us that they had informed SpaceX that the cracks were an unacceptable risk for human spaceflight. SpaceX officials told us that they have made design changes, captured in this Block 5 upgrade, that did not result in any cracking during initial life testing. However, this risk will not be closed until SpaceX successfully completes qualification testing in accordance with NASA's standards without any cracks. SpaceX officials stated they expect this testing to be completed in first quarter calendar year 2018.

Boeing is also mitigating several risks in order to certify its system including challenges related to the performance of its abort system and a component of its parachute system. Boeing is addressing a risk that its abort system may not meet the program's requirement to have sufficient control of the vehicle through an abort. In some abort scenarios, Boeing has found that the spacecraft may tumble, which could pose a threat to the crew's safety. To validate the effectiveness of its abort system, Boeing has conducted extensive wind tunnel testing and plans to complete a pad abort test in April 2018. Boeing is also addressing a risk that during re-entry to the Earth's atmosphere, a portion of the spacecraft's forward heat shield, which protects the parachutes during re-entry, may reconnect and damage the parachute system. NASA's independent analysis indicates that this may occur if both parachutes that pull the forward heat shield away from the spacecraft deploy as expected. Boeing's analysis indicates the risk exists only if one of two parachutes does not deploy as expected. If the program determines this risk is unacceptable, Boeing would need to redesign the parachute system, which the program estimates could result in at least a 6-month delay.

Other Issues to Be Monitored

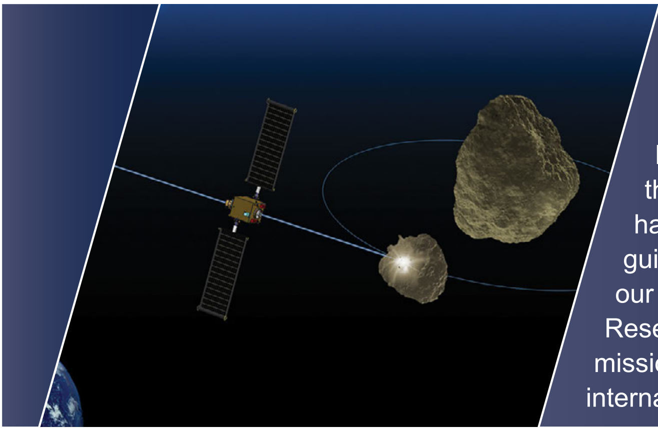
The ability to meet one of the crew safety requirements, which stems from agency policy, is one of the program's top risks. NASA established the "loss of crew" requirement as one way to measure the safety of a crew transportation system, with the intent to minimize the probability of death or permanent disability to one or more crew members. Under the current contracts, the loss of crew requirement is 1 in 270, meaning that the contractors' systems must carry no more than a 1 in 270 probability of incurring loss of crew. Program officials told us that Commercial Crew is the first NASA program that the agency will evaluate against a loss of crew requirement. They said that if the contractors cannot meet the loss of crew requirement, there are several actions the Commercial Crew Program could take to help meet it. Program officials stated, however, these actions may not be enough to completely close the gap. The program has reported it is exploring options, such as on-orbit inspections of the spacecraft. Additionally, program officials told us that one of their greatest upcoming challenges will be to complete two oversight activities—conducting phased safety reviews and verifying that contractors meet requirements—concurrently. For example, the program originally planned to complete phase two of the safety review process in early 2016, but as of October 2017, neither contractor had completed this phase—the program had approved 90 percent of Boeing's phase two reports and 70 percent of SpaceX's.

PROJECT OFFICE COMMENTS

In commenting on a draft of this assessment, program officials stated that NASA's Commercial Crew Program and private industry partners, Boeing and SpaceX, continue to develop the systems that will return human spaceflight to the United States. Both commercial partners are undertaking considerable amounts of testing in 2018 to prove space system designs and the ability to meet NASA's safety and mission requirements for crew flights to the ISS.

[d] GAO-18-317T.

Double Asteroid Redirection Test



The DART project plans to travel to the near-Earth asteroid Didymos, a binary system, and impact the smaller of the two bodies. NASA will assess the deflection result of the impact for potential future use on other potentially hazardous near-Earth objects. The project responds to near-Earth object guidance by the Office of Science and Technology Policy to better understand our impact mitigation posture, and to recommendations by the National Research Council Committee to conduct a test of a kinetic impactor. The DART mission is part of the Asteroid Impact and Deflection Assessment, which is an international collaboration with the European Space Agency.

Source: Johns Hopkins University/Applied Physics Lab. | GAO-18-280SP

PROJECT INFORMATION

NASA Lead Center: **Marshall Space Flight Center**

International Partner: **European Space Agency**

Launch Location: **TBD**

Launch Vehicle: **TBD**

Mission Duration: **22 months**

Requirement Derived from: **NASA Authorization Act of 2008 and implementing guidance**

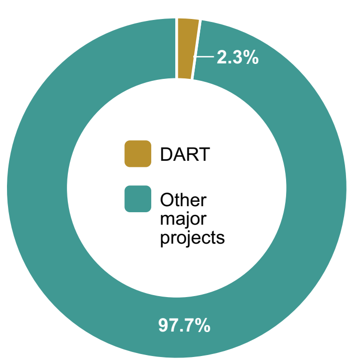
Budget Portfolio: **Science, Planetary Science**

PROJECT SUMMARY

The DART project is working toward preliminary design review and project confirmation, but funding uncertainty and technology maturity of its propulsion system may change the project's schedule. This uncertainty could trigger a re-evaluation of life-cycle costs and overall schedule heading to preliminary design review and project confirmation. Further, DART's planned electric propulsion thruster is facing development delays, particularly in its propulsion power systems. The project is looking at possible schedule delays should thruster issues persist. DART was also intended to be one of two spacecraft to be sent to the Didymos binary asteroid system—along with a spacecraft produced and launched by the European Space Agency. The European spacecraft did not receive necessary funding for 2017 and may be canceled. The DART project is assessing the effect on collected science data of losing proximate observation and is in the early stages of considering various alternatives.

PROJECT BUDGET INFORMATION

percent of current portfolio for fiscal year 2019



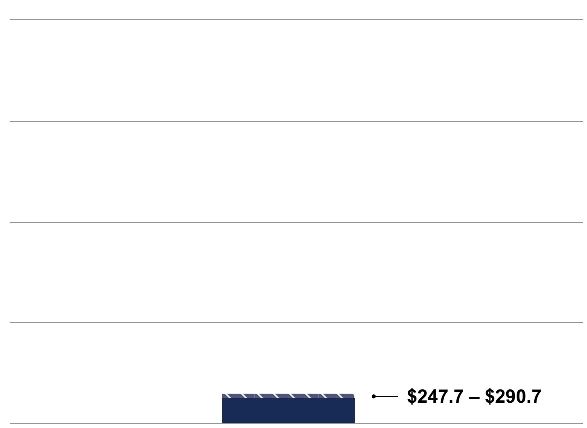
TOTAL FUNDED TO DATE

then-year dollars in millions

$22.5

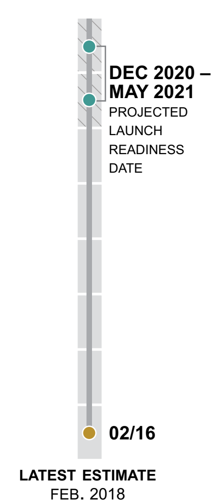
PRELIMINARY COST[a]

then-year dollars in millions



[a]*This estimate is preliminary, as the project is in formulation and there is uncertainty regarding the costs associated with the design options being explored. NASA uses these estimates for planning purposes.*

PRELIMINARY SCHEDULE



Cost and Schedule Status

The DART project entered the preliminary design and technology completion phase in June 2017 with the agency acknowledging that uncertain funding may affect the project's schedule. This could trigger a re-evaluation of life-cycle costs and overall schedule heading to preliminary design review and project confirmation—which the project has delayed by 2 months and 1 month, respectively. DART's planned launch readiness date range is December 2020 – May 2021, with impact of the asteroid occurring in 2022. Project officials told us that if they receive less funding than planned, there is another launch opportunity 2 years later and they are currently studying the effects on the mission if it is delayed to this date. Officials also noted a delayed launch window would likely increase total costs in exchange for lower annual costs.

Technology

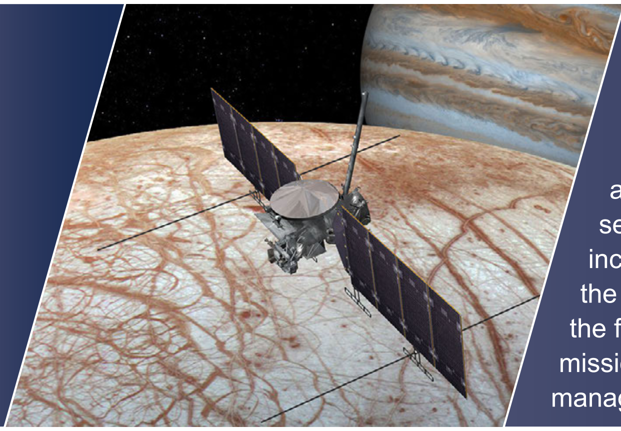
DART's propulsion system includes technologies that remain immature and may delay the mission preliminary design review and potentially the project's launch date. The DART project is working with NASA's Evolutionary Xenon Thruster-Commercial (NEXT-C)—a project managed at Glenn Research Center under the Discovery Program—to provide in-space electric propulsion for the mission. The DART mission will be the first time this technology will fly operationally and, if successful, will serve as qualification for future deep space missions. However, first-time production of this system—DART's critical path and top risk—is proving challenging. The NEXT-C thruster's power processing unit, which provides necessary voltages to the thruster, is the technical risk keeping the thruster from maturing. The project has delayed the mission preliminary design review by 2 months in part to allow more time to mature the NEXT-C technology. In addition, the program is carrying a risk to its launch readiness date dependent upon the NEXT-C meeting delivery and design targets.

Developmental Partner

The DART project's science collection may be less than originally planned due to the European Space Agency not funding DART's sister project, the Asteroid Impact Monitor (AIM) project. DART was designed to work with AIM as part of the collaborative Asteroid Impact & Deflection Assessment. Per the mission plan, as the DART spacecraft impacts the smaller of the Didymos binary asteroids, the AIM spacecraft would collect impact data along with Earth-based observatories. However, the AIM project did not receive necessary funding at the European Space Agency's ministerial meeting in December 2016. Losing AIM will reduce the amount of science data collected on the impact and the asteroids themselves. While the project believes that it can still meet its objectives of characterizing the results of the DART impact on the Didymos system, the project is performing planning and analysis leading up to preliminary design review to determine how effective the Earth-based observatories will be at determining the results of the impact event. As a result of the potential loss of science data, NASA is considering possible alternatives that could provide imagery and data related to the impact.

PROJECT OFFICE COMMENTS

DART project officials provided technical comments on a draft of this assessment, which were incorporated as appropriate.



Europa Clipper

The Europa Clipper mission aims to investigate whether the Jupiter moon could harbor conditions suitable for life. The project plans to launch a spacecraft in the 2020s, place it in orbit around Jupiter, and conduct a series of investigatory flybys of Europa. The mission's planned objectives include characterizing Europa's ice shell and any subsurface water, analyzing the composition and chemistry of its surface and ionosphere, understanding the formation of its surface features, and surveying sites for a potential landed mission. We did not assess the proposed Europa lander mission, which NASA is managing as a separate project in pre-formulation.

Source: Europa Project Personnel, California Institute of Technology, Jet Propulsion Laboratory. | GAO-18-280SP

FORMULATION
- 06/15 Formulation start
- 01/17 System requirements/ mission definition review
- **01/18 GAO review**
- 08/18 Preliminary design review
- 10/18 Project confirmation

IMPLEMENTATION
- 11/19 Critical design review
- 09/20 System integration review
- 06/22 Project launch readiness date
- 07/23 Agency launch readiness date

PROJECT INFORMATION

NASA Lead Center: **Jet Propulsion Laboratory**

International Partner: **None**

Launch Location: **Kennedy Space Center, FL**

Launch Vehicle: **TBD**

Mission Duration: **3 year science mission**

Requirement Derived from: **2011 Planetary Science Decadal Survey**

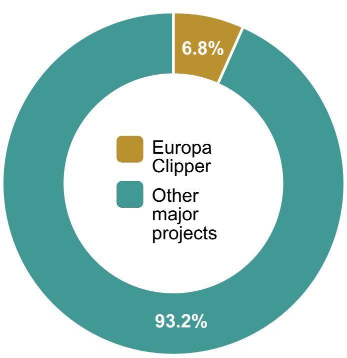
Budget Portfolio: **Science, Planetary Science**

PROJECT SUMMARY

The Europa Clipper project plans to hold its preliminary design review in August 2018 and its confirmation review in October 2018 on schedule, at which point the project will establish its cost and schedule baselines. The project implemented a process to manage instrument costs with options to descope an instrument entirely or in part but has not descoped any instruments to date. The project continues to work toward a June 2022 launch but the availability of a qualified and well-understood launch vehicle could affect that schedule. The project is maintaining compatibility with multiple launch vehicles as it awaits NASA's selection. The project is evaluating design options that may affect the mass and power needed to operate the spacecraft and its 10 instruments. The project has experienced workforce shortages since October 2016, but has seen recent improvements. The project is currently holding cost reserves consistent with Jet Propulsion Laboratory (JPL) policy, but is not meeting JPL's schedule reserve requirement due to technical issues with solar array development.

PROJECT BUDGET INFORMATION

percent of current portfolio for fiscal year 2019

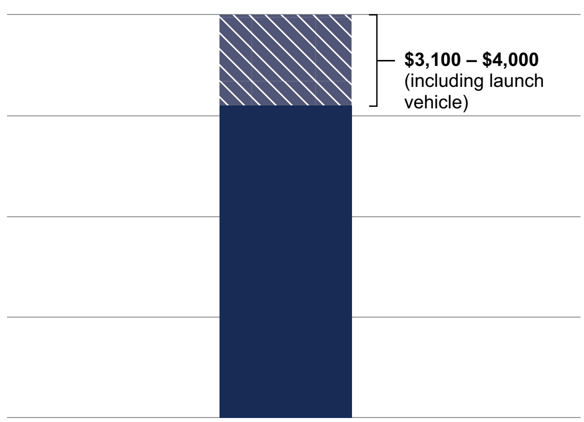


TOTAL FUNDED TO DATE

then-year dollars in millions

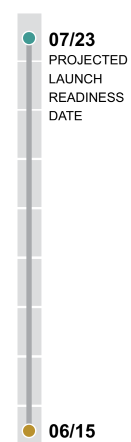
PRELIMINARY COST[a]

then-year dollars in millions



[a]*This estimate is preliminary, as the project is in formulation and there is uncertainty regarding the costs associated with the design options being explored. NASA uses these estimates for planning purposes.*

PRELIMINARY SCHEDULE



LATEST ESTIMATE
FEB. 2018

Cost and Schedule Status

In February 2017, NASA approved the Europa Clipper project to proceed with preliminary design and technology completion, but the project's independent review board highlighted that the complexity and scope of the current 10 instruments may cause cost and schedule growth. In response, the project proposed and NASA approved a process to manage instrument costs with options to descope an instrument entirely or in part to prevent cost growth. For example, if an instrument exceeds its development cost by 20 percent, the project would propose a descope option to NASA that brings instrument cost below that threshold. NASA has not descoped any instruments to date.

The project is currently holding cost reserves consistent with JPL policy, but is not meeting JPL's schedule reserve requirement due to technical issues with solar array development. In March 2017, the project discovered that the materials it planned to use on its solar arrays did not meet requirements under low temperatures. As a result, the project changed the materials it plans to use and is exploring using a different vendor for the solar arrays. Project officials said the technical issues and the project's actions to mitigate them delayed delivery of the solar arrays 3 months beyond the project's baseline need date. However, project officials said the baseline need date was earlier than the actual need date for solar array integration. As a result, the project is reassessing the integration and test flow and may be able to recover some schedule reserves.

The project plans to hold its preliminary design review in August 2018 and its confirmation review in October 2018 on schedule, at which point the project will establish its cost and schedule baseline.

Launch

The Europa Clipper project continues to work toward a June 2022 launch, but the availability of a qualified and well-understood launch vehicle could affect that schedule. Project officials stated that the project needs to select a launch vehicle by the end of 2018 to maintain a 2022 launch date. The project is maintaining compatibility with multiple launch vehicles such as the Delta IV Heavy, Falcon Heavy, and NASA's Space Launch System (SLS); however, each of the launch vehicles under consideration has trade-offs that affect development. The Consolidated Appropriations Act, 2016 requires the project to use SLS; however, recent SLS schedule delays could result in a delay to Europa Clipper's planned June 2022 launch readiness date unless NASA adjusts its current plans for SLS and the associated ground systems. Project officials support using SLS as the launch vehicle, even if it delays the planned launch, because SLS allows a direct flight to Jupiter. This path could reduce the travel time by approximately 4.5 years compared to other launch vehicle options.

Technology and Design

The project is currently meeting JPL mass and power margin requirements, but is evaluating design options that may affect the mass and power needed to operate the spacecraft and its 10 instruments. For example, accommodation of the ice-penetrating radar has been difficult because it requires a higher-than-expected amount of power that could lead to design trades. To mitigate this risk, the project is conducting additional testing of the instrument to evaluate compatibility at lower levels of power. The project is also evaluating design options for its solar arrays, which project officials said will increase available power but may also increase mass.

Other Issues to Be Monitored

The project experienced workforce shortages at JPL in several key areas since October 2016. The project has revised staffing plans several times, but the project continues to face workforce shortages even with NASA headquarters involvement. As of January 2018, project officials reported that improvements have been seen in addressing workforce shortages. Other JPL projects have experienced workforce issues as well, which NASA attributes to the amount of work the laboratory is managing.

PROJECT OFFICE COMMENTS

Europa Clipper project officials provided technical comments on a draft of this assessment, which were incorporated as appropriate.

Exploration Ground Systems

The Exploration Ground Systems (EGS) program is modernizing and upgrading infrastructure at the Kennedy Space Center and developing software needed to integrate, process, and launch the Space Launch System (SLS) and Orion Multi-Purpose Crew Vehicle (Orion). The EGS program consists of several major construction and facilities projects including the Mobile Launcher (pictured to the left), Crawler Transporter, Vehicle Assembly Building, and launch pad, all of which need to be complete before the first uncrewed exploration mission using the SLS and Orion vehicles.

Source: NASA. | GAO-18-280SP

PROJECT INFORMATION

NASA Lead Center: **Kennedy Space Center**

International Partner: **None**

Requirement Derived from: **NASA Authorization Act of 2010**

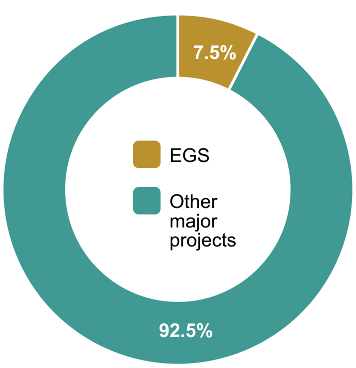
Budget Portfolio: **Exploration, Exploration Systems Development**

PROJECT SUMMARY

In December 2017, NASA announced a new schedule and cost estimate for the EGS program, after determining that the November 2018 launch readiness date for Exploration Mission-1 (EM-1) was no longer feasible. NASA is now planning to a launch readiness date of December 2019, with 6 months of schedule reserve to a June 2020 date. The life-cycle cost estimate for EGS is approximately $3.1 billion to the December 2019 date and $3.2 billion to June 2020. The program's schedule is currently driven by its two major software development efforts, both of which are undergoing technical challenges. For example, the ground control system is in the process of transitioning to a new contractor and is undergoing organizational changes. In addition, while the program has made progress with major projects such as the Vehicle Assembly Building and Launch Pad 39B, the Mobile Launcher is continuing to have technical challenges. Fifteen percent of the Mobile Launcher's accessories and umbilicals still have to complete testing, and there are emerging concerns about the structural integrity of the Mobile Launcher's base.

PROJECT BUDGET INFORMATION

percent of current portfolio for fiscal year 2019

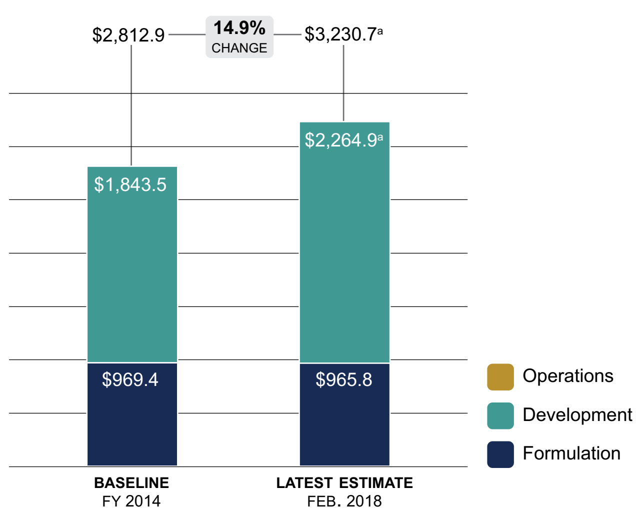


ESTIMATED FUNDING NEEDED

then-year dollars in millions

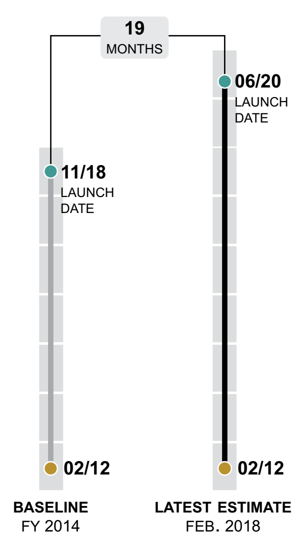
COST PERFORMANCE

then-year dollars in millions



[a]Assumes June 2020 launch date.

SCHEDULE PERFORMANCE



Cost and Schedule Status

In December 2017, NASA announced a new schedule and cost estimate for the EGS program, after determining that the November 2018 launch readiness date for Exploration Mission-1 (EM-1) was no longer feasible. In April 2017, we found that the date was likely unachievable for all three human spaceflight programs—EGS, the Space Launch System, and the Orion Multi-Purpose Crew Vehicle—due to technical challenges continuing to cause schedule delays and the programs having little to no schedule reserve to the EM-1 date, meaning they would have to complete all remaining work with little margin for error for unexpected challenges that could arise.[b] The new launch readiness date for EM-1 is now December 2019, but NASA has allocated 6 months of schedule reserve to June 2020 for possible manufacturing and production schedule risks. This represents a delay of 13-19 months for EM-1. The life-cycle cost estimate for EGS is approximately $3.1 billion to the December 2019 date and $3.2 billion to June 2020, or 11.8 to 14.9 percent above the project's committed baseline.

Technology

EGS's two major software development efforts—Spaceport Command and Control System (SCCS), which will operate and monitor ground equipment, and Ground Flight Application Software (GFAS), which will interface with flight systems and ground crews—are the program's primary schedule drivers, and the program has recently restructured the organization of the SCCS in order to address gaps in systems engineering processes, among other concerns. EGS's other major software development effort, GFAS, continues to face challenges due to late deliveries from the SLS and Orion programs and delays in SCCS; however, program officials stated they have been heavily focused on resolving SCCS challenges. According to program officials, increased processing needs combined with unplanned rework led to higher complexity in the SCCS system. This complexity in turn led to a program review of SCCS, which found gaps in the system development process and in SCCS's organizational structures. As a result of these issues, EGS is restructuring the Systems Engineering and Integration organization, augmenting hardware, and hiring more staff. Program officials noted that a challenge in this restructuring is hiring because NASA is competing for software developers with the local aerospace economy. The program is also executing a pre-planned transition that moves SCCS under the same contractor as GFAS and will shift the SCCS development structure to smaller deliverables that can be released more often. A senior NASA official said that EGS's software development is a top issue leading up to EM-1, and that as a result, the EGS Associate Program Manager was temporarily reassigned to exclusively manage enhancements to the EGS software development effort.

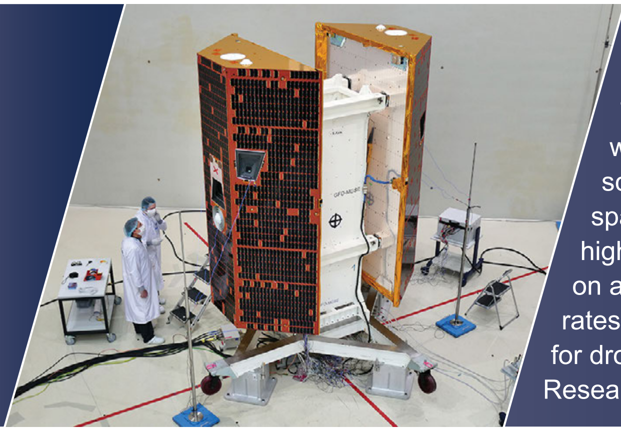
Design

The EGS program has made progress on several projects, including the Vehicle Assembly Building and Launch Pad 39B, but technical challenges continue with the Mobile Launcher. The Mobile Launcher supports the assembly, testing, and servicing of the SLS rocket and provides the platform on which SLS and Orion will launch. The program has started verification and validation activities for the Mobile Launcher, while ground support equipment and umbilical installation projects are still underway. For example, 15 percent of the Mobile Launcher's umbilicals and launch accessories still have to complete testing. Program officials previously said this concurrency increases risk because of uncertainties regarding how systems not yet installed may affect the systems already installed. In November 2017, EGS reported that loads models have indicated low stress margins in critical locations in the Mobile Launcher base. The program attributed this issue to an error in their model. The program is currently designing structural reinforcements for the base of the Mobile Launcher and hydraulics pedestals for the launch pad. Program officials stated this approach could be completed within the program's existing schedule.

PROJECT OFFICE COMMENTS

In commenting on a draft of this assessment, EGS program officials said the vast majority of EGS development and production content is on track for EM-1 and work is proceeding for the first flight of crew on Exploration Mission-2. In addition, officials said EGS has strengthened its ground software development plans to reflect expected deliveries from other programs. Program officials also provided technical comments, which were incorporated as appropriate.

[b] GAO-17-414.



Source: Airbus Defense and Space. | GAO-18-280SP

Gravity Recovery and Climate Experiment Follow-On

The Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) will continue and expand upon the 2002 GRACE mission, which ended science operations in October 2017. The system, which consists of two spacecraft working together to obtain scientific measurements, will provide high-resolution models of Earth's gravity field and insight into water movement on and beneath the Earth's surface for up to 5 years. These models will provide rates of ground water depletion and polar ice melt and enable improved planning for droughts and floods. GRACE-FO is a collaborative effort with the German Research Centre for Geosciences (GFZ).

FORMULATION
- 01/12 Formulation start
- 07/12 System requirements/ mission definition review
- 01/14 Preliminary design review
- 02/14 Project confirmation

IMPLEMENTATION
- 02/15 Critical design review
- 07/15 System integration review
- **01/18 GAO review**
- 02/18 Committed launch readiness date
- 05/18 Manifested launch readiness date

PROJECT INFORMATION

NASA Lead Center: **Jet Propulsion Laboratory**

International Partner: **German Research Centre for Geosciences (GFZ)**

Launch Location: **Vandenberg Air Force Base, CA**

Launch Vehicle: **Falcon 9**

Mission Duration: **5 years**

Requirement Derived from: **NASA 2010 Climate Plan**

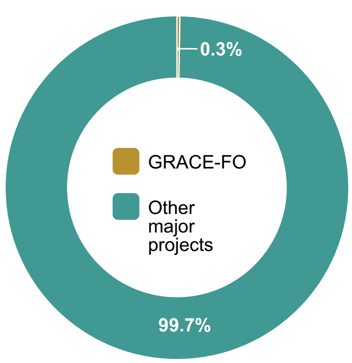
Budget Portfolio: **Science, Earth Science**

PROJECT SUMMARY

The GRACE-FO project plans to launch in May 2018, 3 months later than its committed launch readiness date of February 2018, but within its committed cost baseline. Delays to the project's launch readiness date, which over time have accumulated to 9 months of delays, are related to the project's launch vehicle arrangement. First, GFZ—NASA's partner on the project, which is responsible for the launch vehicle—reported that it was notified by the Russian Federal Space Agency that the Dnepr launch vehicle was no longer available. Subsequently, GFZ arranged to launch the two GRACE-FO spacecraft, along with commercial satellites, on a SpaceX Falcon 9. But the project experienced subsequent delays after SpaceX experienced an anomaly on a launch pad that resulted in delays to the launch schedule. The project used the extra time created by the launch delays to conduct additional risk reduction activities during system-level integration and test.

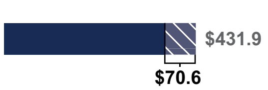
PROJECT BUDGET INFORMATION

percent of current portfolio for fiscal year 2019



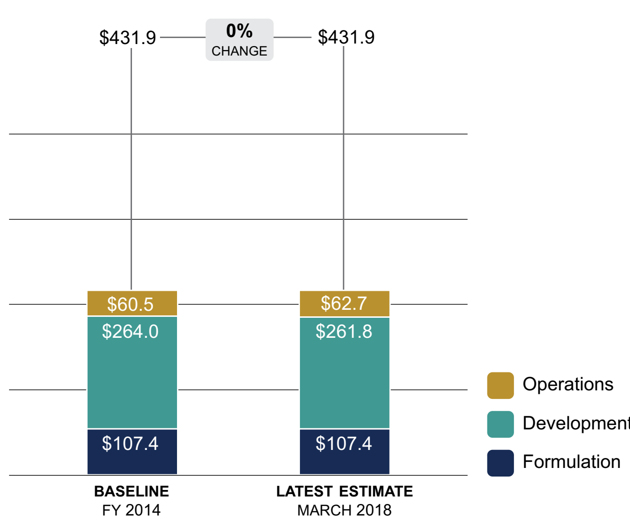
ESTIMATED FUNDING NEEDED

then-year dollars in millions

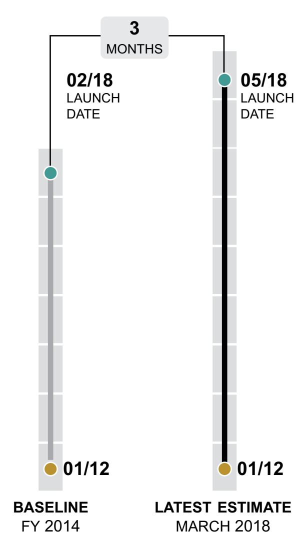


COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The GRACE-FO project plans to launch in May 2018, 3 months later than its committed launch readiness date of February 2018, due to delays related to its launch vehicle arrangement. The project expects to launch within its cost baseline and plans to use its remaining project-held reserves to cover costs through May 2018. The project completed system-level testing on both spacecraft in November 2017 and shipped GRACE-FO to Vandenberg Air Force Base in California for pre-launch activities in December 2017.

Launch and Development Partner

The GRACE-FO project previously planned to launch early in August 2017, but delays related to its launch vehicle arrangement resulted in a 9-month delay to its launch readiness date. The launch vehicle is the responsibility of NASA's partner on the project—GFZ. An initial delay of 4 months occurred when the project changed its launch vehicle after GFZ reported that it was notified by the Russian Federal Space Agency that the Dnepr launch vehicle was no longer available. GFZ, in June 2016, arranged to launch the two GRACE-FO spacecraft, along with commercial satellites, on a SpaceX Falcon 9. SpaceX then experienced an anomaly on a launch pad in September 2016 that resulted in delays to the launch schedule as SpaceX investigated the source of the anomaly. In July 2017, a new 30-day launch readiness window from March to April 2018 was negotiated, resulting in an additional 4 months of delays for the project. In March 2018, the launch was delayed an additional month to May 2018 due to launch range availability.

Integration and Test

The project used the extra time in the schedule due to launch delays to conduct additional risk reduction activities during system-level integration and test. For example, the project identified a design issue with its global positioning system antenna during testing. With the extra time, it replaced the antennas on both spacecraft to resolve the issue. In addition, the project identified a manufacturing issue with one of the two cavities that stabilizes the laser of its Laser Ranging Interferometer (LRI), which is contributed by GFZ. LRI is a technology demonstration that performs the same ranging measurements of GRACE-FO's microwave instrument but with greater precision and is not needed to meet the mission's science requirements. With the extra time, the project was able to replace and reintegrate the cavity with the spacecraft.

In addition, the project is investigating the shifting of an optical system component of LRI during system-level environmental testing in August 2017. The project is investigating the cause, but anticipates the shift is likely due to the expansion of adhesive bonds between the optical components when exposed to temperature and humidity. The project conducted additional tests using spare flight hardware in a vacuum, which removes humidity, to understand future alignment performance in a space-like environment. The project expects that it will be able to use the component as-is because tests indicate there is sufficient performance margin even with the shifting, that exposure to the vacuum of space will reduce the shifting, and it can make operational adjustments to further improve performance, if needed.

PROJECT OFFICE COMMENTS

GRACE-FO project officials provided technical comments on a draft of this assessment, which were incorporated as appropriate.

Ice, Cloud, and Land Elevation Satellite-2

The Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2) is a follow-on mission to ICESat that will measure changes in polar ice-sheet mass and elevation. The measurements will provide researchers a better understanding of the mechanisms that drive polar ice changes and their effect on global sea level. ICESat-2's upgraded laser instrument will allow the satellite to make more frequent measurements and provide better elevation estimates over certain types of terrain than ICESat.

Source: NASA. | GAO-18-280SP

FORMULATION
- 12/09 Formulation start
- 05/11 System requirements/ mission definition review
- 10/12 Preliminary design review
- 12/12 Project confirmation

IMPLEMENTATION
- 02/14 Critical design review
- 05/14 Project rebaseline
- 08/17 System integration review
- **01/18 GAO review**
- 06/18 Committed launch readiness date
- 09/18-10/18 Manifested launch readiness date

PROJECT INFORMATION

NASA Lead Center: **Goddard Space Flight Center**

International Partner: **None**

Launch Location: **Vandenberg Air Force Base, CA**

Launch Vehicle: **Delta II**

Mission Duration: **3 years**

Requirement Derived from: **2007 Earth Science Decadal Survey**

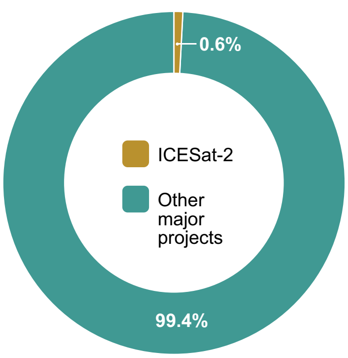
Budget Portfolio: **Science, Earth Science**

PROJECT SUMMARY

The project will miss its rebaselined committed launch date but does not expect the cost to exceed the rebaseline because it has sufficient cost reserves to cover the delay. The project will miss its committed launch readiness date of June 2018 due to issues with its sole instrument—the Advanced Topographic Laser Altimeter System (ATLAS). In July 2016, the ICESat-2 project encountered problems with the flight lasers developed for ATLAS that caused NASA to delay the launch date to October 2018, which is 17 months beyond the original baseline and 4 months beyond the rebaselined date set in 2014. The project held its system integration review and began system-level integration and test in August 2017. The two repaired lasers that will fly on the ATLAS instrument were shipped back to Goddard Space Flight Center, completed flight acceptance testing, and are integrated onto the instrument. The project entered the system assembly and testing phase in October 2017.

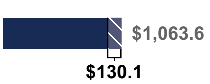
PROJECT BUDGET INFORMATION

percent of current portfolio for fiscal year 2019



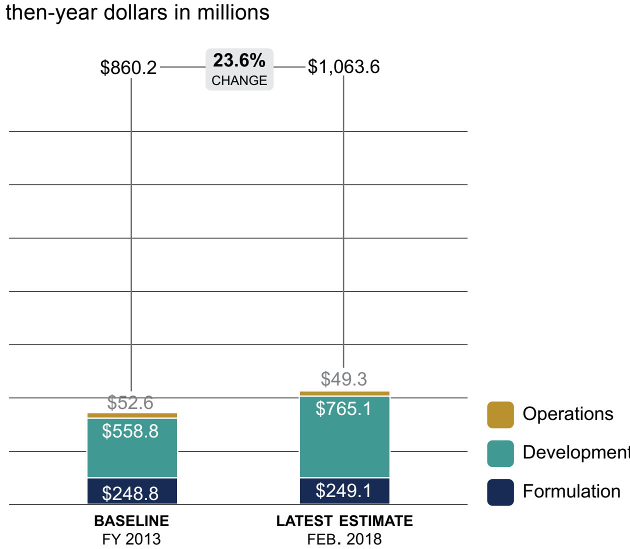
ESTIMATED FUNDING NEEDED

then-year dollars in millions

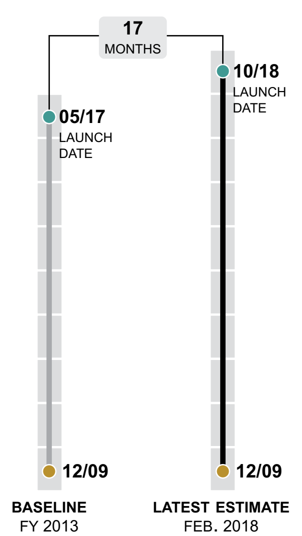


COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The project will miss its rebaselined committed launch date but does not expect the cost to exceed the rebaseline because it has sufficient cost reserves to cover the delay. The ICESat-2 project is proceeding to integration and test after problems with lasers within the primary instrument—the Advanced Topographic Laser Altimeter System (ATLAS)—caused NASA to delay the launch readiness date from June 2018 to October 2018. This represents a 17-month delay beyond the original baseline and a 4-month delay beyond the rebaselined date set in 2014. However, the project is working to an earlier, September 2018 launch readiness date. The project completed a cost and schedule replan in October 2017, which required a large portion of remaining headquarters-held cost reserves, but did not take the project over its baseline commitment of $1,063.5 million.[a] The project is holding cost and schedule reserves at the level required by NASA center policy, but the project will need to realign funding planned for system integration and testing to address a shortfall in cost reserves for the operations phase. The project held its system integration review in August 2017 and received approval to enter the system assembly and testing phase in October 2017.

Technology and Design

Over numerous years, the ICESat-2 project has addressed issues with its flight lasers, and continues to mitigate the risk that they might fail again in the future. During ATLAS environmental testing in 2016, the project determined two of its three lasers needed repairs due to cracked crystal. The remaining laser did not require rework and continued to operate—completing over 2,300 hours of runtime. Subsequently, the project found that components on a test model—similar to the laser that did not need repairs—cracked while in storage. Project officials were unable to identify a single root cause of the cracking but determined this was an indication that the unrepaired laser could fail. ICESat-2 only needs one laser for mission success, but will carry a second for redundancy. In July 2017, following the completion of a trade study to determine which two of its three flight lasers should fly on ATLAS, NASA decided to use the two lasers that were repaired for flight. Officials said this decision was due to uncertainty in the reliability of the unrepaired laser and that the repaired lasers fully address the factors that contributed to the fractures. Since being repaired, together these lasers have completed a total of over 1,200 hours of runtime and have performed to requirements. Flying the two repaired lasers does not affect the project's plans to launch in September 2018. However, the project is carrying multiple risks to account for the potential that the repaired lasers could still fail at various points in time. For example, the project is carrying two risks that weigh the effect of the lasers failing on the ground during integration and test or failing while on orbit. If a laser fails during integration and test, it would take 5 weeks to replace it with a spare.

[a]This total baseline cost differs from the total cost outlined in the table above due to an increase in project labor during the formulation phase. This increase is not related to the ATLAS instrument.

Integration and Test

The ICESat-2 project is proceeding through integration and test now that the ATLAS flight lasers are integrated onto the instrument and undergoing performance testing. The project held its system integration review and began system-level integration and test in August 2017. The two repaired lasers that will fly on the ATLAS instrument were shipped back to Goddard Space Flight Center and completed flight acceptance testing. On one of the repaired lasers, which was fully integrated onto the optical bench, the project observed an unusual pattern in its optical components during initial performance testing, and ATLAS officials have convened a review board to investigate the cause of this issue. The other repaired laser, which performed as expected during acceptance testing, began integration in September 2017 and is now undergoing performance testing.

PROJECT OFFICE COMMENTS

In commenting on a draft of this assessment, ICESat-2 officials stated that during initial ATLAS testing, flight laser two exhibited an anomalous laser behavior. Project officials stated the laser was transported back to the contractor for cleaning and testing, which revealed comparable results to previous tests. The laser was returned to NASA and is performing normally. Project officials also provided technical comments, which were incorporated as appropriate.

Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport

The Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport (InSight) is a Mars lander with two primary objectives. It is intended to further understanding of the formation and evolution of terrestrial planets by determining Mars's size, its composition, and the physical state of the core; the thickness of the crust; and the composition and structure of the mantle, as well as the thermal state of the interior. It will also determine the present level of tectonic activity and the meteorite impact rate on Mars. InSight is based on the Phoenix lander design. Phoenix successfully landed on Mars in 2008.

Source: © California Institute of Technology. | GAO-18-280SP

PROJECT INFORMATION

NASA Lead Center: **Jet Propulsion Laboratory**

International Partners: **Centre National d'Etudes Spatiales (France) and German Aerospace Center (Germany)**

Launch Location: **Vandenberg Air Force Base, CA**

Launch Vehicle: **Atlas V**

Mission Duration: **29 months**

Requirement Derived from: **2011 Planetary Science Decadal Survey**

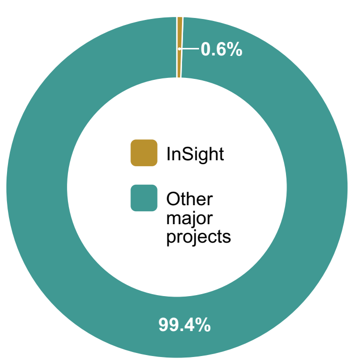
Budget Portfolio: **Science, Planetary Science**

PROJECT SUMMARY

The InSight project is on track to meet its revised cost and schedule agreement after technical issues with its primary instrument—the Seismic Experiment for Interior Structure (SEIS)—caused it to miss the previously planned launch date of March 2016. The project is holding cost and schedule reserves consistent with the level required by Jet Propulsion Laboratory policy. NASA redesigned the SEIS container and integrated it on the lander in August 2017. The project continues to track a risk that sensors within the SEIS will not function as intended, which would affect the project's ability to meet science requirements. To increase confidence that the sensors will perform, the project is completing tests to confirm the sensors' ability to survive for the mission's duration. The project also used the additional time from the launch delay to redesign the wiring within the HP3—a German-contributed instrument that drills into the Martian surface to collect temperature data—to address an anomaly found in testing.

PROJECT BUDGET INFORMATION

percent of current portfolio for fiscal year 2019

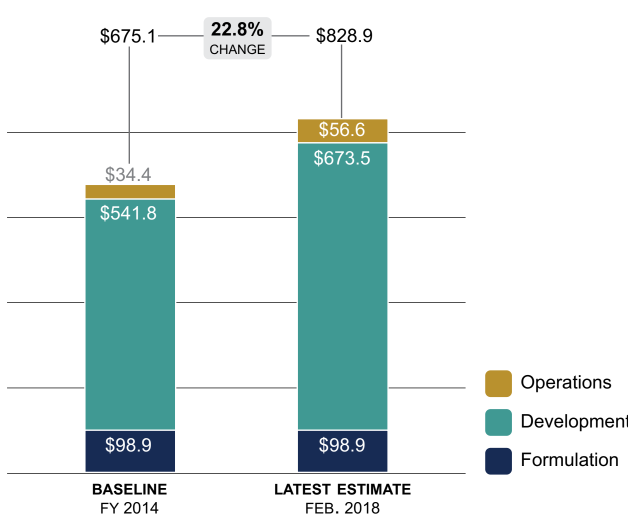


ESTIMATED FUNDING NEEDED

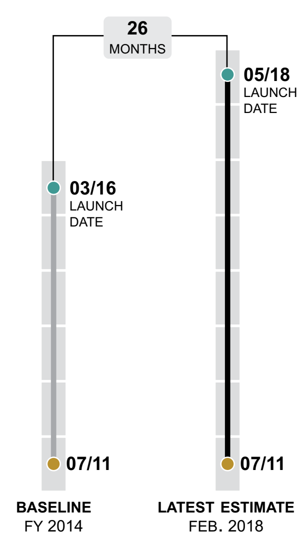
then-year dollars in millions

COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The InSight project is on track to meet its revised cost and schedule agreement approved by NASA in August 2016 after the project missed its previously planned launch date. The InSight project missed its original launch date due to technical issues with the Seismic Experiment for Interior Structure (SEIS) instrument—the project's primary instrument and a contribution from the Centre National d'Etudes Spatiales (CNES)—which increased costs by almost $154 million and delayed the launch by 26 months. The project delivered the InSight spacecraft to the launch site in February 2018 before its planned launch in May 2018. The project is holding cost and schedule reserves consistent with the level required by Jet Propulsion Laboratory policy.

Integration and Test and Development Partner

The InSight project has resolved technical issues that necessitated a SEIS redesign, but is working to mitigate a risk on a key SEIS component that could affect SEIS's performance in operations. After discovering vacuum seal leaks that prevented the SEIS container from sealing properly and ultimately caused the launch delay, the project restructured SEIS responsibilities with NASA redesigning the SEIS container and CNES conducting integration and test. In March 2017, CNES confirmed that the redesign of the SEIS container was successful after completing a leak test, and integrated the SEIS with the lander in August 2017. The project is tracking a risk related to a potential failure of a Very Broad Band (VBB) sensor—a key SEIS component that will be used to measure seismic activity—in operations. The project has requested and received a significant number of VBB waivers. For example, the project requested and received approval to proceed with an oxidized part on several VBBs. The waivers individually have a low risk of causing a VBB failure, but together present a more moderate risk of a failure. More than one VBB failure would prevent the project from meeting its science requirements, according to officials. The project is completing tests to confirm the sensors' ability to survive for the mission's duration, which should provide increased confidence in the VBBs.

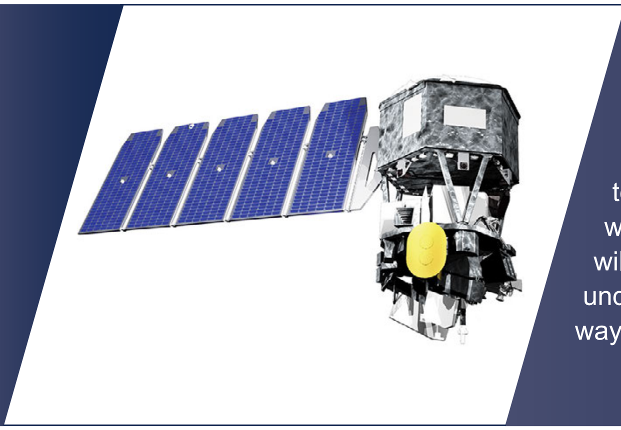
Because the project had additional time in its schedule due to the launch delay, it redesigned the Heat Flow and Physical Properties Probe (HP3)—a contributed instrument that will drill into the Martian surface to take temperature measurements—to resolve anomalies that occurred late in testing and to improve performance. These anomalies included damaged internal wiring caused by shocks generated by the hammering mechanism. The project completed a HP3 trade study, which evaluated whether or not to fly the redesigned HP3 or proceed with the original design, and determined the redesigned HP3 represented the lower risk option for the mission. The project integrated the redesigned HP3 in October 2017 prior to system-level testing. The HP3 is not needed for the project to meet its level 1 science requirements.

Design

The InSight project was tracking a risk related to its parachute that could have consumed approximately 27 percent of its cost reserves, but in October 2017 the project made the decision to use the existing parachute design that removed that risk. According to officials, the InSight project uses the same manufacturer for nylon in its parachute as the Mars 2020 project—another project that will land on Mars—originally planned to use. Mars 2020 discovered a potential problem with the strength of its parachute fabric as the fabric was degrading upon exposure to high heat during a planetary protection activity. As a result, the InSight project was concurrently building a parachute with new nylon material as well as a parachute using existing material. However, the project decided to abandon building a parachute using new material when it was determined that the new nylon material did not meet specifications, the vendor could not meet the required schedule in order to make the risk reduction option viable, and, according to officials, expert reviews rated the existing parachute as acceptable to fly. The Advanced Supersonic Parachute Inflation Research Experiment successfully completed a test in October 2017 that provided the project with additional support for their decision to use the parachute using original material.

PROJECT OFFICE COMMENTS

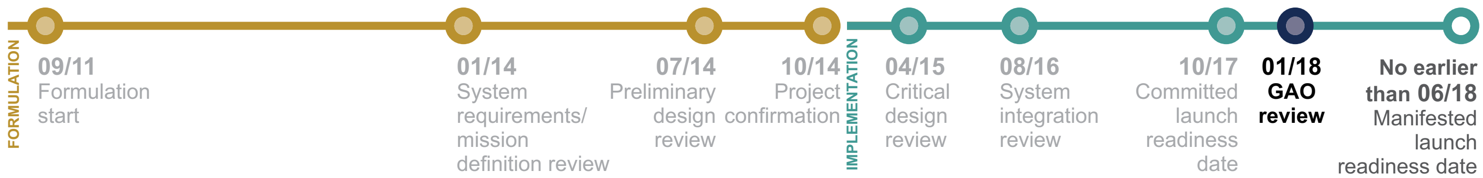
InSight project officials provided technical comments on a draft of this assessment, which were incorporated as appropriate



Source: University of California, Berkeley. | GAO-18-280SP

Ionospheric Connection Explorer

The Ionospheric Connection Explorer (ICON) observatory will orbit Earth to explore its ionosphere—the boundary region between Earth and space where ionized plasma and neutral gas collide and react. Its four instruments will make direct measurements and use remote sensing to further researchers' understanding of Earth's upper atmosphere, the Earth-Sun connection, and the ways in which Earth weather drives space weather.



PROJECT INFORMATION

NASA Lead Center: **Goddard Space Flight Center**

International Partner: **Centre Spatial de Liege Université de Liège (Belgium)**

Launch Location: **Kwajalein (Marshall Islands)**

Launch Vehicle: **Pegasus**

Mission Duration: **2 years**

Requirement Derived from: **2010 Science Mission Directorate Science Plan and 2009 Heliophysics Roadmap Team Report to the NASA Advisory Council**

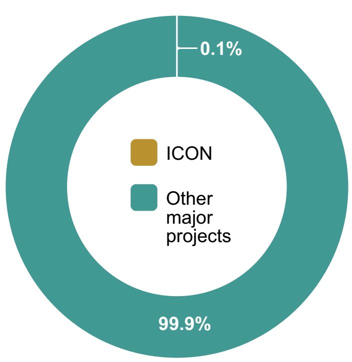
Budget Portfolio: **Science, Heliophysics**

PROJECT SUMMARY

The ICON project has missed its committed launch readiness date of October 2017 and both the project's schedule and costs are under review. Delays to the project's launch readiness date are related to problems with ICON's launch vehicle. The project experienced a 6-month delay due to a transport incident with a launch vehicle segment and launch range conflicts. In September 2017, an anomaly found in testing of the launch vehicle bolt cutter assemblies resulted in additional delays, but the magnitude of these delays is unknown while an investigation of the anomaly is underway. In February 2018, NASA determined the project will launch no earlier than June 2018, but this date is still under review. The ICON project completed its system-level integration and test activities in April 2017 as planned, but has not shipped the spacecraft to the launch site due to the launch delay.

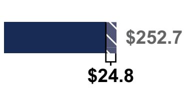
PROJECT BUDGET INFORMATION

percent of current portfolio for fiscal year 2019



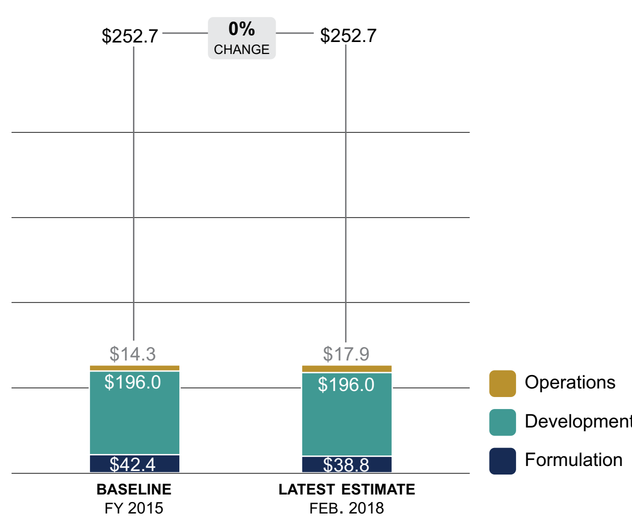
ESTIMATED FUNDING NEEDED

then-year dollars in millions

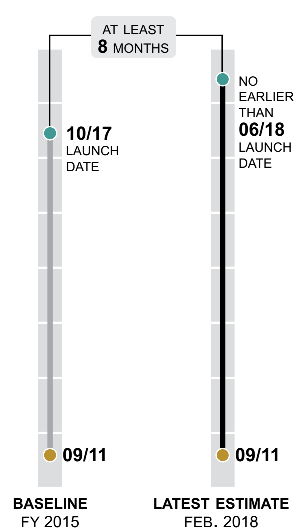


COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The ICON project has missed its committed launch readiness date of October 2017 and both the project's schedule and costs are under review. The project completed its system-level integration and test activities in April 2017 as planned, but has not shipped the spacecraft to the launch site due to ongoing delays related to the launch vehicle. According to officials, the project received $7.8 million of headquarters-held reserves to cover initial delays, but it cannot determine whether it will exceed its cost baseline until NASA and the launch vehicle provider set a new launch date. Project officials said they need about $1 million a month for ICON to remain in storage.

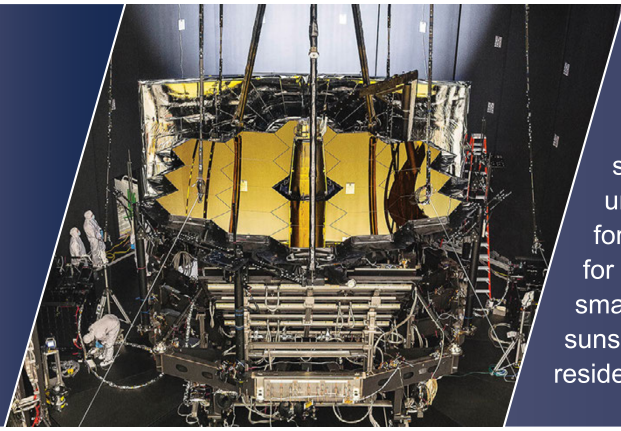
Launch

The ICON project had planned to launch early, in June 2017, but the project has experienced delays associated with its launch vehicle. In January 2017, two of the Pegasus launch vehicle's three stages were involved in a transport accident. The stages were subsequently returned to the launch vehicle contractor facility for inspection and testing, and no damage was found. The launch vehicle contractor then delivered the stages to Vandenberg Air Force Base for integration and testing activities. Due to conflicts at the launch vehicle range, the earliest available launch date was December 2017, which resulted in a 6-month launch delay from the planned June 2017 launch date.

In September 2017, however, an anomaly identified in bolt cutter assembly confidence testing—testing to show that the bolts that hold the launch vehicle and payload together will separate as planned during launch—resulted in additional delays, but the magnitude of the delay is unknown. One of nine bolt cutter assemblies failed to fracture a bolt during testing. As a result, NASA and the contractor halted testing and began an investigation of the anomaly, which is ongoing. NASA's Launch Services Program is working with the launch vehicle provider to identify the root cause of the anomaly, evaluate options to resolve the issue, and determine a new launch readiness date. In February 2018, NASA determined the project will launch no earlier than June 2018, but this date is still under review.

PROJECT OFFICE COMMENTS

In commenting on a draft of this assessment, ICON project officials stated that the project completed all observatory integration and test activities last year. As of January 2018, the observatory remains in the Orbital-ATK cleanroom in Gilbert, Arizona in a safe state—under continuous purge and performing periodic monitoring of the battery voltage—awaiting determination of a new launch date and shipment for launch vehicle integration. Project officials also provided technical comments, which were incorporated as appropriate.



Source: NASA. | GAO-18-280SP

James Webb Space Telescope

The James Webb Space Telescope (JWST) is a large, infrared-optimized space telescope designed to help understand the origin and destiny of the universe, the creation and evolution of the first stars and galaxies, and the formation of stars and planetary systems. It will also help further the search for Earth-like planets. JWST will have a large primary mirror composed of 18 smaller mirrors and a sunshield the size of a tennis court. Both the mirror and sunshield are folded for launch and open once JWST is in space. JWST will reside in an orbit about 1 million miles from the Earth.

FORMULATION
- 03/99 Formulation start
- 01/06 Mission/ system definition review
- 03/08 Preliminary design review
- 07/08 Project confirmation

IMPLEMENTATION
- 03/10 Critical design review
- **01/18 GAO review**
- 06/18 System integration review
- 10/18 Committed launch readiness date
- 05/20 Target launch readiness date

PROJECT INFORMATION

NASA Lead Center: **Goddard Space Flight Center**

International Partners: **European Space Agency, Canadian Space Agency**

Launch Location: **Kourou, French Guiana**

Launch Vehicle: **Ariane 5**

Mission Duration: **5 years (10-year goal)**

Requirement Derived from: **2001 Astrophysics Decadal Survey**

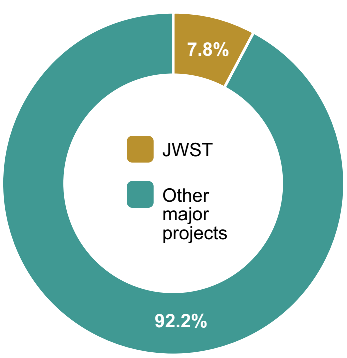
Budget Portfolio: **Science, Astrophysics**

PROJECT SUMMARY

The JWST project delayed its planned launch readiness date by a total of at least 19 months from October 2018 to May 2020. In March 2018, NASA announced the most recent delay to approximately May 2020 based on a schedule analysis by its standing review board. This analysis showed that more time will be needed to integrate and test the telescope and spacecraft elements and conduct environmental testing. For several years, the observatory contractor has overestimated workforce reductions at the beginning of each fiscal year, but technical challenges have prevented the planned reductions and hindered JWST's ability to control costs. As a result, the observatory contractor has maintained higher workforce levels than expected, and may continue to do so in the coming months. Along with the latest launch delay, this puts the project at risk of exceeding its $8 billion congressional cost cap.

PROJECT BUDGET INFORMATION

percent of current portfolio for fiscal year 2019

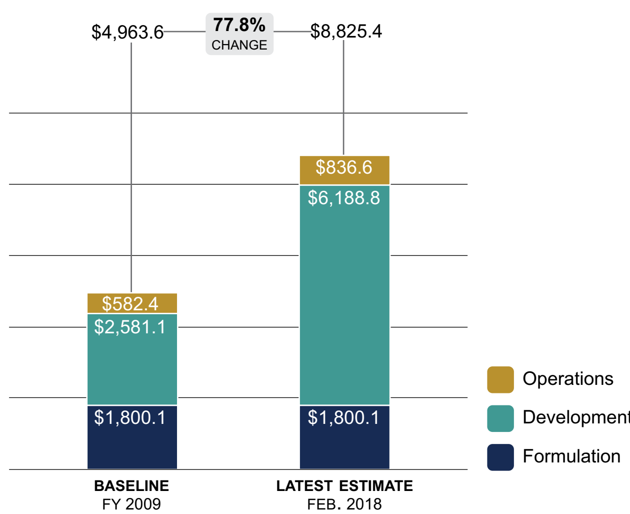


ESTIMATED FUNDING NEEDED

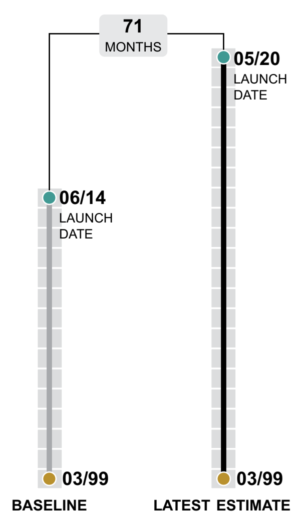
then-year dollars in millions

COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The JWST project has delayed its planned launch readiness date by at least 19 months, from the committed October 2018 launch readiness date to approximately May 2020. NASA announced two delays for the project since we last reported in May 2017.[a] First, in September 2017, the project announced a delay of up to 8 months based on the results of a schedule risk assessment that showed various components of spacecraft element integration were taking longer to complete than expected. Prior to establishing the new launch window, the project used all remaining schedule reserves to address various technical issues, including a test anomaly on the telescope and sunshield hardware challenges. The new launch date included up to 4 months of new schedule reserves. However, by February 2018, the project had consumed the 4 months of reserves due to continuing challenges with spacecraft integration and test. Then, in March 2018, the JWST project announced an 11-month launch readiness delay to approximately May 2020 based on the results of a standing review board schedule analysis. According to the analysis, the previous launch date was not possible due to lessons learned during spacecraft element integration and test and propulsion system rework. The analysis further indicated that more time will be needed to integrate and test the telescope and spacecraft elements and conduct environmental testing.

Due to these challenges, the observatory contractor has maintained higher levels of workforce than expected, and may continue to do so in the coming months. As a result, the project is at risk of exceeding the $8 billion congressional cap for formulation and development costs established in 2011. An external independent review board will conduct a schedule analysis, with the results expected in May 2018, to be followed by the agency's final decision on JWST's launch date in June 2018 and a report to Congress in summer 2018. After the launch date is determined, NASA will update the project's cost estimate.

Integration and Test

The project and observatory contractor significantly underestimated the time required to complete integration and test work on the spacecraft element. Execution of spacecraft integration and test tasks was much slower than planned due to a variety of challenges including complexity of work and reach and access limitations on flight hardware. In addition, the observatory contractor has consumed several weeks of schedule reserves due to various workmanship errors, particularly with respect to the spacecraft propulsion systems. For example, an observatory contractor technician applied too much voltage and damaged components of the propulsion system, and reattaching the replacement components consumed 5 weeks of reserves. Also in May 2017, the observatory contractor discovered that valves in the thruster modules—which help control spacecraft on-orbit positioning—had been damaged by a cleaning solution and had to be refurbished. Reattaching the refurbished modules was expected to be complete by February 2018, but was delayed by one month when a technician applied too much voltage to one of the components in a recently refurbished thruster module.

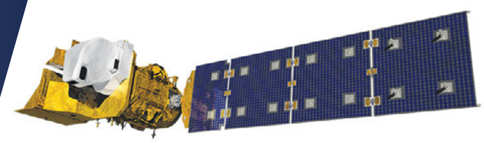
Contractor

The observatory contractor continued to maintain higher than planned workforce levels in the past year, and may continue to do so in the coming months. For several years, the observatory contractor has overestimated workforce reductions at the beginning of each fiscal year, but technical challenges have prevented the planned reductions and hindered JWST's ability to control costs. After completing negotiations on a cost overrun proposal in September 2017, driven by higher-than-planned workforce levels, the project is expected to issue a request for proposal from the observatory contractor in early 2018 for the costs for the remaining work through the new launch window. A cost overrun proposal seeks to increase the value of a cost-reimbursement contract when the total estimated cost is less than the contract's estimated cost to complete the performance of the contract.

PROJECT OFFICE COMMENTS

JWST project officials provided technical comments on a draft of this assessment, which were incorporated as appropriate.

[a] GAO-17-303SP.



Landsat 9

Landsat 9 is the next satellite in the Landsat series Program, which provides a continuous space-based record of land surface observations to study, predict, and understand the consequences of land surface dynamics, such as deforestation. The program is a collaborative, joint mission between NASA and the U.S. Geological Survey. The Landsat data archive constitutes the longest continuous moderate-resolution record of the global land surface as viewed from space and is used by many fields, such as agriculture, mapping, forestry, and geology.

Source: Orbital ATK (artist rendering). | GAO-18-280SP

FORMULATION
- 03/15 Formulation start
- 06/16 System requirements/ mission definition review
- 09/17 Preliminary design review
- 12/17 Project confirmation
- **01/18 GAO review**

IMPLEMENTATION
- 04/18 Critical design review
- 08/19 System integration review
- 12/20 Target launch readiness date
- 11/21 Committed launch readiness date

PROJECT INFORMATION

NASA Lead Center: **Goddard Space Flight Center**

International Partner: **None**

Launch Location: **Vandenberg Air Force Base, CA**

Launch Vehicle: **Atlas V**

Mission Duration: **5 years**

Requirement Derived from: **National Plan for Civil Earth Observations**

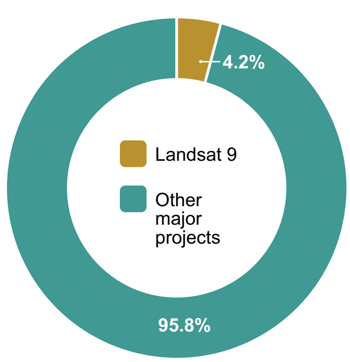
Budget Portfolio: **Science, Earth Science**

PROJECT SUMMARY

The Landsat 9 project entered the implementation phase in December 2017 and formally established its cost and schedule baselines. The project is working to a launch readiness date of December 2020, 11 months earlier than its baselined launch date, in part to help meet a goal of the scientific community to maintain two Landsat satellites on-orbit simultaneously. As a result, the project is not holding schedule reserves at the level required by NASA center policy to address known and unknown risks. The project considers this schedule challenging, but achievable because of the high use of heritage technologies, mature instrument designs, and extensive use of hardware from the prior Landsat mission, Landsat 8. The project entered implementation with mature technologies and stable instrument designs. The project plans to hold its critical design review in April 2018. Our work on product development best practices shows that at least 90 percent of design drawings should be released by critical design review to lower the risk of subsequent cost and schedule growth. As of January 2018, the project had released about 64 percent of its design drawings. Prior to this review, the project will need to mature the design of its spacecraft.

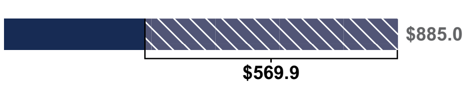
PROJECT BUDGET INFORMATION

percent of current portfolio for fiscal year 2019



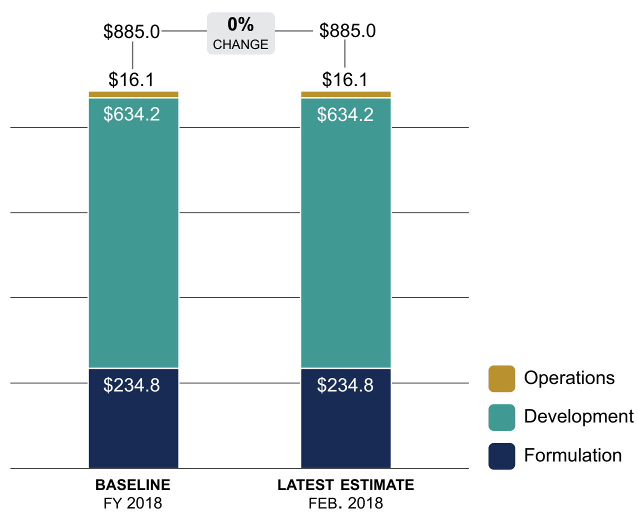
ESTIMATED FUNDING NEEDED

then-year dollars in millions

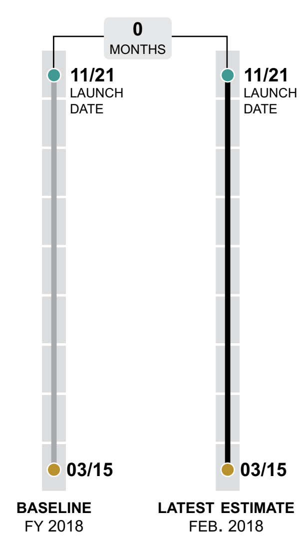


COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The Landsat 9 project entered the implementation phase in December 2017 and formally established its cost and schedule baselines. The project set a baseline life-cycle cost of $885 million and a launch date of November 2021. However, the project is working toward a launch readiness date of December 2020 due to direction in the Explanatory Statement accompanying the Consolidated Appropriations Act, 2016. According to officials, this earlier launch date will help ensure that the Landsat program is able to maintain two Landsat satellites on-orbit simultaneously, which is a goal of the scientific community, but not a requirement for the program. NASA calculated the project's joint cost and schedule confidence level, the likelihood a project will meet its cost and schedule estimate, at 47 percent for the earlier December 2020 launch date. This is slightly lower than the 50 percent required by NASA policy. However, for the baselined launch date of November 2021, the joint cost and schedule confidence level is greater than 70 percent, which meets the requirement in NASA policy.

As a result of working to this earlier launch date, the project is holding schedule reserves below the level required by NASA center policy. This means the project would have less time to address known and unknown risks without affecting its December 2020 launch date. The project considers this schedule challenging, but achievable because of the high use of heritage technologies, mature instrument designs, and extensive use of hardware from the prior Landsat mission, Landsat 8. In addition, project officials said they have confidence that the project can meet this date because they have been executing to this aggressive schedule without needing any schedule reserves. The project is holding cost reserves at the level required by NASA center policy.

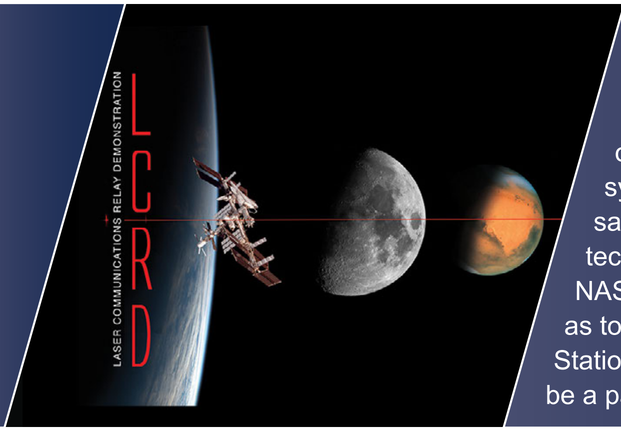
Technology and Design

The Landsat 9 project proceeded into implementation with mature technologies. The project held its preliminary design review in September 2017 with mature technologies and stable instrument designs due to high use of heritage technologies and designs from Landsat 8. Utilizing heritage technologies and designs on projects can help to reduce risk and control costs when they are used for similar purposes in similar environments. Specifically, Landsat 9's instruments—Thermal Infrared Sensor-2 and Operational Land Imager-2—are at a technology readiness level 9 and all components in the flight segments are above a technology readiness level 6. Maturing technologies to a technology readiness level 6 by preliminary design review is a best practice and helps minimize risks for space systems entering product development.

The project also proceeded into implementation with the designs of its two instruments stable. The project plans to hold its critical design review in April 2018. Our work on product development best practices shows that at least 90 percent of design drawings should be released by critical design review to lower the risk of subsequent cost and schedule growth. As of January 2018, the project had released about 64 percent of its design drawings. The project completed critical design reviews for its two instruments prior to mission preliminary design review due to the high level of heritage designs from Landsat 8, and has released over 90 percent of drawings for both. Most of the drawings that have not been released are for the spacecraft. The project's spacecraft also has a design similar to that of Landsat 8 and uses heritage components from other Earth-orbiting satellites. The project plans to hold its spacecraft critical design review in February 2018.

PROJECT OFFICE COMMENTS

In commenting on a draft of this assessment, Landsat 9 project officials stated that all project elements are successfully making progress and on track to support a December 2020 launch readiness date. Officials also provided technical comments on a draft of this assessment, which were incorporated as appropriate.



Laser Communications Relay Demonstration

LCRD is a technology demonstration mission with the goal of advancing optical communication technology for use in deep space and near-Earth systems. LCRD will demonstrate bidirectional laser communications between a satellite and ground stations, develop operational procedures, and transfer the technology to industry for future use on commercial and government satellites. NASA anticipates using the technology as a next generation Earth relay as well as to support near-Earth and deep space science, such as the International Space Station and human spaceflight missions. The project is a mission partner and will be a payload on a U.S. Air Force Space Test Program satellite.

Source: Universities Space Research Association (USRA). | GAO-18-280SP

PROJECT INFORMATION

NASA Lead Center: **Goddard Space Flight Center**

International Partners: **N/A**

Launch Location: **Cape Canaveral Air Force Station, FL**

Launch Vehicle: **Atlas V 551**

Mission Duration: **2+ years**

Requirement Derived from: **NASA Strategic Plan**

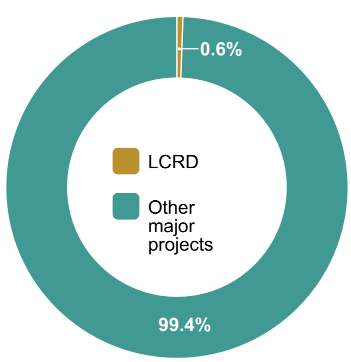
Budget Portfolio: **Space Technology, Research and Development**

PROJECT SUMMARY

The LCRD project established its cost and schedule baselines in April 2017 at a higher cost and later schedule than preliminary estimates due to funding, programmatic, and design changes made after preliminary design review in October 2013. The LCRD project has had to delay its schedule, change its host spacecraft, and adjust its design to accommodate scope changes as well as funding shortfalls in prior years. LCRD has also added a redundant communication capability that adds longevity but also cost and complexity to the spacecraft. In addition, multiple hardware components have been delivered late and are consuming project schedule reserves heading into integration and test.

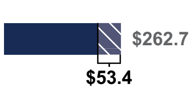
PROJECT BUDGET INFORMATION

percent of current portfolio for fiscal year 2019



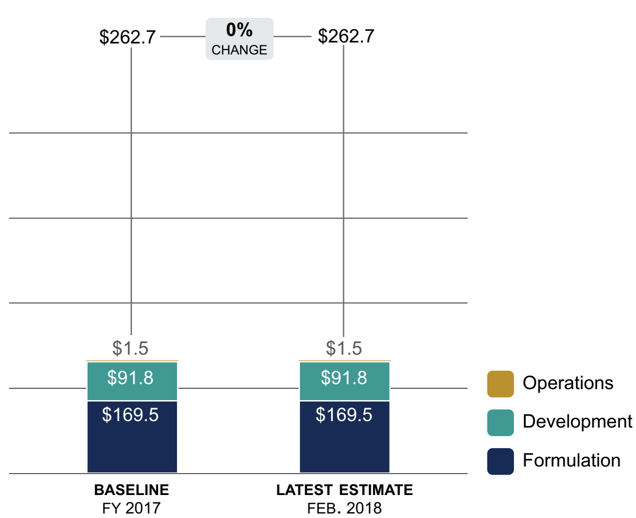
ESTIMATED FUNDING NEEDED

then-year dollars in millions

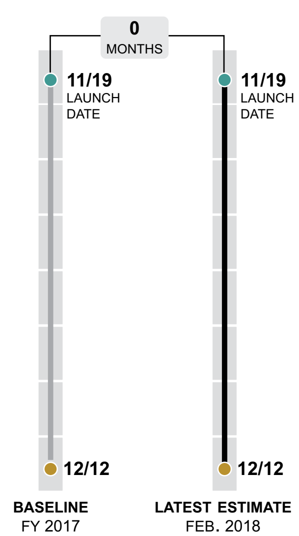


COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The LCRD project's cost and schedule baselines increased compared to its preliminary estimates due to funding, programmatic, and design changes made after preliminary design review in October 2013. LCRD entered the implementation phase in April 2017 and formally established its cost and schedule baselines of $262.7 million to launch by November 2019, which is $23.4 million higher and 23 months later than the preliminary cost estimate. The cost and schedule increases over the preliminary estimate are due in part to externally driven design changes that the project has had to address. The new launch date also reflects the project delaying its confirmation review from late 2013 until April 2017 due to funding and programmatic challenges. For example, funding for fiscal years 2015 and 2016 was less than planned, which led the project to halt development of the ground segment for 2 years. The project has also changed management and undertaken numerous replans and descopes since 2013. As of October 2017, the project was holding cost reserves below levels required by NASA center policy.

Technology

LCRD's technologies were not mature by preliminary design review. As a technology demonstration, Goddard Space Flight Center does not require technologies to be at technology readiness level 6 at that review. However, the same risks of subsequent technical problems apply to technology demonstrations, which can result in cost growth and schedule delays. Further, because technologies are being demonstrated to support future missions, the project added a high-bandwidth radio transceiver as a backup to the optical modules to increase reliability, redundancy, and longevity. A drawback of the laser communication system is that it requires an unobstructed line of sight in order to transmit and receive data. The radio transceiver allows LCRD to transmit data with less interruption as the radio transceiver increases redundancy should the line-of-sight be obstructed, and longevity should an optical unit fail during the mission. In 2017, the proposal for the high-bandwidth radio transceiver came in at a higher than expected cost but LCRD received funding from sources outside the project office. In addition, LCRD is working with its host spacecraft to solve potential on-orbit vibration that could impact data transmission, but the project will have to fund additional damping.

Design

The project held its critical design review in December 2016 with a stable design and then held project confirmation in April 2017, which allowed the project to enter final design and fabrication. The project held its confirmation after its critical design review in part due to adding encryption to the project following its preliminary design review. Adding encryption to the project required a change in host spacecraft to one with proper facility clearances, changes to the interface designs between LCRD and the new host, and changes to the onboard LCRD hardware to accommodate encryption.

Integration and Test

Late component deliveries have delayed integration and testing and further delays could begin to affect LCRD integration as well as spacecraft integration prior to launch. For example, payload integration and testing has been delayed by about 6 weeks due to a number of late component deliveries. In one instance, delivery of the flight support assembly—which interfaces the LCRD payload to the host spacecraft and maintains the thermal environment—was behind schedule due to late procurement of heaters and temperature sensors. In another, delivery of one of the two flight modems was late due to rework and component replacement.

PROJECT OFFICE COMMENTS

LCRD project officials provided technical comments on a draft of this assessment, which were incorporated as appropriate.

Source: NASA. | GAO-18-280SP

Low Boom Flight Demonstrator

LBFD is a flight demonstration project planned to demonstrate that noise from supersonic flight—sonic boom—can be reduced to acceptable levels, allowing for eventual commercial use of overland supersonic flight paths. Plans include multiple flights beyond fiscal year 2022 to gather community responses to the flights and to create a database to support development of international noise rules for supersonic flight.

FORMULATION
- 03/13 Start of concept formulation studies
- 03/14 Mission definition review
- 09/16 LBFD formulation start
- **01/18 GAO review**
- 07/18 Preliminary design review
- 09/18 Project confirmation

IMPLEMENTATION
- 07/19 Critical design review
- 06/21 Projected first flight date
- 03/22 System acceptance review

PROJECT INFORMATION

NASA Lead Center: **None**

International Partner: **None**

Requirement Derived from: **Aeronautics Research Mission Directorate Strategic Implementation Plan**

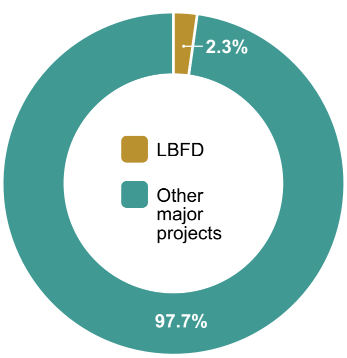
Budget Portfolio: **Aeronautics, Integrated Aviation Systems Program**

PROJECT SUMMARY

The LBFD project entered the preliminary design and technology development phase and established preliminary cost and schedule targets in September 2016. The project expects that its preliminary cost estimate of at least $390 million will increase when it establishes its cost and schedule baseline at project confirmation planned for September 2018, due in part to the estimate not including cost and schedule reserves. The project began under a concept study effort known as the Quiet Supersonic Technology (QueSST) project and was conducted under an existing research contract. NASA selected a post-preliminary design and build contractor in March 2018. Under the QueSST effort, the project matured three of LBFD's six technologies and will need to mature its remaining three technologies before the project's preliminary design review. These include one critical technology: the design tools needed to create the aircraft's outer shape, which is necessary to meet the project's mission.

PROJECT BUDGET INFORMATION

percent of current portfolio for fiscal year 2019



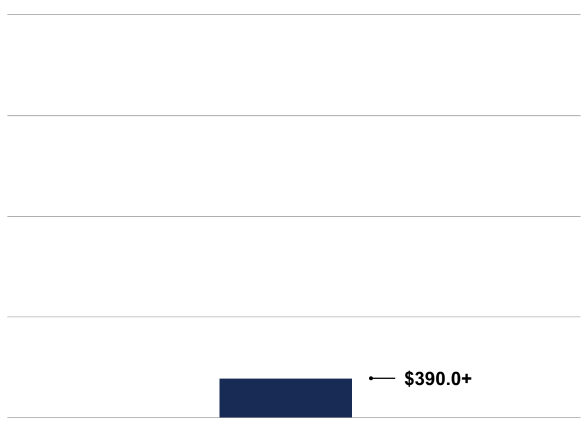
TOTAL FUNDED TO DATE

then-year dollars in millions

$75.7

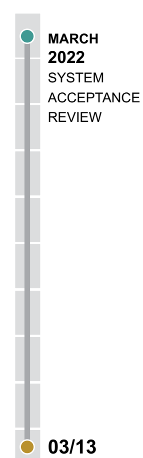
PRELIMINARY COST[a]

then-year dollars in millions



[a]This estimate is preliminary, as the project is in formulation and there is uncertainty regarding the costs associated with the design options being explored. NASA uses these estimates for planning purposes.

PRELIMINARY SCHEDULE



LATEST ESTIMATE
MARCH 2018

Cost and Schedule Status

The LBFD project entered the preliminary design and technology development phase and established preliminary cost and schedule targets in September 2016. The project's preliminary cost estimate is $390 million but the project expects the estimate to increase when it establishes a cost and schedule baseline at its confirmation review planned for September 2018. For example, the preliminary cost estimate does not include cost reserves.

Further, according to project officials, the cost estimate will also include an additional $39 million associated with requirements and concept study efforts—that included developing a preliminary design—conducted from 2014 to 2016. Known as the Quiet Supersonic Technology (QueSST) project, the effort was conducted under an existing research contract with Lockheed Martin. Project officials explained that QueSST used funding available each year for concept studies, but that the LBFD project is slated for dedicated funding following its preliminary design review. However, project officials do not plan to include some of the costs associated with the flights to gather community responses because a separate NASA project—the Commercial Supersonic Technology project—will lead this effort.

Additionally, the project's preliminary schedule is in flux. Since the release of the fiscal year 2019 Presidential Budget Request in February 2018, project officials indicated that dates for some key events have changed, and the system acceptance review is now scheduled 5 months later than previously planned.

Design and Technology

In March 2018, NASA selected Lockheed Martin for the post-preliminary design contract for LBFD development. Officials reported that the solicitation did not require that proposals use the preliminary design developed by Lockheed Martin under QueSST. But officials said that part of the evaluation criteria was whether the proposed concept was at a preliminary design review-level of maturity.

Based on the work completed under QueSST, the LBFD project is continuing to mature its one critical technology—the design tools used to create the aircraft's outer shape, which is necessary to achieve low-boom supersonic flight. Project officials said developing these tools and the shape, which directly impacts the sound produced by the aircraft during supersonic flight, will be the majority of the development work necessary to fly and test the LBFD aircraft. The project has assessed the design tools to be at a technology readiness level 5, which means the basic components have been integrated and tested in a simulated environment.

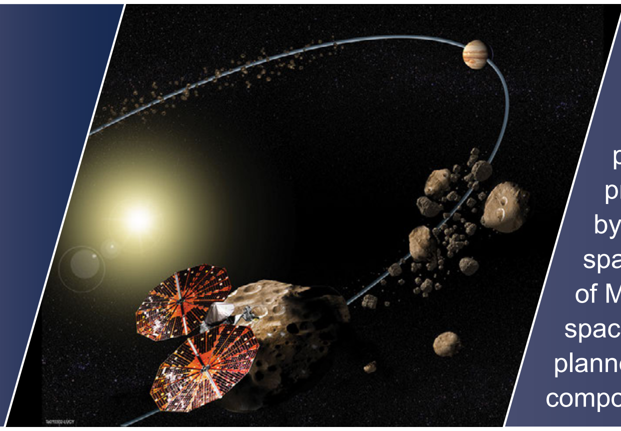
Three of LBFD's five heritage technologies were matured as part of the QueSST effort. The project will need to mature the remaining technologies as well as the design tools prior to its preliminary design review in July 2018. Maturing technologies during preliminary design helps reduce risks for systems entering product development. The fiber optic sensing system, which will measure bend and twist of the wings and stabilizer, and the external vision system, which includes cameras and monitors to provide forward visibility for the pilot—are not yet mature and will require additional development work. The project noted that these two technologies have flown before but not as part of a research aircraft.

Other Issues to Be Monitored

The LBFD project is using a virtual project office and is in the process of making decisions on how to execute the project using this model. The project team includes personnel from many NASA centers, allowing specialized staff in different centers to collaborate more than they would normally. The virtual project office model may highlight an organizational structure that could be beneficial for future projects, but it is too soon to tell. In addition, officials stated that the project has not decided which NASA center's policies it will follow, which include the cost and schedule reserve requirements the project will need to meet, among other guidelines.

PROJECT OFFICE COMMENTS

In commenting on a draft of this assessment, LBFD project officials stated that the project is continuing with its formulation activities in fiscal year 2018. These activities will lead to authorization to proceed, with implementation following the confirmation review planned for September 2018, at which time the project will be baselined. Project officials also stated that the information contained in this project assessment reflects the most currently available projections. Project officials also provided technical comments, which were incorporated as appropriate.



Lucy

Lucy will be the first mission to investigate the Trojans, which are a population of never-explored asteroids orbiting in tandem with Jupiter. The project aims to understand the formation and evolution of planetary systems by conducting flybys of these remnants of giant planet formation. The Lucy spacecraft will first encounter a main belt asteroid—located between the orbits of Mars and Jupiter—and then will travel to the outer solar system where the spacecraft will encounter six Trojans over an 11-year mission. The mission's planned measurements include asteroid surface color and composition, interior composition, and surface geology.

Source: Southwest Research Institute (SwRI). | GAO-18-280SP

FORMULATION
- 12/16 Project selection
- 01/18 **GAO review**
- 02/18 Spacecraft system requirements/ systems definition review
- 09/18 Preliminary design review
- 12/18 Project confirmation

IMPLEMENTATION
- 10/19 Critical design review
- 07/20 System integration review
- 10/21 Projected launch readiness date

PROJECT INFORMATION

NASA Lead Center: **Goddard Space Flight Center**

International Partner: **None**

Launch Location: **Kennedy Space Center, FL**

Launch Vehicle: **TBD**

Mission Duration: **11.6 years**

Requirement Derived from: **Discovery Program Announcement of Opportunity 2014**

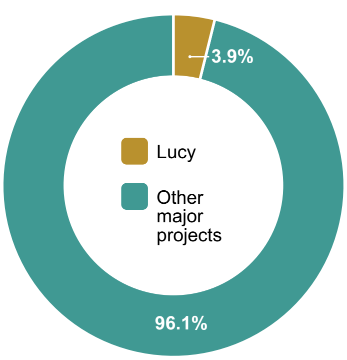
Budget Portfolio: **Science, Planetary Science**

PROJECT SUMMARY

In December 2016, Lucy was one of two projects selected by the Discovery program—a series of competed missions that have focused investigations and short development periods—to proceed to preliminary design and technology completion phase. Lucy is expected to have its rehearsal flyby of a main belt asteroid in 2025, and then fly by Trojan asteroids over the course of the next 8 years. Project officials stated that the design is based heavily on heritage hardware and does not require development of any critical technologies. The project is evaluating the extent to which risks are posed by existing hardware. For example, the project is tracking a risk related to the size of the solar array, which is larger than what the contractor typically builds. The project also implemented a trade on its spacecraft to address the risk of on-orbit failure from a heritage engine. Additionally, the project and NASA Launch Services have identified two launch vehicle options, but the project does not expect NASA to select a vehicle before its preliminary design review in September 2018.

PROJECT BUDGET INFORMATION

percent of current portfolio for fiscal year 2019



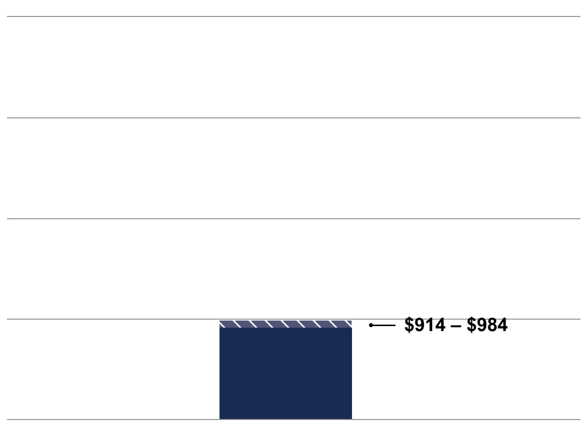
TOTAL FUNDED TO DATE

then-year dollars in millions

$57.4

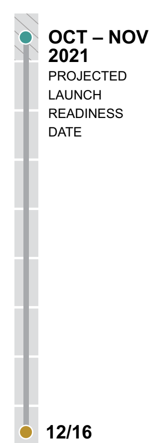
PRELIMINARY COST[a]

then-year dollars in millions



[a]*This estimate is preliminary, as the project is in formulation and there is uncertainty regarding the costs associated with the design options being explored. NASA uses these estimates for planning purposes.*

PRELIMINARY SCHEDULE



LATEST ESTIMATE
FEB. 2018

Cost and Schedule Status

In December 2016, Lucy was one of two projects selected by the Discovery program—a series of competed missions that have focused scientific investigations and short development periods—to proceed to the preliminary design and technology completion phase. At that same time, the project established preliminary cost and schedule estimates. The project's planned launch window is October-November 2021. Under that planned launch date, Lucy is expected to have its rehearsal flyby–a main belt asteroid encounter that will allow the project to test instruments—in 2025 and then fly by Trojan asteroids over the course of the next 8 years. If the project misses that launch date, another launch window opens in 2022. The project's preliminary cost range is $914 million to $984 million, and the project is currently holding cost and schedule reserves consistent with the level required by NASA center policy. The project plans to hold its preliminary design review in September 2018 and its confirmation review in December 2018, at which point it will establish its cost and schedule baseline.

Technology and Design

Project officials characterize the Lucy design as low risk because it does not require development of any critical technologies and has a high heritage design. For example, these officials stated that Lucy's design has the same architecture as prior NASA projects such as Juno and the Mars Atmosphere and Volatile Evolution Mission (MAVEN). The project plans to fly three instruments—a thermal spectrometer, a reconnaissance imager, and an imaging spectrometer—that are not exact replicas of previously flown versions but leverage heritage hardware. The Lucy project reports that its one heritage technology—an ultraflex solar array—is mature, but the project plans to use the technology in a different environment than previously demonstrated as well as make modifications that affect form, fit, and function. We have previously asserted that mature, heritage technologies must be demonstrated in a relevant environment and should be very close to form, fit, and function. The project is tracking a risk related to the size of the solar array since, at approximately 6 meters, it is larger than what the contractor typically builds. Because the contractor has not flown an array of this size, officials said they anticipate being more involved in this procurement, but there are no technical issues at this point.

According to officials, the Lucy spacecraft's proposed main engine was the same model used on a series of environmental satellites that have had engine performance problems. The engine has failed in flight more than once and was a single point failure for the Lucy project. As a result, the project completed an engine trade study in July 2017 and decided to select a different engine.

Launch

In coordination with NASA Launch Services at Kennedy Space Center, project officials identified the Atlas V and Falcon Heavy as vehicles that meet mission requirements. However, as of January 2018, the Falcon Heavy had not flown, so launch environment data was not yet available to the project. Project officials are tracking a risk that it could be necessary to rework hardware due to the Falcon Heavy launch environment. However, the project has assessed the cost impact of this scenario should the Falcon Heavy be selected. Officials said they do not expect NASA to select a launch vehicle prior to the project's planned September 2018 preliminary design review, the point at which projects prefer to select a launch vehicle. Until then, the project is designing to a mix of the two potential launch vehicles' requirements.

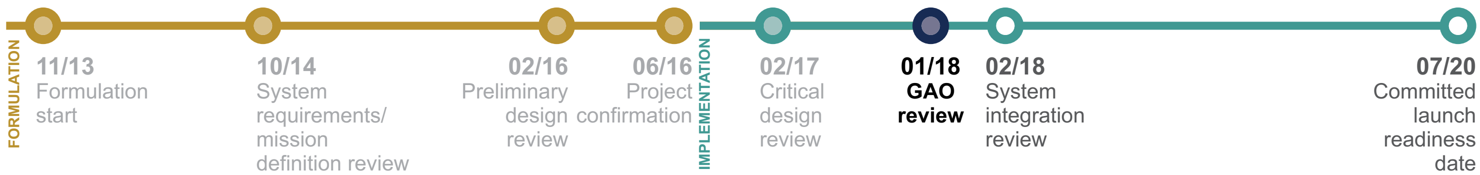
PROJECT OFFICE COMMENTS

Lucy project officials provided technical comments on a draft of this assessment, which were incorporated as appropriate.

Source: NASA/JPL-Caltech. | GAO-18-280SP

Mars 2020

Mars 2020 is part of the Mars Exploration Program, which seeks to further understand whether Mars was, is, or can be a habitable planet. Its rover and science instruments will explore Mars and conduct geological assessments, search for signs of ancient life, determine potential environmental habitability, and prepare soil and rock samples for potential future return to Earth. The rover will include a technology demonstration instrument designed to convert carbon dioxide into oxygen. Mars 2020 is based heavily on the Mars Science Laboratory, or Curiosity, which landed on Mars in 2012 and remains in operation.



PROJECT INFORMATION

NASA Lead Center: **Jet Propulsion Laboratory**

International Partners: **Centre National d'Etudes Spatiales (France), Centro de Astrobiología and Center for the Development of Industrial Technology (Spain), Norwegian Defence Research Establishment (Norway)**

Launch Location: **Eastern Range, FL**

Launch Vehicle: **Atlas V**

Mission Duration: **2 years**

Requirement Derived from: **2011 Planetary Science Decadal Survey**

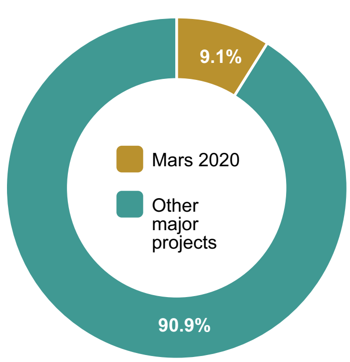
Budget Portfolio: **Science, Planetary Science**

PROJECT SUMMARY

The Mars 2020 project has encountered cost growth and schedule delays due to technical and design challenges for some components and subsystems—including a new and highly complex development—but these delays have not affected the project's overall schedule. The project did not mature all of its technologies until after the project's critical design review, which is later than recommended by best practices. Further, the project's new and complex developments continue to face technical challenges that could affect cost and schedule. Additionally, the project had an unstable design at its critical design review, with 72 percent of its drawings released. This is lower than recommended by best practices and new and highly complex developments were not stable at the time of the design review. The project is working toward system integration review in February 2018, but the project is tracking several risks that may affect schedule. For example, the new Sampling and Caching System (SCS) that will collect and cache Martian soil and rock samples is facing technical and schedule challenges.

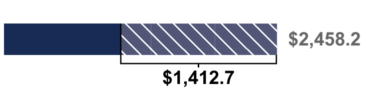
PROJECT BUDGET INFORMATION

percent of current portfolio for fiscal year 2019



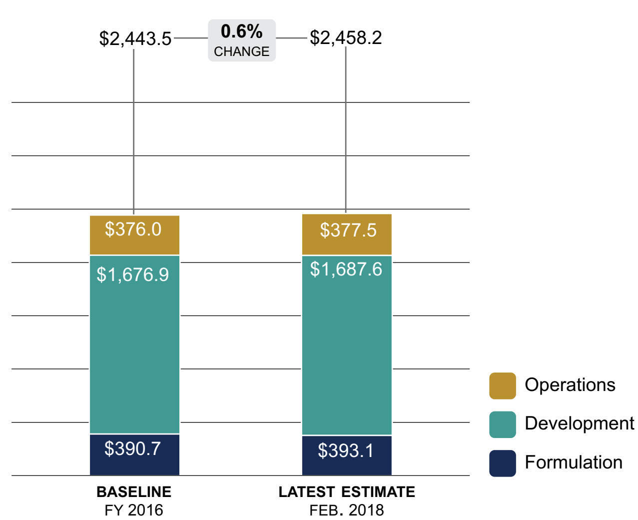
ESTIMATED FUNDING NEEDED

then-year dollars in millions

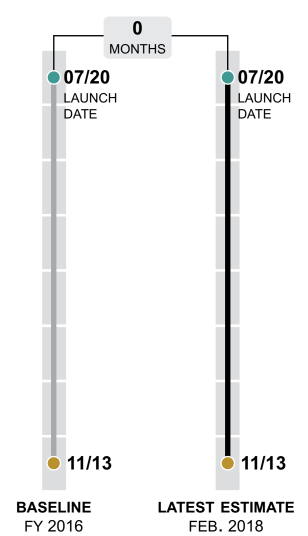


COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The Mars 2020 project continues to meet its schedule baseline, but is not meeting the cost baseline established at its confirmation review in June 2016. The project experienced $14.7 million in cost growth due to technical challenges with a technology demonstration instrument and higher than expected integration costs for an entry, descent, and landing instrument. In addition, the project has also experienced schedule delays for some of its new developments, but these delays have not affected the project's overall schedule. For example, the project delayed its system integration review by about 3 months to February 2018 to allow for more time to build new development hardware, which were behind schedule due to technical and design challenges. Even with this delay, project officials said they are confident in the schedule established at the confirmation review because the project is holding schedule reserves at about two times the level required by Jet Propulsion Laboratory policy. In addition, the project allocated a significant portion of cost reserves to the new development items. The project is not holding cost reserves at the level required by Jet Propulsion Laboratory policy, but expects to be meeting the policy once the project receives additional funds in February 2018.

Technology

The Mars 2020 project matured its technologies later than recommended by best practices and several new and highly complex developments continue to face significant technical challenges that could affect cost and schedule. Best practices recommend maturing technologies to a technology readiness level 6 by the project's preliminary design review to help minimize risks for space systems entering product development. However, all of the technologies for the Mars 2020 project were not mature until after the program's critical design review. Further, the project is concerned late hardware deliveries and unfavorable sample contamination test results might cause the Sampling and Caching System (SCS)—the project's most challenging development that will collect and cache Martian soil and rock samples—to be delivered late to integration and test. Additionally, the project experienced technical issues with multiple components within an instrument that will search for organics and minerals that have been altered by water, which have negatively affected the instrument's cost and schedule. To mitigate these challenges, the project allocated additional reserves and brought on additional expertise. Further, the project is utilizing existing SCS development models rather than build new ones to reduce cost and schedule risk.

Design

The Mars 2020 project held its critical design review before it had a stable design, which increases the project's risk of cost growth and schedule delays during the integration and test phase. At this review, the project released about 72 percent of design drawings, which is less than the best practice of releasing 90 percent of design drawings at this review. Project officials stated that they held the design review earlier than normal to avoid delaying progress on the development of heritage technologies, which make up a large percentage of the rover. As a result of holding the review early, new and highly complex developments, such as the SCS, were not stable at the time of the design review. The unstable design contributed to delays in fabricating parts for the SCS engineering unit. As a result, the project reduced the number of engineering models it will build to help meet schedule.

The project has a series of parachute tests underway to determine whether it can fly with its heritage parachute or needs to use a strengthened parachute. These tests are to help mitigate risks related, in part, to supersonic test failures observed on an unrelated project. Officials said the project successfully tested its heritage design at supersonic speeds in October 2017, which reduces the risk that a new parachute design will be necessary. However, if future tests do not successfully demonstrate that either the heritage or redesigned parachute inflate as intended, the project may have to conduct additional development and tests, which could consume all of Mars 2020's available schedule reserve.

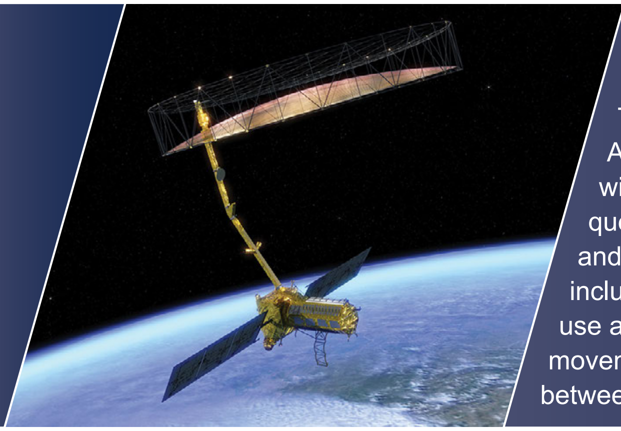
Other Issues to Be Monitored

The Mars 2020 project has experienced workforce shortages in several key areas, but, according to officials, the Jet Propulsion Laboratory has largely been able to meet the project's needs because it prioritized staffing for the Mars 2020 project. Other Jet Propulsion Laboratory projects have experienced workforce issues as well, which NASA attributes to the amount of work the laboratory is managing.

PROJECT OFFICE COMMENTS

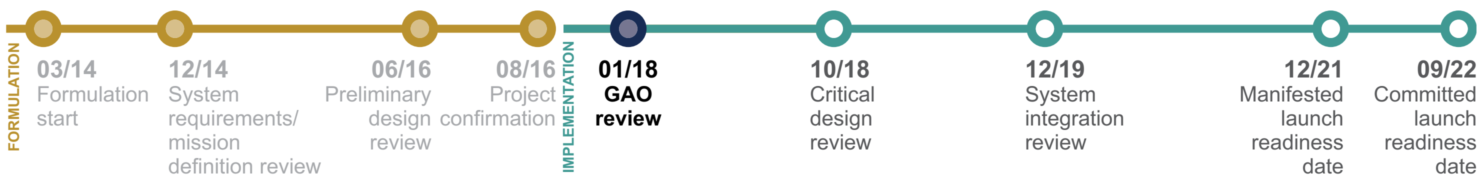
In commenting on a draft of this assessment, Mars 2020 project officials stated the project matured all its new technologies to the appropriate level by critical design review. Further, officials stated the project had backup technologies but none were required. Officials also stated the project has accommodated schedule delays within available schedule reserves and continues to maintain robust schedule reserve along the critical path. Project officials also provided technical comments, which were incorporated as appropriate.

NASA ISRO – Synthetic Aperture Radar



The NASA Indian Space Research Organisation (ISRO) – Synthetic Aperture Radar (NISAR) is a joint project between NASA and ISRO that will study the solid Earth, ice masses, and ecosystems. It aims to address questions related to global environmental change, Earth's carbon cycle, and natural hazards, such as earthquakes and volcanoes. The project will include the first dual frequency synthetic aperture radar instrument, which will use advanced radar imaging to construct large-scale data sets of the Earth's movements. NISAR represents the first major aerospace science partnership between NASA and ISRO.

Source: © California Institute of Technology/Jet Propulsion Laboratory. | GAO-18-280SP



PROJECT INFORMATION

NASA Lead Center: **Jet Propulsion Laboratory**

International Partner: **Indian Space Research Organisation (India)**

Launch Location: **Satish Dhawan Space Centre, India**

Launch Vehicle: **Geosynchronous Satellite Launch Vehicle Mark II**

Mission Duration: **3 years**

Requirement Derived from: **2007 Earth Science Decadal Survey**

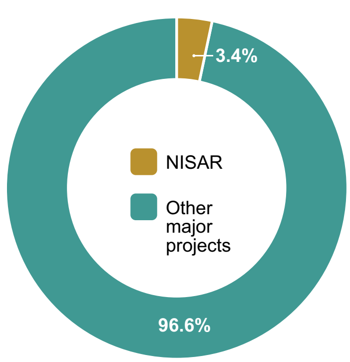
Budget Portfolio: **Science, Earth Science**

PROJECT SUMMARY

The NISAR project continues to operate within its schedule baseline, but is not meeting its cost baseline established at its confirmation review in August 2016. The project experienced $30 million in cost growth as the result of an increase in the scope of data collection. Also, about 2 months after confirmation, the project learned that its radar reflector contractor entered into two commercial contracts, which could put a strain on the contractor's workforce and increased cost and schedule risk to the project. NASA increased near-term funding of the project in May 2017, which allowed the project to accelerate radar reflector development. In addition, the project made design changes to the radar reflector boom assembly—used to deploy the reflector when the spacecraft reaches orbit—to address risks that could prevent the boom from latching in place. The NISAR project continues to track cost and schedule risks related to its partnership with ISRO. NISAR is progressing toward its critical design review in October 2018.

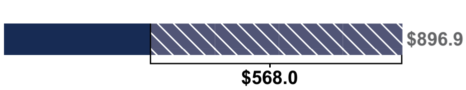
PROJECT BUDGET INFORMATION

percent of current portfolio for fiscal year 2019



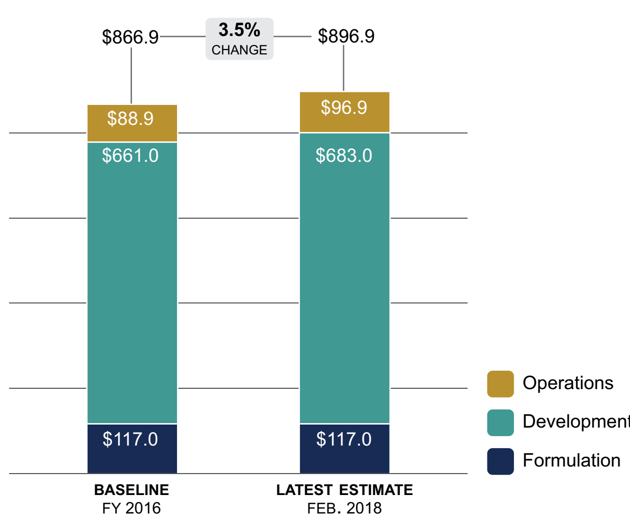
ESTIMATED FUNDING NEEDED

then-year dollars in millions

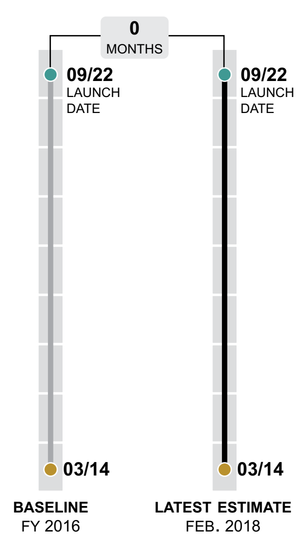


COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The NISAR project continues to operate within its schedule baseline, but is not meeting the cost baseline established at its confirmation review in August 2016. The project experienced $30 million in cost growth as the result of an increase in the scope of data collection in response to additional data needs being identified by an interagency working group. The additional data include soil moisture and natural hazard data that would be of value for other federal agencies and the science community. Also, about 2 months after confirmation, the project learned that its radar reflector contractor entered into two commercial contracts, which could put a strain on the contractor's workforce and increased cost and schedule risk to the project. To avoid schedule conflicts with the contractor's new contracts, NASA increased the project's near-term funding in May 2017 so that the project could accelerate development of the radar reflector. NISAR is progressing toward its critical design review in October 2018 and is currently holding cost and schedule reserves consistent with the level required by Jet Propulsion Laboratory policy.

Design

The NISAR project made design changes to the radar reflector boom assembly—used to deploy the radar reflector when the spacecraft reaches orbit—to address risks that could prevent the boom from latching in place. Specifically, the project modified how the boom is deployed, including using spring dampers to deploy the boom instead of a cable-driven system and non-explosive launch restraints to reduce shock levels. Project officials said the boom redesign has single point failures, but the probability of failure is lower compared to the previous design.

The NISAR project continues to track the system's mass as a significant risk. Maintaining adequate mass margins is a key indicator of design stability. Project officials stated that they continue to improve their knowledge of mass through the use of engineering models and more matured design, and sometimes this has led to an increase in mass. For example, the project used computer aided design to determine the length of cabling needed and found this increased its mass estimate over prior estimates. In July 2017, the project instituted a mass control plan, which project officials said would require all increases in mass to be reported and determinations be made regarding the necessity of the change.

Developmental Partner

The NISAR project continues to track a risk that process differences between NASA and its development partner, the Indian Space Research Organisation (ISRO), could negatively affect cost and schedule, but a recent project assessment concluded that collaboration between the two organizations has been effective. For example, in July 2017, the project signed an updated cooperative project plan that outlines how the two organizations should interface on topics such as requirements and technical information.

The project is also tracking a risk related to the ISRO-provided launch vehicle—the Geosynchronous Satellite Launch Vehicle (GSLV) Mark II—which must meet all NASA-ISRO agreed-upon criteria before it can be used. For example, the GSLV Mark II must have three successful launches and one successful 4-meter fairing launch prior to NISAR's planned launch date in 2021. As of January 2018, ISRO had four consecutive successful GSLV Mark II launches, but had not yet planned a 4-meter fairing launch.

PROJECT OFFICE COMMENTS

NISAR project officials provided technical comments on a draft of this assessment, which were incorporated as appropriate.

Source: © 2017 Lockheed Martin Corporation. | GAO-18-280SP

Orion Multi-Purpose Crew Vehicle

The Orion Multi-Purpose Crew Vehicle (Orion) is being developed to transport and support astronauts beyond low-Earth orbit, including traveling to Mars or an asteroid. The Orion program is continuing to advance development of the human safety features, designs, and systems started under the Constellation program, which was canceled in 2010. Orion is planned to launch atop NASA's Space Launch System (SLS). The current design of Orion consists of a crew module, service module, and launch abort system.

- 07/06 Formulation start under Constellation program
- 02/10 Orion canceled under Constellation program
- FORMULATION
- 02/12 Formulation start
- 08/14 Preliminary design review
- 12/14 Exploration flight test
- 09/15 Project confirmation
- IMPLEMENTATION
- 10/15 Critical design review
- **01/18 GAO review**
- 12/19-06/20 First uncrewed flight replanned launch readiness date
- 04/23 First crewed flight committed launch readiness date

PROJECT INFORMATION

NASA Lead Center: **Johnson Space Center**

International Partner: **European Space Agency**

Launch Location: **Kennedy Space Center, FL**

Launch Vehicle: **Space Launch System**

Mission Duration: **Up to 21 day active mission duration capability with four crew**

Requirement Derived from: **NASA Authorization Act of 2010**

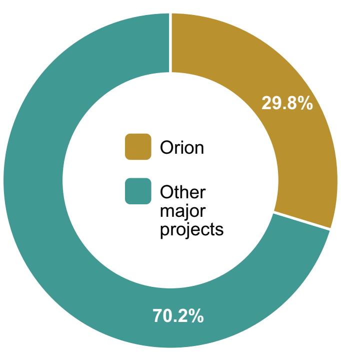
Budget Portfolio: **Exploration, Exploration Systems Development**

PROJECT SUMMARY

The Orion program continues to operate within its schedule baseline but NASA expects the program to exceed its cost baseline through Exploration Mission-2 (EM-2) due to new hardware and the program addressing development challenges. The extent of cost growth is unknown, but NASA plans to complete a new cost estimate by June 2018. For example, according to NASA, the cost increases have been driven in part by moving from a single-piece, or monolithic, heatshield design to one that employs blocks in order to improve its structural strength. The program's service module—contributed by the European Space Agency—is currently driving the program schedule as well as the launch schedule for the first mission. The module has proven more difficult to produce than expected and has been delayed numerous times. The service module is at risk of further delays that may affect NASA's planned launch date for EM-1, which would begin to consume schedule reserve for EM-2. In addition, the program is addressing some parts material failures. Specifically, the spacecraft's avionics cards did not withstand vibration testing and required a materials change.

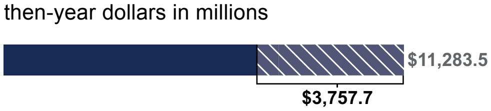
PROJECT BUDGET INFORMATION

percent of current portfolio for fiscal year 2019



ESTIMATED FUNDING NEEDED[a]

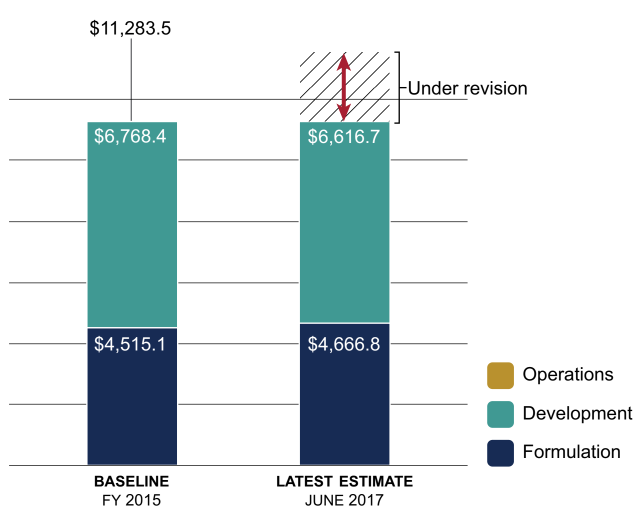
then-year dollars in millions



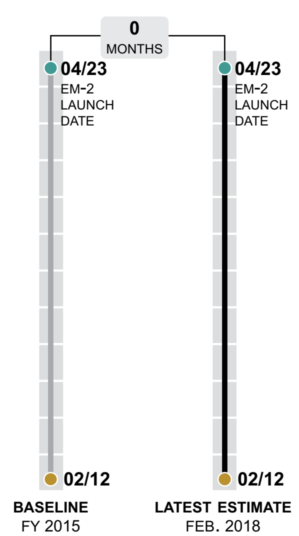
[a]Includes funding through Exploration Mission-2.

COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The Orion program continues to operate within its schedule baseline but NASA expects the program to exceed its cost baseline through EM-2, and is at risk for future schedule delays. The project's life-cycle cost estimate is expected to increase beyond its $11.28 billion baseline—due in part to the EM-1 schedule delay—when a planned, new cost estimate for the program is complete in June 2018. According to preliminary analysis, major drivers of the potential cost increase also include new hardware and addressing development challenges. For example, there was a cost impact when the program moved from a single-piece, or monolithic, heatshield design to one that employs blocks in order to improve its structural strength.

In December 2017, NASA announced December 2019 as the new internal launch readiness date for EM-1 and that the agency also allocated 6 months of schedule reserve to June 2020 for possible manufacturing and production schedule risks. While the Orion program did not have a committed launch date for EM-1, the recent delay has reduced the amount of time available to the program between EM-1 and its committed EM-2 launch date of April 2023. In addition, the delay means that the program will continue to consume resources for EM-1 that would have otherwise been available for development on EM-2, thus increasing pressure on the EM-2 cost and schedule. If NASA delays EM-1 beyond December 2019—which is likely given both Orion and the Space Launch System have no schedule margin to meet their deliveries for this date—the schedule reserve for Orion's committed EM-2 launch date of April 2023 would continue to erode and put the program at risk for future schedule delays.

Developmental Partner

The late completion and delivery of the European Service Module (ESM)—a European Space Agency contribution via agreement with NASA—is driving the program's schedule and may further delay EM-1. The European Space Agency has delayed delivery of the service module 14 months since the element's critical design review in June 2016. The ESM currently has no schedule reserve to support the December 2019 launch schedule, meaning that any additional delays will compress or delay integration activities prior to launch. Further, NASA is tracking a risk that the ESM could be delayed beyond the current estimated delivery date of June 2018. Such a delay would likely delay the EM-1 launch date beyond December 2019.

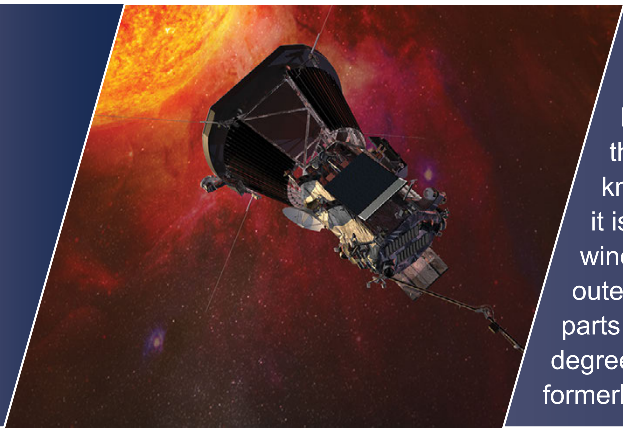
Program officials stated that recent ESM delays are due in part to late component deliveries from subcontractors, especially valves. However, they also noted at least one of those valves is currently not meeting specifications, indicating that the design was not sufficiently mature prior to production. The valve, a heritage design from the Space Shuttle program that maintains pressure in the propulsion system, is not sealing properly due to the increased pressures necessary on the ESM. The program has previously stated that all sides believed that the development of the ESM would be easier than it has proven to be, being based on a prior European Space Agency spacecraft. However, the changes have been more substantial than expected and the production of the first flight unit has faced setbacks. The program stated that they expect the production of the flight unit for the second flight to be quicker, though it will require some additional elements to support crew.

Technology and Design

Avionics design has recently become an issue for the Orion program and is currently 2 months behind the ESM in terms of driving the program's schedule. The avionics cards, along with many other onboard systems, have to withstand the vibration and radiation environment on Orion. The program found that the circuits on the avionics cards were cracking under operating conditions due to a poor design. As a result, officials stated that the program determined the root cause of the failure and redesigned the cards' base material to better withstand the environment. The program worked to reorganize the integration and test schedule to allow for the replacement of the cards.

PROGRAM OFFICE COMMENTS

In commenting on a draft of this assessment, Orion program officials stated that they believe the risk-informed approach that they use to address and resolve issues has proven to be successful. Also, program officials stated the program remains on track to meet its April 2023 baseline for EM-2. Program officials also provided technical comments, which were incorporated as appropriate.



Parker Solar Probe

PSP will be the first NASA mission to visit a star. Using the gravity of Venus, the spacecraft will orbit the Sun 24 times and gather information to increase knowledge about the solar wind, including its origin, acceleration, and how it is heated. PSP instruments will observe the generation and flow of solar winds from very close range and sample and take measurements of the Sun's outer atmosphere, where solar particles are energized. To achieve its mission, parts of the spacecraft must be able to withstand temperatures exceeding 2,500 degrees Fahrenheit and endure blasts of extreme radiation. The project was formerly named Solar Probe Plus, or SPP, and was renamed in May 2017.

Source: Johns Hopkins University/Applied Physics Lab. | GAO-18-280SP

FORMULATION
- 12/09 Formulation start
- 11/11 System requirements/ mission definition review
- 01/14 Preliminary design review
- 03/14 Project confirmation

IMPLEMENTATION
- 03/15 Critical design review
- 05/16 System integration review
- **01/18 GAO review**
- 08/18 Committed launch readiness date

PROJECT INFORMATION

NASA Lead Center: **Goddard Space Flight Center**

International Partner: **None**

Launch Location: **Cape Canaveral Air Force Station, FL**

Launch Vehicle: **Delta IV-heavy class with NASA-provided upper stage**

Mission Duration: **7 years**

Requirement Derived from: **2012 Heliophysics Decadal Survey**

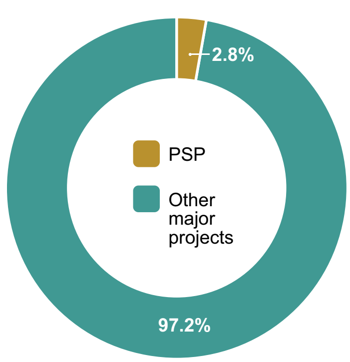
Budget Portfolio: **Science, Heliophysics**

PROJECT SUMMARY

The PSP project continues to target an August 2018 planetary launch, but the project is encountering a number of technical issues that may lead to a schedule delay or result in the project launching with fewer capabilities than originally planned. The project will need to resolve the following three issues by spring 2018 to maintain the launch window. First, the Solar Probe Cup, which is one component of an instrument package necessary to meet top-level mission requirements, has encountered several technical issues during development. Some of these issues may require the project to descope this instrument. Second, the project is completing qualification testing of the separation system after several separation bolts in the launch vehicle interface failed during a test. Lastly, the project has identified contamination stemming from an alloy used in three locations on two instruments. In one of the locations, the project must determine if it can limit the contamination. If it cannot, the project will need to delay its launch in order to replace the affected part.

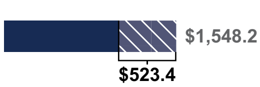
PROJECT BUDGET INFORMATION

percent of current portfolio for fiscal year 2019



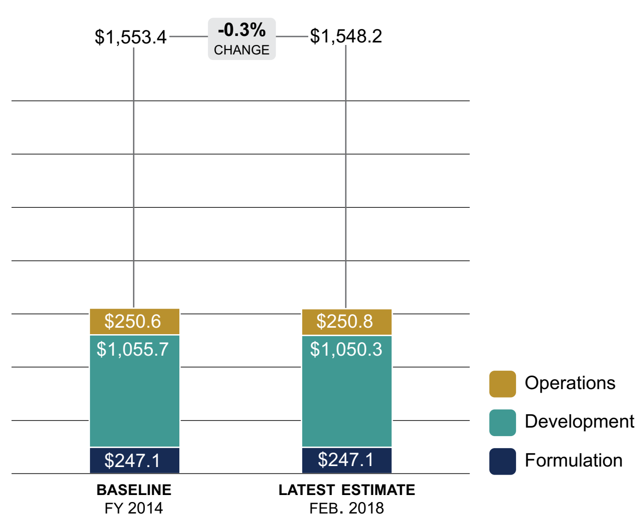
ESTIMATED FUNDING NEEDED

then-year dollars in millions

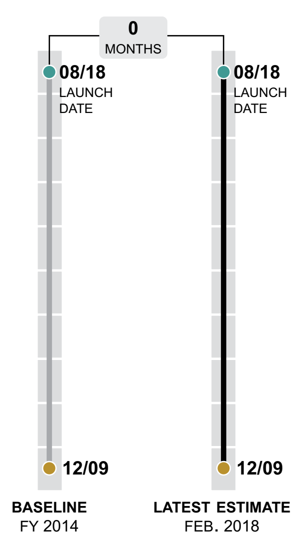


COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The PSP project continues to target an August 2018 planetary launch, but the project is encountering a number of technical issues that may lead to a schedule delay. Maintaining the project's 2018 launch window is important because a potential window only opens every 10 months. The 2019 launch window would result in a longer mission duration and require more fuel, and after that, the next window that meets requirements is 2023. The project continues to hold schedule reserves at Applied Physics Laboratory-recommended levels, but the project is tracking a risk that there may not be adequate reserves to address any future issues that may arise. The project is also tracking a risk that it may exhaust its cost reserves in fiscal year 2018 addressing instrument issues and retaining project staff, which could lead to the need for additional headquarters-held cost reserves.

Launch

In September 2017, while testing the interface between the launch vehicle and the spacecraft, three of the six separation nuts failed to release their bolts. If this occurred during launch, it would result in a total mission failure. NASA's Launch Services Program, which obtained launch services for PSP, initiated an anomaly investigation. This investigation determined that the bolts were improperly installed. The investigation board identified corrective actions, which have passed initial tests. The separation system plan includes completing qualification testing by April 2018 and includes schedule margin. However, if additional issues are identified, the project could potentially miss the 2018 launch window.

Integration and Test

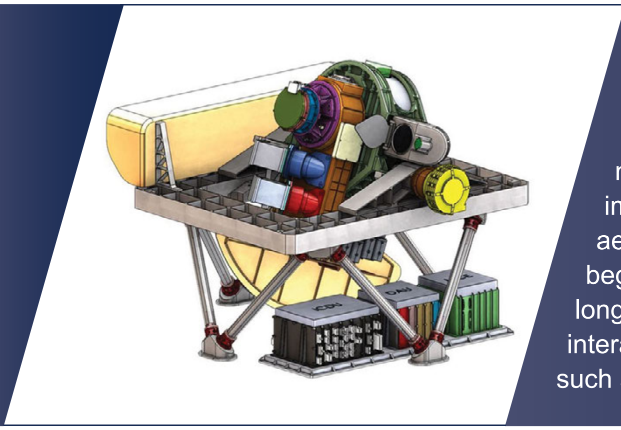
The Solar Probe Cup (SPC), which is part of an instrument package necessary to meet top-level mission requirements to gather information about particles in the solar wind, has encountered several technical issues during integration and testing. For example, recent testing has identified scenarios where the spacecraft's different operating temperature environments could result in twisting between the SPC and spacecraft, which could lead to cracks over time. To mitigate this risk, the project is conducting testing to determine the scope of this issue. If twisting could occur repeatedly throughout the mission, the project will consider de-scoping the SPC, which would require approval from NASA. The project plans to make a decision in March 2018 about whether to fly the SPC.

Other Issues to Be Monitored

The project is tracking a risk that an alloy used in several locations on the spacecraft will release gases when exposed to the high temperatures found where the spacecraft is intended to operate. The released gases can later re-solidify and contaminate the spacecraft. The alloy is found in three locations, supporting two instrument suites, on the spacecraft—the four FIELDS whip antennas, their respective thermal shields, and the SPC thermal shield—which are required to meet top-level mission requirements. Testing to understand the alloy's performance revealed that the alloy released gases even at temperatures much cooler than where the spacecraft will operate. The project is pursuing two mitigations. First, it is conducting tests to develop a contamination model, which should indicate the effects, if any, the re-solidified gases have on the spacecraft and help project officials determine if it is safe to fly the spacecraft with the existing alloy. Second, officials told us that they have ordered new material which could be used to replace the four FIELDS whip antennas and the SPC thermal shield. The project plans to make a decision if they will replace existing parts with the new material by February 2018. The project cannot replace the FIELDS thermal shields, so they have designed and implemented an additional shield, which will undergo testing in March 2018.

PROJECT OFFICE COMMENTS

PSP project officials provided technical comments on a draft of this assessment, which were incorporated as appropriate.



Plankton, Aerosol, Cloud, ocean Ecosystem

The Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) is a polar-orbiting mission that will use advanced global remote sensing instruments to improve scientists' understanding of ocean biology, biogeochemistry, ecology, aerosols, and cloud properties. PACE will extend climate-related observations begun under earlier NASA missions, which will enable researchers to study long-term trends on Earth's oceans and atmosphere, and ocean-atmosphere interactions. PACE will also enable assessments of air and coastal water quality, such as the locations of harmful algae blooms.

Source: NASA. | GAO-18-280SP (Note: Ocean Color Instrument pictured above.)

FORMULATION
- 06/16 Formulation start
- 01/17 System requirements/ mission definition review
- **01/18 GAO review**
- 03/19 Preliminary design review
- 06/19 Project confirmation

IMPLEMENTATION
- 01/20 Critical design review
- 05/21 System integration review
- 08/22 Projected launch readiness date

PROJECT INFORMATION

NASA Lead Center: **Goddard Space Flight Center**

International Partner: **None**

Launch Location: **TBD**

Launch Vehicle: **TBD**

Mission Duration: **3 years**

Requirement Derived from: **2007 Earth Science Decadal Survey**

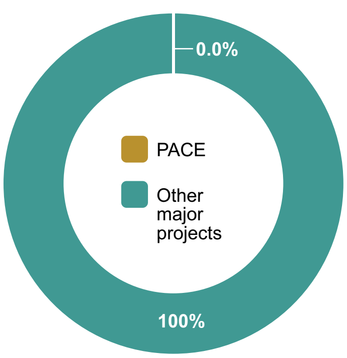
Budget Portfolio: **Science, Earth Science**

PROJECT SUMMARY

The PACE project entered the preliminary design and technology completion phase in July 2017, but is facing funding uncertainty. The fiscal year 2018 President's Budget Request did not include funding for PACE. In order to meet scientific requirements and stay within NASA's established $805 million cost cap, the PACE project modified capabilities and made system trades. The project used a design-to-cost process, which requires the project to determine what baseline capabilities are achievable within cost limitations. The PACE mission cost cap continues to create risk around the project's launch vehicle selection, but officials are mitigating this risk by exploring alternative launch options, such as a ride share agreement with the Air Force. Project officials said they expect NASA to select a launch vehicle before project confirmation, currently planned for June 2019.

PROJECT BUDGET INFORMATION

percent of current portfolio for fiscal year 2019



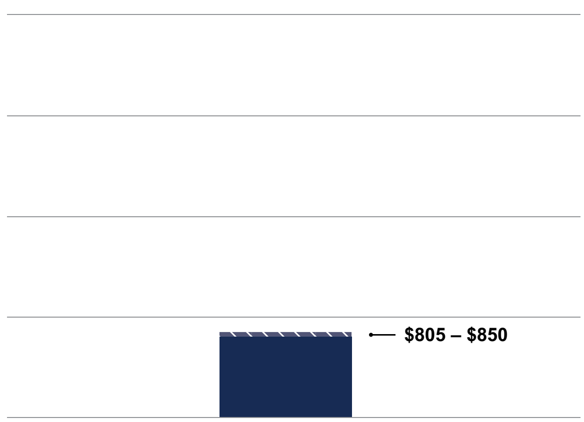
TOTAL FUNDED TO DATE

then-year dollars in millions

$98.1

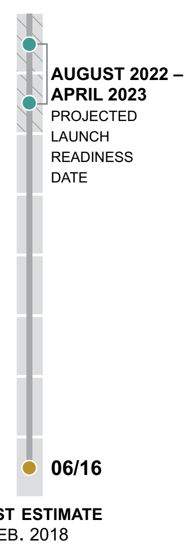
PRELIMINARY COST[a]

then-year dollars in millions



[a]*This estimate is preliminary, as the project is in formulation and there is uncertainty regarding the costs associated with the design options being explored. NASA uses these estimates for planning purposes.*

PRELIMINARY SCHEDULE



Cost and Schedule Status

In July 2017, NASA approved the PACE project to enter the preliminary design and technology completion phase, but with funding uncertainty. NASA did not request funding for PACE in its fiscal year 2018 budget request—an action attributed to budget constraints and higher science mission priorities. NASA also did not request funding for PACE in its fiscal year 2019 budget request. Despite proposed cancellation, the project is working toward preliminary design review scheduled for March 2019 and is continuing to use the design-to-cost process that requires the project to determine a baseline set of capabilities that are achievable within the project's $805 million mission cost cap at the 65 percent confidence level. This includes the $705 million allocated to the project and $100 million allocated to NASA headquarters for science-related activities, such as the calibration and validation of instrument data and processing of science data. The project is holding cost and schedule reserves consistent with NASA center policy.

Technology and Design

The PACE project modified capabilities and made system trades to meet scientific requirements within NASA's established $805 million cost cap. As part of the design-to-cost process, the project added capability to its primary instrument—the Ocean Color Instrument (OCI)—including extending performance to a new ultraviolet range and adding components for daily calibration. Additionally, the project originally sought an agreement with the Indian Space Research Organisation (ISRO) for a contributed polarimeter because the cost of procuring the instrument was higher than the amount allocated under the project's cost cap. However, according to officials, ISRO's inability to meet schedule needs and the uncertainty surrounding the future of the project led ISRO to withdraw its concept of a contributed polarimeter. The project is now pursuing two smaller contributed instruments that have mature designs from the University of Maryland-Baltimore County and the Netherlands Space Office—the Dutch space agency. According to officials, the project would use these smaller instruments in place of the larger ISRO polarimeter. While the ISRO polarimeter was a more capable instrument, the two polarimeters are expected to provide substantive scientific information for the cloud and atmospheric science community. The project will continue to make capability trades as part of the design-to-cost approach until project confirmation.

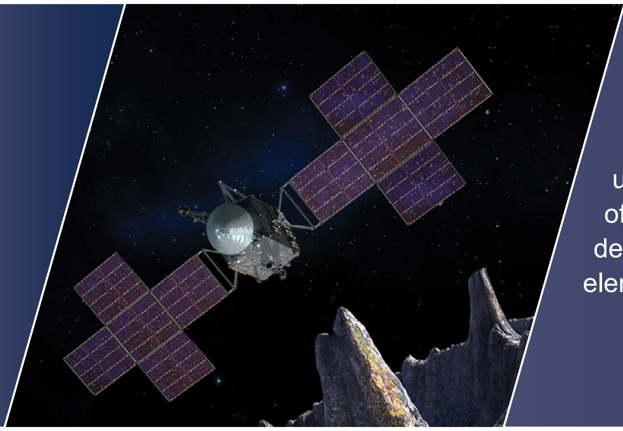
The PACE project made a design decision to tilt the OCI on a platform as opposed to tilting the entire spacecraft in order to meet a requirement that the OCI must tilt during some points of operation to avoid sun glint, or reflection of the sun off the ocean that causes a loss in data. The project came to this decision through a trade study, which, according to officials, demonstrated that tilting the entire spacecraft would take longer than tilting just the platform, lessening the amount of time the project has to collect data. However, the project is now tracking a risk that the inertia created by the OCI platform could interfere with data collection, which the project plans to mitigate by optimizing the placement and alignment of the OCI on its platform.

Launch

The PACE project is pursuing a shared ride agreement with the Air Force, which could help to mitigate a launch vehicle risk that the project is tracking. The launch vehicle cost remains the project's top risk, which could cause the project to exceed the $705 million allocated to the project or have to reduce its science capabilities. According to officials, a shared ride option would allow PACE to be the primary mission with a secondary Air Force payload at launch, which would reduce the project's launch vehicle costs and free up funding for other areas. The project has a launch vehicle budget of $105 million, and under a potential shared ride agreement, the project would be required to cover only a portion of the total vehicle costs. Project officials said they expect NASA to select a launch vehicle before project confirmation, currently planned for June 2019.

PROJECT OFFICE COMMENTS

PACE project officials provided technical comments on a draft of this assessment, which were incorporated as appropriate.



Source: NASA/JPL-Caltech/Arizona State Univ./Space Systems Loral/Peter Rubin. | GAO-18-280SP

Psyche

Psyche will be the first mission to visit a metal asteroid and aims to understand a previously unexplored component of the early building blocks of planets: iron cores. The project plans to orbit the Psyche asteroid to determine if it is a planetary core, characterize its topography, assess the elemental composition and determine the relative ages of its surface regions.

FORMULATION

- **12/16** Project selection
- **01/18** **GAO review**
- **04/18** Project mission system review
- **03/19** Preliminary design review
- **05/19** Project confirmation

IMPLEMENTATION

- **04/20** Critical design review
- **12/20** System integration review
- **08/22** Projected launch readiness date

PROJECT INFORMATION

NASA Lead Center: **Jet Propulsion Laboratory**

International Partner: **None**

Launch Location: **Cape Canaveral Air Force Station, FL**

Launch Vehicle: **TBD**

Mission Duration: **21 months science operation**

Requirement Derived from: **Discovery Program Announcement of Opportunity 2014**

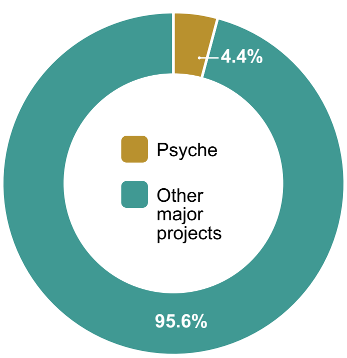
Budget Portfolio: **Science, Planetary Science**

PROJECT SUMMARY

In December 2016, Psyche was one of two projects selected by the Discovery program—a series of competed missions that have focused scientific investigations and short development periods—to proceed to the preliminary design and technology completion phase. NASA selected the project's 2023 launch proposal, but later directed the project to work to an accelerated launch readiness date of August 2022. The accelerated launch date will allow Psyche to arrive at the asteroid over 4 years earlier than the original timeline due to a quicker flight. According to project officials, the Psyche project's current design utilizes mature, heritage technologies with some modifications. The project plans to fly three instruments that have flown on prior planetary missions and buy a commercially available spacecraft design. The project also plans to fly the Deep Space Optical Communications technology demonstration (DSOC), which is a laser-based communication device that could be beneficial to future deep space missions requiring high data rates, but it is not needed to meet Psyche's science requirements. As a result, Psyche could launch without DSOC if it experiences delays.

PROJECT BUDGET INFORMATION

percent of current portfolio for fiscal year 2019



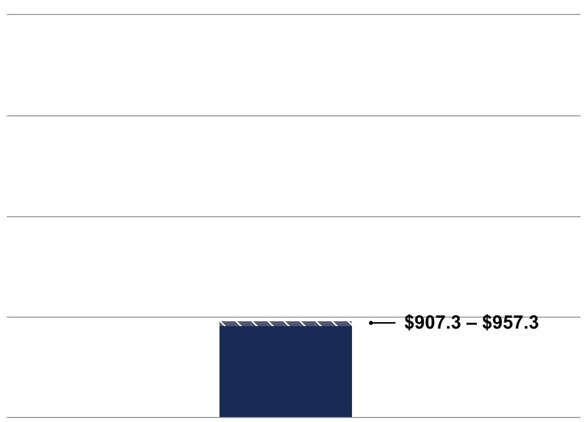
TOTAL FUNDED TO DATE

then-year dollars in millions

$50.3

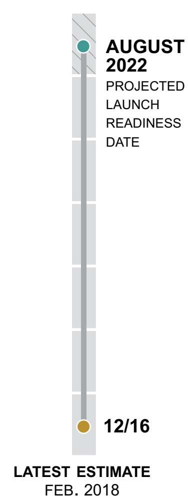
PRELIMINARY COST[a]

then-year dollars in millions



[a]*This estimate is preliminary, as the project is in formulation and there is uncertainty regarding the costs associated with the design options being explored. NASA uses these estimates for planning purposes.*

PRELIMINARY SCHEDULE



Cost and Schedule Status

In December 2016, Psyche was one of two projects selected by the Discovery program—a series of competed missions that have focused scientific investigations and short development periods—to proceed to the preliminary design and technology completion phase. NASA selected the project's 2023 launch proposal, but later directed the project to work to an accelerated launch readiness date of August 2022. The accelerated launch will allow Psyche to arrive at the asteroid over 4 years earlier than the original timeline due to a quicker flight path. At the most recent decision point, the project set a preliminary cost range of $907.3 million to $957.3 million. The project plans to hold its preliminary design review in March 2019 and its confirmation review in May 2019, at which point it will formally establish its cost and schedule baseline. The project is currently holding cost and schedule reserves consistent with the level required by Jet Propulsion Laboratory policy.

Technology and Design

The Psyche project reported that its current design does not use any critical technologies and is based heavily on heritage technologies with modifications, which project officials assess as all being matured to at least technology readiness level 6. We have previously asserted that mature technologies must be demonstrated in a relevant environment and should be very close to form, fit, and function. The Psyche project reports that its heritage technologies are mature, but the project plans to modify some technologies. For example, the project plans to modify the Gamma Ray Neutron Spectrometer instrument—previously used on a mission to Mercury and will be used to determine Psyche's elemental composition—by adding a new cooling system, which the project is tracking as a risk because of possible problems accommodating the new cooling system. Project officials stated the spacecraft bus design—reported mature by the project—is based on a commercially available design that is used for Earth-orbiting communication satellites. The project plans to make minor modifications to some of the spacecraft bus to enable it to operate more robustly in deep space.

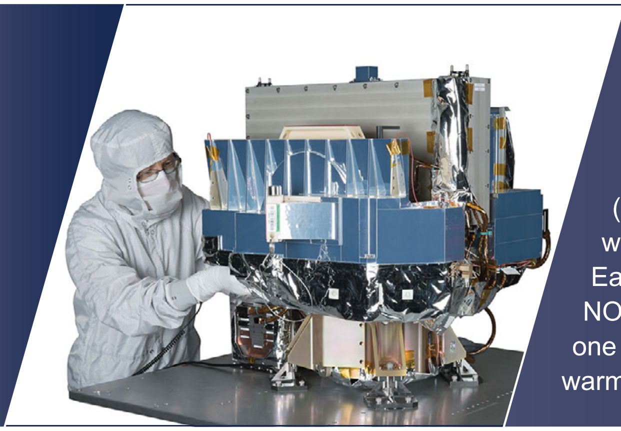
The project also plans to fly the Deep Space Optical Communications technology demonstration (DSOC), which is a laser-based communication device that could be beneficial to future deep space missions requiring high data rates. NASA is developing and funding DSOC as a separate project in the Space Technology Mission Directorate. As a result, the Psyche project does not control the cost or schedule for DSOC. The Psyche and DSOC projects have been working closely together to align their schedules, such as by establishing regular team meetings and developing a memorandum of understanding to ensure consistent expectations between both projects. If DSOC experiences delays, project officials stated that there is an option that Psyche could launch without it because DSOC is not needed to meet Psyche's science requirements.

Other Issues to be Monitored

In September 2017, the project reported a risk that it may have to conduct integration and testing off-site because it is planning to share a clean room with the Europa Clipper project, which has stricter planetary protection and contamination control requirements. These stricter requirements have a cost impact and the project is researching options to partition the clean room without jeopardizing the Europa Clipper project's requirements. The project is also researching options to conduct integration and testing off-site, such as using the contractor's facilities.

PROJECT OFFICE COMMENTS

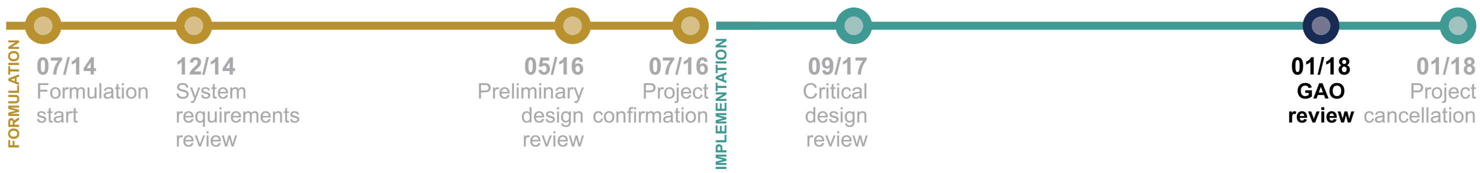
Psyche project offícals provided technical comments on a draft of this assessment, which were incorporated as appropriate.



Source: Harris Corporation. | GAO-18-280SP

Radiation Budget Instrument

The Radiation Budget Instrument (RBI) is a scanning radiometer that NASA planned to launch on the National Oceanic and Atmospheric Administration's (NOAA) Joint Polar Satellite System 2 (JPSS-2). RBI's planned mission was to support global climate monitoring by continuing measurements of the Earth's reflected sunlight and emitted thermal radiation made by NASA and NOAA satellites over the past 30 years. This data was intended to represent one of two key sets of measurements needed to determine whether the Earth is warming or cooling.



PROJECT INFORMATION

NASA Lead Center: **Langley Research Center**

International Partner: **None**

Launch Location: **Not applicable**

Launch Vehicle: **Not applicable; instrument hosted on JPSS-2 spacecraft**

Mission Duration: **7 years**

Requirement Derived from: **NASA Strategic Plan**

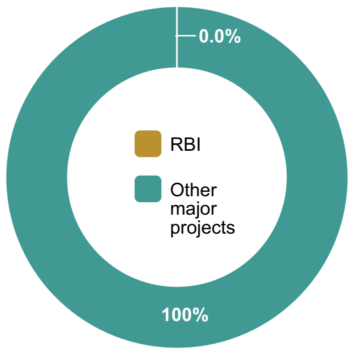
Budget Portfolio: **Science, Earth Science**

PROJECT SUMMARY

According to NASA's cancellation memorandum, NASA canceled the RBI project because of continued cost growth, technical issues, and poor contractor performance. The RBI project continued to experience contract cost growth, and as of November 2017, contract costs for design, fabrication, and delivery of RBI had grown by about 110 percent from the original value for this work, or an increase of $115 million. This increase depleted all remaining project-held cost reserves as the project entered the riskiest point of the development cycle. Ultimately, NASA determined that continuing to fund RBI from within the Earth Science Division budget would slow other important activities.

PROJECT BUDGET INFORMATION

percent of current portfolio for fiscal year 2019

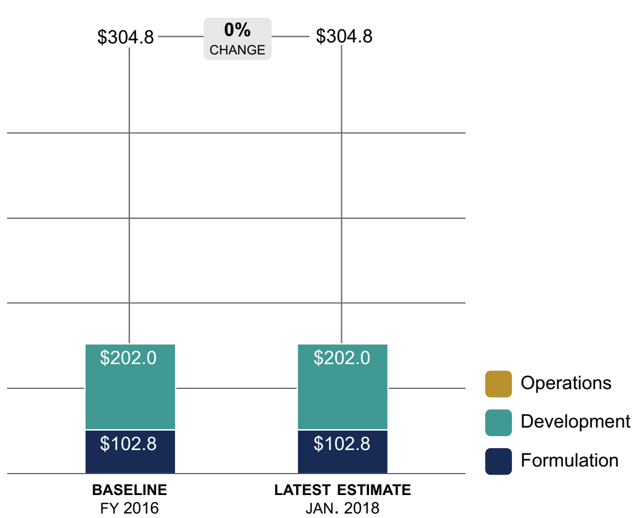


ESTIMATED FUNDING NEEDED

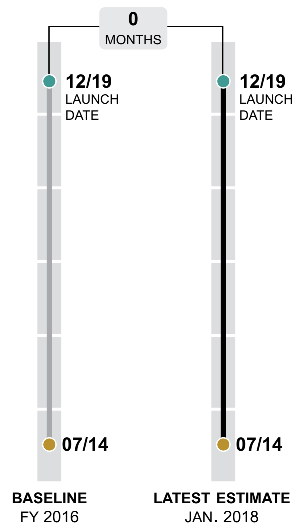
then-year dollars in millions

COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Project Status

According to NASA's cancellation memorandum, the RBI project was canceled because of continued cost growth, technical issues, and poor contractor performance. The project identified the following specific issues that contributed to poor project cost and schedule performance: schedule planning that did not realistically account for contractor past performance, insufficient oversight of the contractor and its subcontractors, and poor integration of government and contractor teams with limited transparency concerning risks and issues. In 2017, both the government and the contractor took steps to respond to poor project performance, including changes to both the government and contractor program management teams, but ultimately NASA determined that continuing to fund RBI from within the Earth Science Division budget would slow other important activities. Based on the historical performance of other instruments and assessments of the likely remaining lifetime of on-orbit satellites, NASA believes the risk of a data gap is low if the next radiation budget-measuring instrument launches in 2027.

Cost and Schedule Status

The RBI project continued to experience contract cost growth, and was likely to exceed its cost baseline. As of November 2017, contract costs for design, fabrication, and delivery of RBI had grown by about 110 percent from the original value for this work, or an increase of $115 million. This cost increase depleted all remaining project-held cost reserves as the project entered the riskiest point of the development cycle—the integration and test phase. In 2016 and 2017, we found that projects appear most likely to rebaseline during this period.[a] In November 2017, the project requested additional reserves to cover increased contractor costs. If NASA would have approved the increase, it would have brought the project's costs to within approximately $2 million of its established cost baseline, which officials said was likely to be exceeded.

To support the decision of whether or not to continue the project, the project updated its joint cost and schedule confidence level, which is the likelihood that a project will meet its cost and schedule baseline. The update indicated that the project had a 30 percent chance of meeting the original delivery date of April 2019. As a result, the project updated the delivery date with NOAA to July 2019. The confidence level update showed that RBI had a 70 percent chance of meeting the later delivery date, but it would likely require additional funding in excess of the project's cost baseline if other technical issues arose.

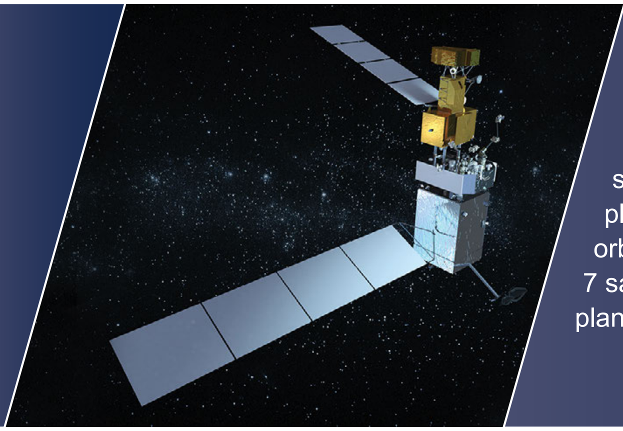
[a] GAO-16-309SP and GAO-17-303SP.

Technology and Design

The RBI project held its critical design review in September 2017 with 100 percent of its design drawings released. Best practices show that releasing 90 percent of design drawings by critical design review lowers the risk of subsequent cost and schedule growth. The review, previously scheduled for June 2017, was delayed to provide more time to resolve technical issues and to have additional test results available to inform the review board on the project's readiness to proceed. More specifically, the project conducted testing on an engineering development unit as a risk reduction measure and identified technical issues with the telescope and various electronic components that needed to be addressed prior to the review.

PROJECT OFFICE COMMENTS

In commenting on a draft of this assessment, RBI project officials stated that RBI was not included in the President's fiscal year 2018 budget request and continuing to fund RBI from within the Earth Science Division budget would slow other important activities. Project officials stated that multiple efforts by the RBI government and contractor team to improve performance were yielding positive results, including the resolution of technical issues leading to a successful critical design review. Officials also said improved cost and schedule controls were also proving to be effective. Project officials also provided technical comments, which were incorporated as appropriate.



Restore-L

The Restore-L project will demonstrate the capability to refuel on-orbit satellites for eventual use by commercial entities. Specifically, Restore-L plans to autonomously rendezvous with, inspect, capture, refuel, adjust the orbit of, safely release, and depart from the U.S. Geological Survey's Landsat 7 satellite. Landsat 7 can extend operations if successfully refueled, but it is planned for retirement if the technology demonstration is unsuccessful.

Source: NASA. | GAO-18-280SP

FORMULATION
- 05/16 Formulation start
- 10/16 System requirements/ mission definition review
- 11/17 Preliminary design review
- **01/18 GAO review**
- 04/18 Project confirmation

IMPLEMENTATION
- 01/19 Critical design review
- 04/20 System integration review
- 12/21 Projected launch readiness date

PROJECT INFORMATION

NASA Lead Center: **Goddard Space Flight Center**

International Partner: **None**

Launch Location: **Vandenberg Air Force Base, CA**

Launch Vehicle: **TBD**

Mission Duration: **12 months**

Requirement Derived from: **Consolidated Appropriations Act, 2016**

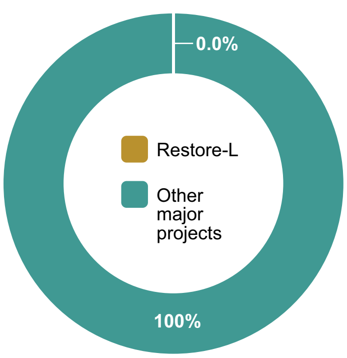
Budget Portfolio: **Space Technology, Research and Development**

PROJECT SUMMARY

The Restore-L project is no longer working to the preliminary cost and schedule estimates that NASA approved when it entered the preliminary design phase because the Space Technology Mission Directorate's proposed budget does not allow the project to execute to that plan. The mission directorate asked the project to evaluate two scenarios based on future funding possibilities. The project is to present a plan based on these scenarios to the mission directorate prior to the project establishing its cost and schedule baselines at its confirmation review in April 2018. The project reported that it does not use any new, critical technologies and that all six heritage technologies are modified from prior projects to fit the Restore-L design. The project matured five of these six technologies to the level recommended by best practices at its November 2017 preliminary design review. The technology that was not mature was a replacement for the prior vision navigation system, which did not meet requirements and the vendor was unable to resolve the issue. Project officials stated that they have a plan in place to mature the new system by December 2018.

PROJECT BUDGET INFORMATION

percent of current portfolio for fiscal year 2019



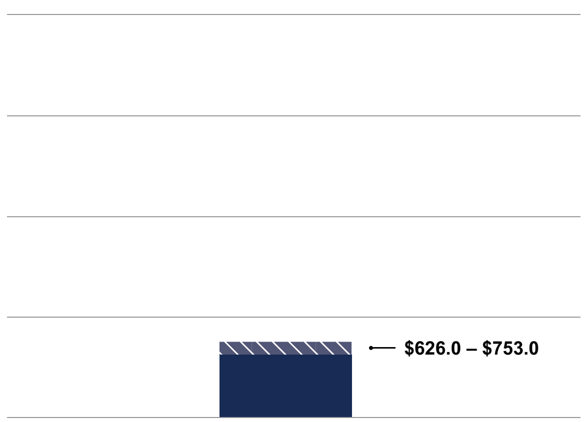
TOTAL FUNDED TO DATE

then-year dollars in millions

$260.0

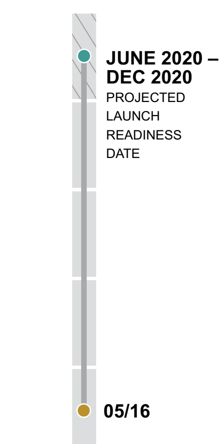
PRELIMINARY COST[a]

then-year dollars in millions



[a]*This estimate is preliminary, as the project is in formulation and there is uncertainty regarding the costs associated with the design options being explored. NASA uses these estimates for planning purposes.*

PRELIMINARY SCHEDULE



Cost and Schedule Status

The Restore-L project is no longer working to the preliminary cost and schedule estimates that NASA approved when it entered the preliminary design phase because the Space Technology Mission Directorate's proposed budget does not allow the project to execute to that plan. In April 2017, NASA set a preliminary cost estimate range of $626 million to $753 million with a projected launch readiness date between June and December 2020. However, the funding profile the Space Technology Mission Directorate proposed for future years will not allow the project to maintain a launch in 2020. As a result, the mission directorate asked the project to evaluate two scenarios based on future funding possibilities. According to NASA officials, one scenario assumes $130 million in project funding per fiscal year through the updated preliminary launch date for on-orbit demonstration. The other assumes $130 million for fiscal year 2018 followed by about $45 million for each of the fiscal years 2019 through 2024—focusing on technology development for industry use. The project is to present a plan based on these scenarios to the mission directorate prior to project confirmation review—the point at which the project will formally establish its cost and schedule baselines. The project has delayed its confirmation review from September 2017 to April 2018, in part to allow for more time to evaluate the scenarios. As of December 2017, the project's notional schedule is for a launch readiness date in December 2021, 1 year later than planned when the project entered the preliminary design phase. This notional schedule is based on various funding scenarios the project could face, and provides additional schedule reserve.

Technology and Design

The Restore-L project matured five of its six technologies to the level recommended by best practices at its preliminary design review in November 2017. Best practices recommend maturing technologies to a technology readiness level 6 by the project's preliminary design review to help minimize risks for space systems entering product development. The technology that was not mature at the review was a replacement vision navigation system that is new to the project. The prior vision navigation system did not meet requirements and the vendor was unable to resolve the issue. The project's independent review board stated that Restore-L needed a comprehensive plan to mature the technology at the review and project officials said they have a plan in place to mature the new system to a technology readiness level 6 by December 2018. The project reported that it does not use any new, critical technologies and that all 6 heritage technologies are modified from prior projects to fit the Restore-L design. Project officials said that although Restore-L uses all heritage technologies, the technologies will be used together in a new way to complete the mission's requirements.

The robot system is driving the project's schedule and the project has had to redesign system components, which consumed schedule reserve and put pressure on the project's preliminary launch schedule of December 2020. The robot system, which includes the spacecraft's robotic arm and associated components, will be used to capture the Landsat 7 spacecraft and will then employ tools to access the Landsat 7's propellant system, transfer propellant, and seal the system prior to releasing the spacecraft. The resolver pre-amp assembly—a component used to amplify signals to the robotic arm—is undergoing redesign to address signal distortion concerns. Another element, the robotic electronics units used to control the arm, is being redesigned to simplify and reduce the number of components in order to reduce schedule risk during integration and test. This redesign consumed schedule reserve before the project began working to a December 2021 notional schedule.

Other Issues to be Monitored

The project's current notional schedule would delay Restore-L's launch outside the servicing window for Landsat 7. Specifically, the agreed upon servicing window is January through September 2021, which the notional project launch schedule in December 2021 does not meet. However, that window may be extended if NASA reimburses the U.S. Geological Survey for additional costs to continue Landsat 7 operations.

PROJECT OFFICE COMMENTS

Restore-L project officials provided technical comments on a draft of this assessment, which were incorporated as appropriate.

Source: NASA. | GAO-18-280SP

Space Launch System

The Space Launch System (SLS) is intended to be NASA's first human-rated heavy-lift launch vehicle since the Saturn V was developed for the Apollo program. SLS is planned to launch NASA's Orion spacecraft and other systems on missions between the Earth and Moon and to enable deep-space missions, including Mars. NASA is designing SLS to provide an initial lift capacity of 70 metric tons to low-Earth orbit, and be evolvable to 130 metric tons, enabling deep space missions. The 70-metric-ton capability will include a core stage, powered by four RS-25 engines, and two five-segment boosters. The 130-metric-ton capability will use a new upper stage and evolved boosters.

PROJECT INFORMATION

NASA Lead Center: **Marshall Space Flight Center**

International Partner: **None**

Launch Location: **Kennedy Space Center, FL**

Launch Vehicle: **N/A**

Mission Duration: **Varied based on destination**

Requirement Derived from: **NASA Authorization Act of 2010**

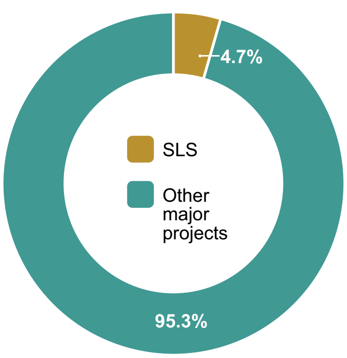
Budget Portfolio: **Exploration, Exploration Systems Development**

PROJECT SUMMARY

In December 2017, NASA announced a new schedule and cost estimate for the SLS program, after determining that the November 2018 launch readiness date for Exploration Mission-1 (EM-1) was no longer feasible. NASA is now planning to an internal launch readiness date of December 2019, with 6 months of schedule reserve to a June 2020 date. The life-cycle cost estimate for SLS is approximately $9.7 billion to the December 2019 date and $9.8 billion to the June 2020 date. The delivery schedule for the program's core stage—which functions as the SLS's fuel tank and structural backbone—has continued to slip as the program addresses a series of technical challenges, including the completion of welding its large, first stage. The program currently has no schedule reserve to ship the core stage for testing, as well as from the test site to the launch site, in order to meet the December 2019 launch readiness date. Should problems or issues arise during testing, they will likely affect the enterprise integration and test schedule.

PROJECT BUDGET INFORMATION

percent of current portfolio for fiscal year 2019

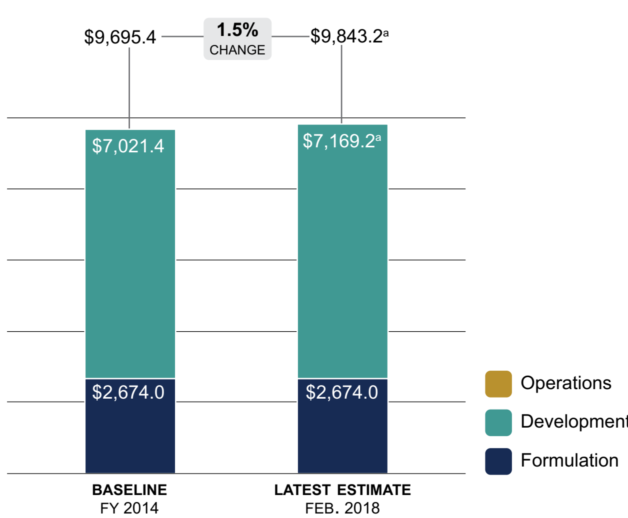


ESTIMATED FUNDING NEEDED

then-year dollars in millions

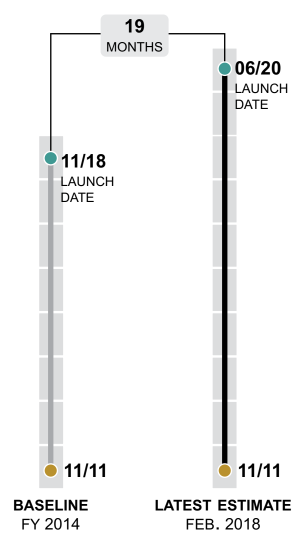
COST PERFORMANCE

then-year dollars in millions



ªAssumes June 2020 launch date.

SCHEDULE PERFORMANCE



Cost and Schedule Status

In December 2017, NASA announced a new schedule and cost estimate for the SLS program, after determining that the November 2018 launch readiness date for Exploration Mission-1 (EM-1) was no longer feasible. In April 2017, we found that the date was likely unachievable for all three human spaceflight programs—Exploration Ground Systems, SLS, and Orion Multi-Purpose Crew Vehicle—due to technical challenges continuing to cause schedule delays and the programs having little to no schedule reserve to the EM-1 date, meaning they would have to complete all remaining work with little margin for error for unexpected challenges that could arise.[b] The new internal launch readiness date for EM-1 is now December 2019, but NASA has also allocated 6 months of schedule reserve to June 2020 for possible manufacturing and production schedule risks. This represents a delay of 13-19 months for EM-1. The life-cycle cost estimate for SLS is about $9.7 billion to the December 2019 date and $9.8 billion to the June 2020 date, or 0.4 to 1.5 percent above the project's committed baseline.

Technology, Design, and Manufacturing

The delivery schedule for the program's core stage—which functions as the SLS's fuel tank and structural backbone—has slipped 14 months in the last year to May 2019, due in large part to production issues that have delayed completion of the core stage element. According to program officials, the liquid hydrogen tank has proven difficult to weld to specifications because it is thicker than metals that have been used by industry in the past. Without a history of similar efforts to compare to, officials explained that they have to check and test every potential anomaly with increased scrutiny than if they were producing something already used throughout the aerospace industry. In addition, according to officials, because this is the first flight article, the contractors are performing extensive testing to ensure that their production processes and methods are resulting in end items that meet or exceed specifications so that the next unit can be produced more quickly.

In addition to these issues, the program has faced work slowdowns and stoppages due to severe weather. In February 2017, a tornado hit parts of the Michoud Assembly Facility in Louisiana, where the core stage is being produced. While work resumed shortly after the storm, according to program officials, it did so at less than full capacity and delayed the program by a total of about 2 months. According to officials, repair work is complete in SLS manufacturing areas and should not further impact production work at the facility.

[b]GAO-17-414.

Integration and Test

The program has no schedule reserve through delivery of the core stage to Kennedy Space Center for the December 2019 launch date. In addition to completing production of flight and test articles, the program has to integrate the engines to the core stage and ship them to Stennis Space Center for a green run test. During this test, the core stage is fueled and the four main engines fired for about 500 seconds for the first time. This test will stress the flight components as well as the ground equipment used for the test. For example, according to program officials, 7 of the 12 cryogenic fluid pumps at Stennis Space Center must work together in order to fuel the vehicle. Should issues arise, the program will likely need additional time to assess and mitigate difficulties or glitches, which would likely affect delivery to Kennedy Space Center and could delay the enterprise integration and test schedule.

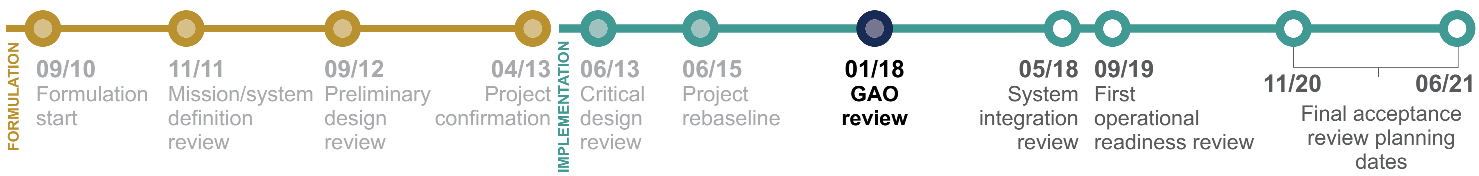
PROJECT OFFICE COMMENTS

In commenting on a draft of this assessment, SLS program officials stated that a vast majority of SLS development and production work is on track for EM-1 and that work is also proceeding for the first crewed flight—EM-2. In addition, officials state that the program is successfully working through first-time production issues that are not unprecedented for a program of this scope and ambition. Program officials also provided technical comments, which were incorporated as appropriate.

Space Network Ground Segment Sustainment

Source: NASA. | GAO-18-280SP

The Space Network Ground Segment Sustainment (SGSS) project plans to develop and deliver a new ground system for one Space Network site. The Space Network provides essential communications and tracking services to NASA and non-NASA missions. Existing systems, based on 1980s technology, are increasingly obsolete and unsustainable. The new ground system will include updated systems, software, and equipment that will allow the Space Network to continue to provide critical communications services for the next several decades. The Space Network is managed by the Space Communication and Navigation (SCaN) program.



PROJECT INFORMATION

NASA Lead Center: **Goddard Space Flight Center**

International Partner: **None**

Launch Location: **N/A**

Launch Vehicle: **N/A**

Mission Duration: **25 years with periodic, required upgrades to hardware and software**

Requirement Derived from: **March 2008 Space Network modernization concept study**

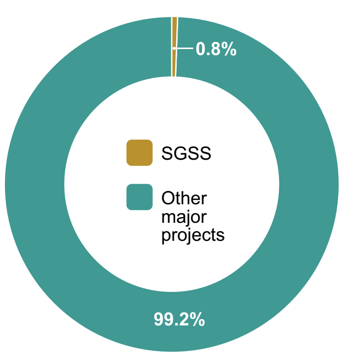
Budget Portfolio: **Space Operations, Space and Flight Support**

PROJECT SUMMARY

In 2017, the SGSS project experienced additional cost growth and schedule delays beyond the rebaselined cost and schedule estimate NASA set in 2015. Since the 2015 rebaseline, the project's total costs increased by at least $112.9 million, from $1,207.9 million to $1,320.8 million even as the scope decreased from nine terminals at three Space Network sites to six terminals at one site. According to the fiscal year 2019 budget request, NASA plans to conduct an independent review in 2018 to inform a decision on whether to continue the project. If the project continues, additional cost growth is expected as the latest cost estimate covers only through the initial operational readiness review, currently planned for September 2019. Project officials attributed the cost growth and delays to an incomplete understanding of requirements by the contractor, which led to poor contractor plans and late design changes. Contractor performance has been a concern for the project, but project officials stated that contractor performance improved in fiscal year 2017. The project delivered the final software increment in May 2017 and the software is now in integration and testing.

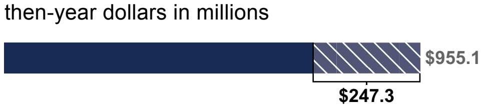
PROJECT BUDGET INFORMATION

percent of current portfolio for fiscal year 2019



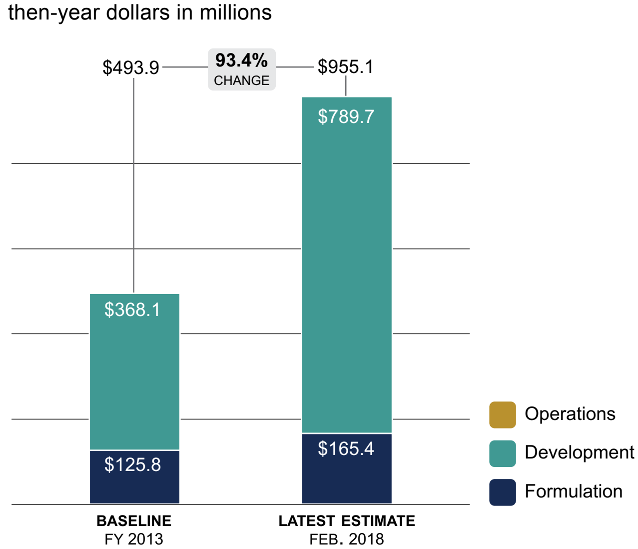
ESTIMATED FUNDING NEEDED

then-year dollars in millions



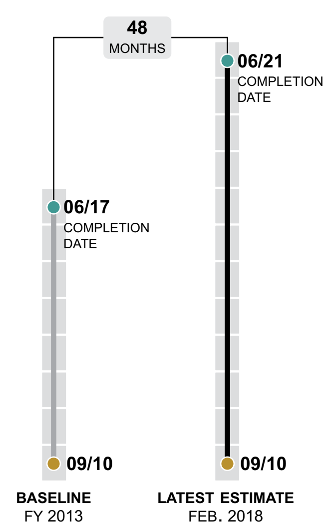
COST PERFORMANCE

then-year dollars in millions



Note: The SGSS project has received an additional $365.7 million from Space Network users outside of NASA.

SCHEDULE PERFORMANCE



Cost and Schedule Status

In 2017, the SGSS project experienced additional cost growth and schedule delays beyond the cost and schedule rebaseline NASA set for it in 2015. In 2016, SGSS was reclassified as a hybrid sustainment project instead of a major project, which means that NASA is no longer measuring the project against its cost and schedule baseline, among other oversight implications. However, according to officials, the project is still required to provide quarterly and annual status reports to NASA on their cost and schedule. Since the 2015 rebaseline, however, the project's total costs increased by at least $112.9 million, from $1,207.9 million to $1,320.8 million, even as the scope decreased from upgrading nine terminals at three Space Network sites to six terminals at one site. The SGSS project presented its new cost and schedule estimate to NASA headquarters in August 2017, which NASA approved up through the initial operational readiness review, currently planned for September 2019.

Additional cost growth is expected for SGSS when NASA revisits project costs through future budget cycles. According to the fiscal year 2019 budget request, an independent review of the project is underway to determine whether the project will continue and was initiated due to budget challenges. In the event the project continues, officials stated the project plans to evaluate various funding scenarios, including continuing but receiving less funding than requested. Project officials attributed the cost growth and delays to an incomplete understanding of requirements by the contractor, which led to poor contractor plans and late design changes, but project management has been a challenge as well. For example, the project has historically struggled to manage contractor performance and has faced staffing shortfalls in key areas, such as systems engineering and business management. However, as of January 2018, NASA officials stated that these workforce issues had largely been resolved because some positions were filled by reassigning staff to these areas and others are no longer needed. The project delivered the final software increment in May 2017 and the software is now in integration and testing. The project is working toward the systems integration review in May 2018.

Contractor

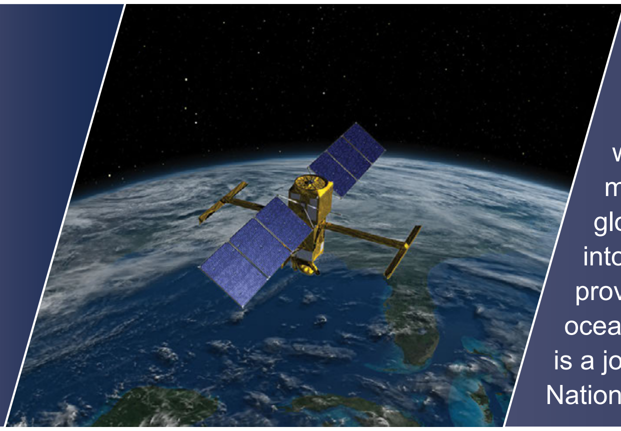
Contractor performance has been an ongoing concern for the project, but project officials stated that performance improved in fiscal year 2017. The SGSS project attributes most of its cost and schedule growth to the contractor underestimating the scope of the development effort. The contractor moved a large portion of the software's required functionality into the last software development increment after experiencing problems with earlier increments. Project officials stated the contractor did not fully understand the requirements, technical planning was inadequate, and the contractor's planning did not account for resolving software defects. In response to the issues the project has faced, the SGSS project has taken action to try to address contractor performance problems. For example, the project worked with the contractor to develop new, more reliable cost and schedule estimates both for 2017 and beyond. The new schedule focuses on discrete tasks, which enables better tracking and measurability. In addition, the project managers for the project and the contractor were replaced. Project officials stated that contractor performance improved in fiscal year 2017 as the project successfully completed most of the plan it created for fiscal year 2017, which included delivery of the final software increment to integration and testing in May 2017.

Integration and Test

The project is tracking several risks to completing integration and testing—a period where problems are commonly found and schedules tend to slip—on schedule. For example, the project is tracking a risk that Space Network and mission partner users may be unavailable for testing, which could slow progress. The project is also tracking the number of software defects as a risk. While the project and the contractor's models generally agree on defect resolution timeframes, officials said there is a risk that defects could arise that would take longer than planned to fix. Additionally, the project is continuing work to demonstrate end-to-end performance and stability of the SGSS system. As part of the fiscal year 2017 plan, the project established five operational scenarios as measures of performance and stability. The project completed four of the operational scenarios, but was unable to complete the fifth due to a problem with third-party software. The project is working with the software vendor to resolve the issue.

PROJECT OFFICE COMMENTS

In commenting on a draft of this assessment, project officials noted the contractor performed on plan for fiscal year 2017 and completed all the milestones within the critical path. The project also provided technical comments, which were incorporated as appropriate.



Surface Water and Ocean Topography

The Surface Water and Ocean Topography (SWOT) mission will use its wide-swath radar altimetry technology to take repeated high-resolution measurements of the world's oceans and freshwater bodies to develop a global survey. This survey will make it possible to estimate water discharge into rivers more accurately, and help improve flood prediction. It will also provide global measurements of ocean surface topography and variations in ocean currents, which will help improve weather and climate predictions. SWOT is a joint project between NASA and the French Space Agency—the Centre National d'Etudes Spatiales (CNES).

Source: California Institute of Technology/Jet Propulsion Laboratory (artist depiction). | GAO-18-280SP

FORMULATION
- 11/12 Formulation start
- 05/14 System requirements/ mission definition review
- 04/16 Preliminary design review
- 05/16 Project confirmation

IMPLEMENTATION
- **01/18 GAO review**
- 02/18 Critical design review
- 07/19 System integration review
- 04/21 Manifested launch readiness date
- 04/22 Committed launch readiness date

PROJECT INFORMATION

NASA Lead Center: **Jet Propulsion Laboratory**

International Partners: **Centre National d'Etudes Spatiales (France), Canadian Space Agency (Canada), United Kingdom Space Agency (United Kingdom)**

Launch Location: **Vandenberg Air Force Base, CA**

Launch Vehicle: **Falcon 9**

Mission Duration: **3 years**

Requirement Derived from: **2007 Earth Science Decadal survey**

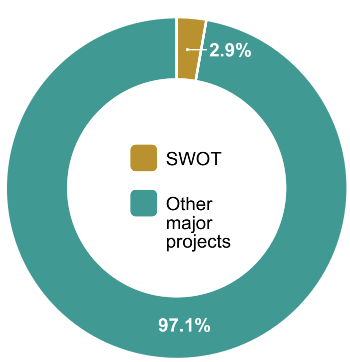
Budget Portfolio: **Science, Earth Science**

PROJECT SUMMARY

The SWOT project continues to operate within its cost baseline and plans to launch in April 2021, a year earlier than its committed schedule baseline, despite encountering technical issues with its main instrument—the Ka-Band Radar Interferometer (KaRIn). An engineering model of the KaRIn high voltage power supply was damaged during testing due to three electrical arcing events that were caused by manufacturing and handling of parts, and weaknesses in the packaging design. In addition, the project augmented the main beams that connect the instrument antennas to the spacecraft, which resulted in delays to releasing design drawings. The project discovered signal interference off the main beams that could distort KaRIn's science measurements. Project officials said they planned to release about 90 percent of design drawings at the planned February 2018 critical design review, which is a best practice.

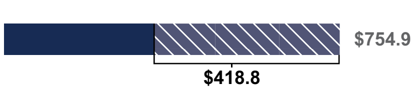
PROJECT BUDGET INFORMATION

percent of current portfolio for fiscal year 2019



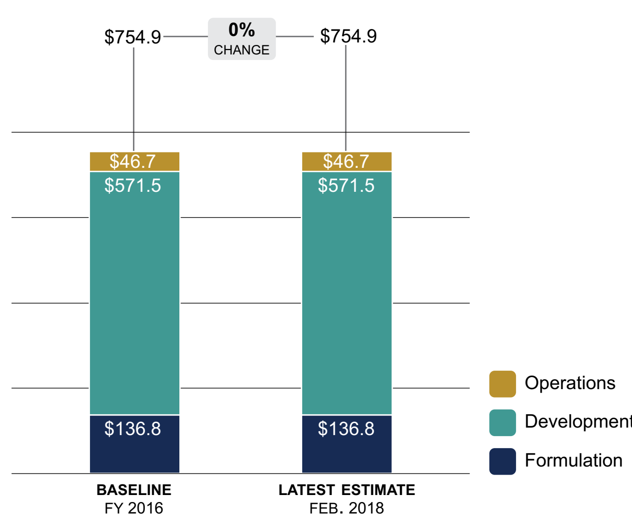
ESTIMATED FUNDING NEEDED

then-year dollars in millions

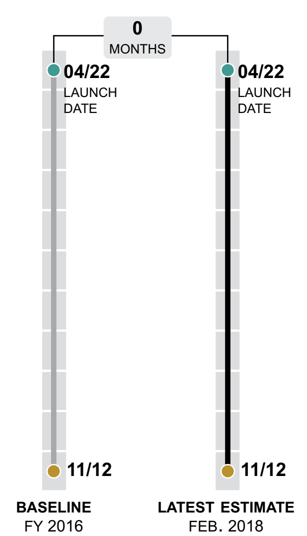


COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The SWOT project continues to operate within its cost baseline and plans to launch in April 2021, a year earlier than its committed schedule baseline. The project is holding schedule reserves consistent with the level required by Jet Propulsion Laboratory policy, but did not meet cost reserve requirements in fiscal year 2017 due to costs associated with risk reduction activities and to stay on schedule. For example, project officials said they used cost reserves to build higher-fidelity engineering models and to secure a higher than planned workforce to execute fiscal year 2017 tasks. However, the project was able to reconstitute some of its cost reserves due to lower-than-expected launch vehicle costs and is meeting cost reserve requirements for fiscal year 2018 as of January 2018. The project is progressing toward its critical design review scheduled for February 2018.

Technology and Design

The project's primary instrument—the Ka-Band Radar Interferometer (KaRIn)—continues to be the most complicated development effort and has experienced technical issues that have had cost and schedule implications. During testing, an engineering model of the KaRIn high voltage power supply (HVPS) was damaged due to three electrical arcing events that were caused by manufacturing and handling of parts as well as weaknesses in the packaging design. To mitigate these events, the project repaired the electrical board within the engineering model with temporary fixes to support upcoming testing and built a second electrical board with enhanced handling procedures for a key thermal vacuum test in February 2018. As a result, HVPS development is driving the project's schedule. To maintain its current schedule, the project is building the HVPS flight model in parallel to its ongoing testing of the engineering model. The project determined this approach was less risky than delaying flight model development until engineering model testing is complete. The project is tracking a risk, however, that development of the flight model concurrently may cause late rework.

In addition, the project augmented the main beams that connect the instrument antennas to the spacecraft, which resulted in delays to releasing design drawings. The project discovered signal interference off the main beams that could distort KaRIn's science measurements. To mitigate this risk, the project added a reflective plate to the main beam to minimize signal distortion and successfully held a mechanical critical design review with the modified main beam design. As a result, however, the project is 3 months behind schedule in releasing drawings for the modified design and is working with the Jet Propulsion Laboratory to secure additional staff to accelerate drawing production.

As of January 2018, SWOT released 87 percent of its expected drawings and project officials said they plan to release about 90 percent of design drawings at critical design review. Best practices show that releasing at least 90 percent of design drawings by this review can decrease a project's risk of cost growth and schedule delays.

Other Issues to Be Monitored

After the project experienced challenges with one of the tools—AirSWOT—that it plans to use to help understand the data returned from the KaRIn instrument once SWOT is in orbit, the project selected two additional methods to augment ocean measurements. The project determined that the performance of AirSWOT, which is an airborne sensor, was likely to be insufficient and that heavy wave activity when collecting ocean data was the root cause of measurement abnormalities. The project selected an airborne laser-based remote sensor along with a network of underwater gliders to augment the measurements from in-orbit satellites that were planned with AirSWOT. This approach successfully passed a technical peer review in December 2017 and the project plans to complete additional experiments using the selected approach to inform its calibration and validation plan.

PROJECT OFFICE COMMENTS

In commenting on a draft of this assessment, project officials stated that SWOT is a challenging mission making a first of a kind measurement of global surface water. Officials also stated the project has been advancing the heritage systems development allowing the project to focus on the challenging KaRIn development. The project is completing thorough testing of engineering models along with a series of technical reviews in preparation for the flight model development. The project's focus remains on systematically rectifying technical issues while devising workarounds to maintain the overall milestones. SWOT officials also provided technical comments, which were incorporated as appropriate.

Source: NASA. | GAO-18-280SP

Transiting Exoplanet Survey Satellite

The Transiting Exoplanet Survey Satellite (TESS) will use four identical, wide field-of-view cameras to conduct the first extensive survey of the sky from space for transiting exoplanets—or planets in other solar systems. The mission's goal is to discover these exoplanets during transit, the time when the planet's orbit carries it in front of its star as viewed from Earth. The project plans to discover rocky and potentially habitable Earth-sized and super-Earth planets orbiting nearby bright stars for further evaluation through ground- and space-based observations by other missions, such as the James Webb Space Telescope.

FORMULATION
- 04/13 Formulation start
- 02/14 System requirements/ mission definition review
- 09/14 Preliminary design review
- 10/14 Project confirmation

IMPLEMENTATION
- 08/15 Critical design review
- 07/17 System integration review
- **01/18 GAO review**
- 04/18 Manifested launch readiness date
- 06/18 Committed launch readiness date

PROJECT INFORMATION

NASA Lead Center: **Goddard Space Flight Center**

International Partner: **None**

Launch Location: **Cape Canaveral Air Force Station, FL**

Launch Vehicle: **Falcon 9**

Mission Duration: **2 years**

Requirement Derived from: **2010 Astrophysics Decadal Survey**

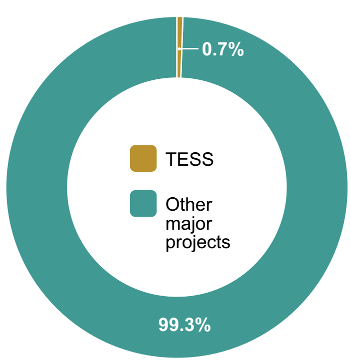
Budget Portfolio: **Science, Astrophysics**

PROJECT SUMMARY

The TESS project launched on April 18, 2018, before its committed launch date and within its cost baseline. The project expected to launch in March 2018 but did not meet this date due to certification delays with the SpaceX Falcon 9 upgrade known as Block 4. To cover the 1-month delay, NASA shifted funding previously budgeted for the operations phase to the development phase. The project did not have headquarters-held reserves to cover a launch past March 2018 because NASA reallocated $15 million of TESS's headquarters-held reserves to another astrophysics project. The TESS project completed environmental testing and conducted additional testing on its spare camera at temperatures seen in space to better understand expected camera performance on orbit. During thermal testing, the project found that the substance attaching the lenses to the camera barrel places pressure on the lenses and causes the cameras' focus to shift slightly. However, in June 2017, NASA directed the project to integrate the cameras because they are still expected to meet TESS's top-level science requirements even with the anomaly.

PROJECT BUDGET INFORMATION

percent of current portfolio for fiscal year 2019

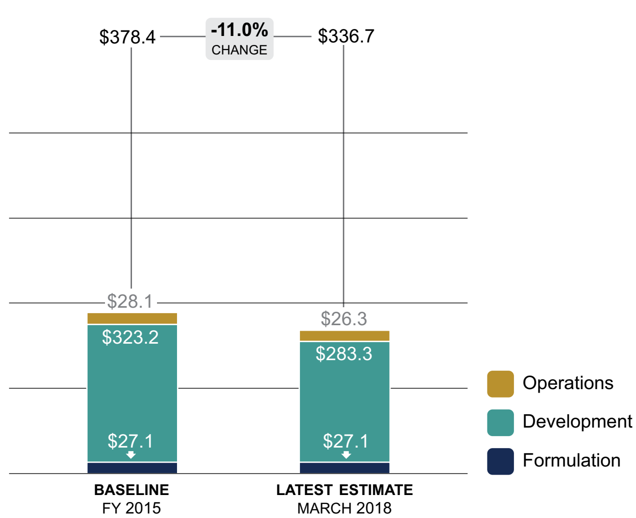


ESTIMATED FUNDING NEEDED

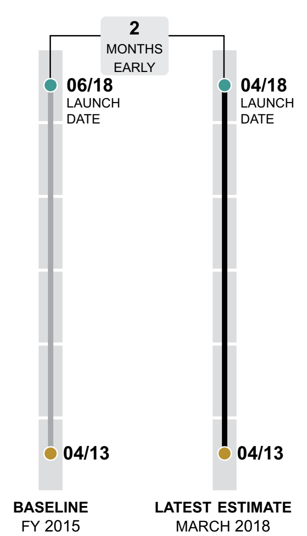
then-year dollars in millions

COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The TESS project launched on April 18, 2018—2 months early and within its cost baseline. The project had planned to launch in March 2018, but the launch date was moved by a month due to delays related to its launch vehicle. At the key decision review prior to the project entering the operations and sustainment phase, NASA approved shifting $1.9 million prevously budgeted for the operations phase to the development phase to cover the 1-month delay. The project did not have any headquarters-held cost reserves available to cover a launch past March 2018 because NASA reallocated $15 million of TESS's headquarters-held reserves to another astrophysics project, the Wide-Field Infrared Survey Telescope project. The project is holding cost and schedule reserves at the level required by NASA center policy.

Integration and Test

The project completed observatory environmental testing after overcoming spacecraft and instrument challenges to its cost and schedule. The project entered system assembly, integration and test—the phase where problems are most commonly found and schedules tend to slip—in August 2017. The project mitigated two risks related to its spacecraft. First, the project integrated its flight Ka-band transmitter in October 2017 after a 2-year delivery delay. The transmitter, essential for TESS as it transmits the mission data back to Earth, experienced continued contractor performance and manufacturing issues such as incorrectly placed parts. The project used schedule reserves to accommodate delays, installed an on-site representative to oversee the contractor's work, and developed a contingency plan to fly TESS with the transmitter's engineering development unit, which performed well in testing. Second, the project closed a risk that its slip rings—components within the solar array drive assembly necessary for power transmission—could be unsafe for flight. In May 2017, the project found damage to a small number of its slip rings, but later determined the slip rings were acceptable for flight after testing showed that they performed as expected.

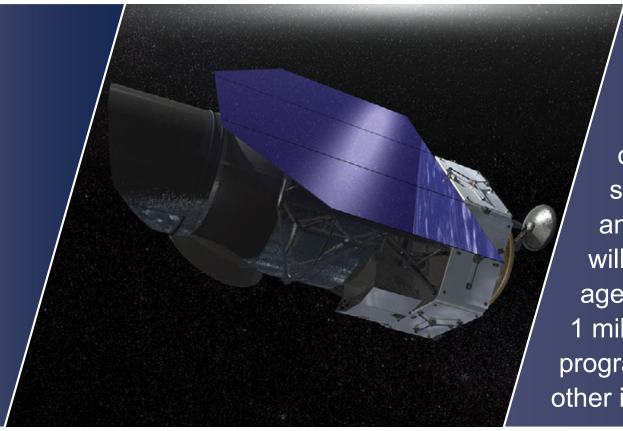
The project conducted additional testing on its spare camera at temperatures experienced in space to better understand expected camera performance on orbit after finding that the focus of each camera shifts slightly at the temperatures in which TESS will operate. In thermal testing, the project found that the substance attaching the lenses to the camera barrel places pressure on the lenses and causes the cameras' focus to shift slightly at on-orbit temperatures. Prior to system integration review, NASA deemed the four cameras acceptable as they are expected to meet top-level science requirements even with the anomaly and in June 2017 directed the project to integrate the cameras. In July 2017, the project integrated the cameras with an alternative data handling unit, which powers the cameras and serves as the instrument data storage and processing computer. The project decided to use the alternative data handling unit because the unit originally designed for the project was behind schedule due to technical issues and contractor performance.

Launch

The project did not meet its expected March 2018 launch date due to certification delays for its launch vehicle, the SpaceX Falcon 9 upgrade known as Block 4. Certification is necessary because it will be the first time that a NASA instrument will launch on the Block 4 version of the vehicle. The TESS project expected that NASA's Launch Services Program would certify the Block 4 in September 2017, 7 months before TESS is scheduled to launch. However, NASA needed additional time to investigate the Falcon 9 second stage pressure vessel, which was involved in an anomaly that caused an explosion in September 2016. SpaceX also required extra time to meet NASA's Launch Services Program requirements.

PROJECT OFFICE COMMENTS

TESS project officials provided technical comments on a draft of this assessment, which were incorporated as appropriate.



Source: NASA. | GAO-18-280SP

Wide-Field Infrared Survey Telescope

The Wide-Field Infrared Survey Telescope (WFIRST) is an observatory designed to perform wide-field imaging and survey of the near-infrared sky to answer questions about the structure and evolution of the universe, and expand our knowledge of planets beyond our solar system. The project will use a telescope that was originally built and qualified by another federal agency. The project plans to launch WFIRST in the mid-2020s to an orbit about 1 million miles from the Earth. The project is also planning a guest observer program, in which the project may provide observation time to academic and other institutions.

PROJECT INFORMATION

NASA Lead Center: **Goddard Space Flight Center**

International Partner: **TBD**

Launch Location: **TBD**

Launch Vehicle: **TBD**

Mission Duration: **5¼ years (Including on-orbit commissioning)**

Requirement Derived from: **2010 Astrophysics Decadal Survey**

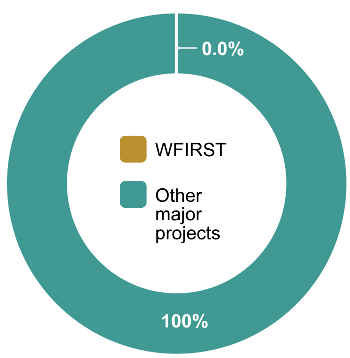
Budget Portfolio: **Science, Astrophysics**

PROJECT SUMMARY

NASA's preliminary cost and schedule estimates for the WFIRST project are currently under review as the project responds to findings from an independent review. The review found that the mission is not aligned with the resources provided and concluded that the mission is not executable without adjustments and/or additional resources. NASA agreed with the study team's results and directed the project to reduce the cost and complexity of the design in order to maintain costs within the project's $3.2 billion preliminary cost target. As a result of the review, design trade-offs are being made. The project plans to make a final decision on the design features and international partners as it prepares for its system requirements and mission definition review in March 2018. The WFIRST project also matured its two critical technologies, but is tracking a risk concerning the production of Wide Field Instrument detectors. Project officials stated large array detectors always pose fabrication challenges. The President's 2019 Budget Request proposed canceling the WFIRST project.

PROJECT BUDGET INFORMATION

percent of current portfolio for fiscal year 2019

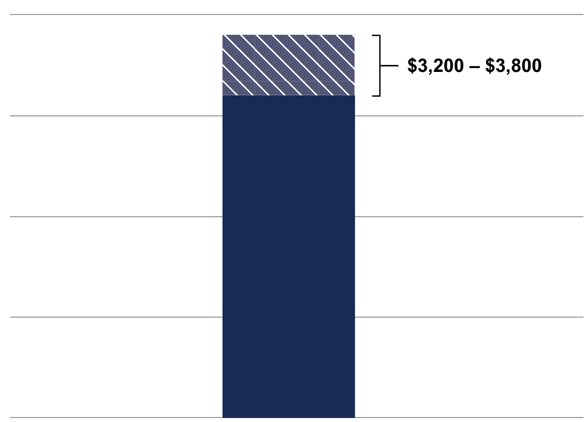


TOTAL FUNDED TO DATE

then-year dollars in millions

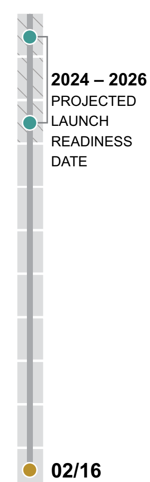
PRELIMINARY COST[a]

then-year dollars in millions



[a]*This estimate is preliminary, as the project is in formulation and there is uncertainty regarding the costs associated with the design options being explored. NASA uses these estimates for planning purposes.*

PRELIMINARY SCHEDULE



LATEST ESTIMATE
FEB. 2018

Cost and Schedule Status

The WFIRST project's preliminary cost and schedule estimates are currently under review as the project responds to findings from an October 2017 independent review conducted to ensure the mission's scope and required resources are well understood and executable. The review found that the project is not executable unless its mission scope is redesigned or its preliminary cost target is increased. NASA agreed with the study team's results and directed the project to reduce the cost and complexity of the design in order to maintain costs within the project's $3.2 billion preliminary cost target. In February 2018, the President's 2019 Budget Request proposed canceling the WFIRST project.

Design and Technology

In response to the independent review, the project developed a system design proposal that will be presented at its system requirements and mission definition review in March 2018 to reduce WFIRST cost and complexity. As of January 2018, the project was planning to reach the $3.2 billion cost target by treating the coronagraph—designed to perform high contrast imaging and spectroscopy of nearby exoplanets—as a technology demonstration as opposed to a science instrument. This, according to officials, allows the project to make a trade between performance and risk, and thereby avoid potential impacts to the project's cost and schedule. In addition, the project plans to review the capabilities of the Wide Field Instrument, which is intended to measure light from a billion galaxies and perform a survey of the inner Milky Way, as part of the review. NASA is also considering whether or not to maintain capability for WFIRST to be "starshade ready." A starshade is a device that is launched with or separately from an observatory and positioned between it and the star being observed to block out the starlight while allowing the light emitted by the planet through. NASA planned to review and formally approve the changes at the project's next key decision review, planned for April 2018, prior to entering the preliminary design and technology completion phase. Finally, in response to the independent review, NASA upgraded the risk classification of the project, which could increase project costs due to more system reliability and mission assurance requirements.

The WFIRST project has matured its two critical technologies to a technology readiness level 6, which helps to minimize risks for space systems when entering production, but is tracking a risk concerning the production of Wide Field Instrument detectors. Project officials stated large array detectors always pose fabrication challenges. To date, detector production has exceeded historical trends, but the project is completing ongoing tests to validate detector quality.

Developmental Partner

NASA is considering several potential contributions with various international partners, including the Canadian Space Agency, European Space Agency, France, Germany, and Japan, for elements of the Wide Field Instrument, coronagraph, and ground system. These contributions could potentially reduce the project's cost. NASA also expects to determine its international partners before the project enters the preliminary design and technology completion phase.

PROJECT OFFICE COMMENTS

WFIRST project officials provided technical comments on a draft of this assessment, which were incorporated as appropriate.

Agency Comments and Our Evaluation

We provided a draft of this report to NASA for its review and comment. In its written response, NASA generally agreed with our findings and stated that the report provides NASA with a valued independent perspective on its major acquisitions. NASA also noted that we incorporated technology demonstration projects into the audit this year, and that it is important to remember that the purpose of these activities is to mature specific new technologies to a technology readiness level 6 or higher by the end of their demonstration phase in a relevant environment. As a result, it is NASA's view that our best practice to mature technologies to a technology readiness level 6 by the preliminary design review is not applicable to technology demonstration projects.

As discussed in the report, we included two technology demonstration projects—LCRD and Restore-L—in our assessment this year because these two projects each had a life-cycle cost estimate of over $250 million. In addition, we included these two projects in our analysis of NASA major projects attaining technology maturity at preliminary design review because both projects planned to mature their technologies prior to launch, not at the end of their demonstration phase in a relevant environment as NASA described in its letter. Therefore, these two projects are still susceptible to the same risks projects might experience if they fall short of the best practice of meeting a technical readiness level 6 by preliminary design review. These risks include subsequent technical problems that could result in cost growth and schedule delays. In the future, if other technology demonstration projects have a life-cycle cost estimate over $250 million and enter the portfolio of projects that we assess, we will continue to discuss project technology maturity goals for those specific projects with NASA. These discussions will inform our determination of whether we will compare those projects against our best practices on technology maturity.

NASA's written comments are reprinted in appendix VI. NASA also provided technical comments, which we incorporated as appropriate.

We are sending copies of the report to the NASA Administrator and interested congressional committees. In addition, the report will be available at no charge on GAO's website at http://www.gao.gov.

If you or your staff have any questions about this report, please contact me at (202) 512-4841 or chaplainc@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made major contributions to this report at listed in appendix VII.

Cristina T. Chaplain
Director, Contracting and National Security Acquisitions

List of Committees

The Honorable Jerry Moran
Chairman
The Honorable Jeanne Shaheen
Ranking Member
Subcommittee on Commerce, Justice, Science, and Related Agencies
Committee on Appropriations
United States Senate

The Honorable Ted Cruz
Chairman
The Honorable Edward J. Markey
Ranking Member
Subcommittee on Space, Science, and Competitiveness
Committee on Commerce, Science, and Transportation
United States Senate

The Honorable John Culberson
Chairman
The Honorable José Serrano
Ranking Member
Subcommittee on Commerce, Justice, Science, and Related Agencies
Committee on Appropriations
House of Representatives

The Honorable Brian Babin
Chairman
The Honorable Ami Bera
Ranking Member
Subcommittee on Space
Committee on Science, Space, and Technology
House of Representatives

Appendix I: Objectives, Scope, and Methodology

The objectives of our review were to assess (1) the cost and schedule performance of the National Aeronautics and Space Administration's (NASA) portfolio of major projects, (2) the maturity of technologies and stability of project designs at key points in the development process, and (3) the extent to which NASA is assessing future workforce capacity challenges that may affect its ability to manage its portfolio of projects. We also described the status and assessed the risks and challenges faced by NASA's 26 major projects, each with life-cycle costs more than $250 million. When NASA determines that a project has an estimated life-cycle cost of over $250 million, we include that project in our annual review up through launch or completion. We did not develop an assessment for the Asteroid Redirect Robotic Mission project because, as of June 2017, the project closed out most project development activities at the direction of NASA headquarters.

To respond to these objectives, we developed several standard data collection instruments (DCI). We developed multiple DCIs, which were completed by NASA's Office of the Chief Financial Officer, to gather data on each project's cost, schedule, funding, and notional 5-year budget. We used another DCI, which was completed by each project office, to gather data on project's technology and design maturity and development partners. The information available on individual projects depends on where a project is in its life cycle. For example, for projects in an early stage of development called formulation there are still unknowns about requirements, technology, and design. We also analyzed DCI data from prior reviews.

To assess the cost and schedule performance of NASA's major projects, we compared cost and schedule data as of February 2018 provided on DCIs by NASA for the 17 projects in the implementation phase during our review to previously established cost and schedule baselines.[1] The Commercial Crew Program has a tailored project life cycle and project management requirements, so it was excluded from this analysis. In addition, we assessed development cost and schedule performance for NASA's portfolios of major projects for each reporting period between 2009 and 2018 to examine longer-term trends. To determine cost performance, we compared the projects' baseline development costs and development costs as of February 2018. For the Orion program, we used

[1]For the purpose of this review, cost performance is defined as the percentage of total development cost growth over the development cost baseline.

a June 2017 cost estimate because NASA was revising the program's life-cycle cost estimate at the time of our review. For two projects—Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) and Transiting Exoplanet Survey Satellite (TESS)—the cost performance is current as of March 2018 because NASA updated cost information after we received the cost DCI in February 2018. All cost information in this report is presented in nominal then-year dollars for consistency with budget data. Current baseline costs for all projects are adjusted to reflect the cost accounting structure in NASA's fiscal year 2009 budget estimates. For the fiscal year 2009 budget request, NASA changed its accounting practices from full-cost accounting to reporting only direct costs at the project level. To determine schedule performance, we compared the project's baseline launch readiness or completion date and launch readiness or completion date as of February 2018. For three projects—GRACE-FO, James Webb Space Telescope, and TESS—the schedule performance is current as of March 2018 because NASA provided an updated schedule after we received the schedule DCI in February 2018.

To assess technology maturity, we asked project officials to complete a DCI that provided the technology readiness levels of each of the project's critical and heritage technologies at various stages of project development including the preliminary design review. We did not verify or validate project office supplied data on the technology readiness level of technologies, or the classification of technologies as critical or heritage. For the 17 projects that had held a preliminary design review and identified critical or heritage technologies, we compared those levels against our technology maturity best practice and NASA policy on technology maturity to determine the extent to which the portfolio was meeting the criteria. Our work has shown that reaching a technology readiness level 6—which indicates that the representative prototype of the technology has been demonstrated in a relevant environment that simulates the harsh conditions of space—by the preliminary design review is the level of maturity needed to minimize risks for space systems entering product development. Originally developed by NASA, technology readiness levels are measured on a scale of one to nine, beginning with paper studies of a technology's feasibility and culminating with a technology fully integrated into a completed product. See appendix IV for the definitions of technology readiness levels. We compared this year's results against those in prior years to assess whether NASA was improving in this area. We did not assess technology maturity for those projects that had not yet reached the preliminary design review at the time of this assessment or for projects that reported no critical or heritage technologies. We also excluded 2009 from our analysis since the data were only for critical technologies and did not include heritage technologies. We compared the number of critical technologies being developed per project with those in prior years to determine how the number of critical technologies developed per project had changed. We also collected information on the use of heritage technologies in the projects; including what heritage technologies were being used; what effort was needed to modify the form, fit, and function of the technology for use in the new system; and whether the project considered the heritage technology as a risk to the project.

To assess design stability, we asked project officials to complete a DCI that provided the number of engineering drawings completed or projected for release by the preliminary and critical design reviews and as of our current assessment.[2] We did not verify or validate project office supplied data on the number of released and expected engineering drawings. However, we collected the project offices' rationale for cases where it appeared that only a small percentage of the expected drawings were completed by the time of the design reviews or where the project office reported significant growth in the number of drawings released after the critical design review. In accordance with best practices, projects were assessed as having achieved design stability if at least 90 percent of projected drawings were released by the critical design review. We omitted the Exploration Ground Systems program in this year's analysis and retroactively excluded the program from prior year analyses in 2016 and 2017 because program officials said they do not track design drawings as a management tool and we found that the prior data submissions were not inclusive all subsystems. We compared this year's results against those in prior years to assess whether NASA was improving in this area. For this year's assessment, 12 projects had held a critical design review and reported data on design drawings. We did not assess the design stability for those projects that had not yet reached the critical design review at the time of this assessment. To assess project technical margins, we gathered project mass and power information using a DCI and compared it against NASA requirements. We omitted the

[2]In our calculation for the percentage of total number of drawings projected for release, we used the number of drawings released at the critical design review as a fraction of the total number of drawings projected, including where a growth in drawings occurred. Therefore, the denominator in the calculation may have been larger than what was projected at the critical design review. We believe that this more accurately reflected the design stability of the project.

Exploration Ground Systems, Space Network Ground Segment Sustainment, and Space Launch System as those projects do not contain spacecraft. We excluded the Orion program because it does not have applicable metrics. To assess completion of project validation and verification plans, we asked project officials to complete a DCI that provided data on whether a plan was completed by the critical design review.

To assess the extent to which NASA is assessing future workforce capacity challenges that may affect its ability to manage its portfolio of projects, we did the following:

- Analyzed NASA major project documents, such as monthly status reports, and interviewed project officials to determine if the projects were experiencing any workforce challenges. We also discussed the process of staffing Jet Propulsion Laboratory projects with officials within the NASA Management Office at the laboratory.
- Interviewed Mission Support Directorate and Office of the Chief Engineer officials responsible for agency-wide capability assessments to identify if workforce challenges were raised as a concern in these assessments. Through an initial review of documents and discussions with officials, we identified select technical areas that workforce capability gaps were identified in the assessments for additional review, including the technical capability areas of sensors and instruments, and guidance, navigation and control. We also selected the human capital, budget, and procurement business assessments because of the relation to the acquisitions process and acquisition workforce functions that could affect NASA's ability to manage its major projects. We reviewed the recommendations in each assessment and identified those specifically related to aspects of workforce capacity and human capital management. We interviewed relevant officials on the status of implementation plans for these recommendations—including NASA's efforts to improve strategic workforce planning and cross-center collaboration—and discussed the role these efforts would play in the broader implementation of NASA's operating model.
- Analyzed publicly available workforce data from NASA's Workforce Information Cubes for NASA (WICN) to identify workforce characteristics that could affect NASA's workforce capacity. WICN contains snapshots of workforce composition as of certain dates and are updated every two weeks by NASA's Shared Services Center. We obtained and analyzed data from WICN as of January 2018. Specifically, we examined (1) total employee staffing levels for the

past 5 years, (2) age, (3) retirement eligibility, and (4) the average number of years staff stay past initial retirement eligibility by occupational category. To assess the reliability of the workforce data used in the review, we reviewed NASA's responses to questions on the database, which included information on the source of the data, how NASA uses the data, and the reliability of the data; interviewed officials with knowledge of how the database is used at the agency and how the information is compiled; and reviewed the data for errors, such as by confirming correct sums and checking the consistency of workforce totals across the data. We concluded the workforce data were sufficiently reliable for purposes of this report.

Our work was performed primarily at NASA headquarters in Washington, D.C. In addition, we and related GAO engagement teams visited Goddard Space Flight Center in Greenbelt, Maryland; the Jet Propulsion Laboratory in Pasadena, California; Kennedy Space Center in Merritt Island, Florida; Johnson Space Center in Houston, Texas; and Marshall Space Flight Center in Huntsville, Alabama.

Project Profile Information on Each Individual Project Assessment

This year, we developed project assessments for the 26 projects in the portfolio with an estimated life-cycle cost greater than $250 million. For each project assessment we included a description of each project's objectives, information concerning the NASA center, and international partners involved in the project, if applicable, the project's cost and schedule performance, a schedule timeline identifying key project dates, and a brief narrative describing the current status of the project. We also included budget information, including the percentage of NASA's fiscal year 2019 budget for all major projects in the current portfolio that the project represents. The budget information is based on NASA's fiscal year 2019 budget. For projects in formulation, we included the total funding that has been allocated to the project since formulation start through the end of fiscal year 2017. For projects in implementation, we included the funding needed to be allocated for project completion or launch through the project's current life-cycle cost estimate. We also provided a detailed discussion of project challenges for selected projects as applicable.

To assess the cost and schedule changes of each project, we obtained data directly from NASA's Office of the Chief Financial Officer through our DCI. For the Commercial Crew program, we obtained data directly from the program on the total amount of funds obligated and the schedule. When applicable, we compared the level of cost and schedule reserves held by the project to the level required by center policy. To determine the funding received to date for each of the projects in formulation we calculated the total funding allocated to the project since formulation start.[3] For projects in implementation, we calculated the funding needed for project launch or completion through its current life-cycle cost estimate.

The project's timeline is based on acquisition cycle time, which is defined as the number of months between the project's start, or formulation start, and the projected or actual launch date. Formulation start generally refers to the initiation of a project; NASA refers to a project's start as key decision point (KDP)-A, or the beginning of the formulation phase. The preliminary design review typically occurs toward the end of the formulation phase, followed by a review at KDP-C, known as project confirmation, which allows the project to move into the implementation phase. The critical design review is generally held during the latter half of the final design and fabrication phase of implementation and demonstrates that the maturity of the design is appropriate to support continuing with the final design and fabrication phase. The manifested launch date is the launch date which the project is working toward, and when a launch vehicle is available to launch the project. This date is only a goal launch date for the project, not a commitment that they will launch on this date. The committed launch readiness date is determined through a launch readiness review that verifies that the launch system, spacecraft, and payloads are ready for launch. The implementation phase includes the operations of the mission and concludes with project disposal.

Project Challenges Discussion on Each Individual Project Assessment

To assess the status, risk, and challenges for each project, we submitted a DCI to each project office. In the DCI, we requested information on the maturity of critical and heritage technologies, the number of releasable design drawings at project milestones, and international partnerships.[4] We also held interviews with representatives from all of the projects to discuss the information on the DCI. We then reviewed project documentation—including project plans, schedules, risk assessments, and major project review documentation—to corroborate any testimonial evidence we received in the interviews. These reviews led to identification

[3]This does not include funds for studies prior to key decision point (KDP)-A, the start of formulation.

[4]We did not collect this information for the Commercial Crew Program.

of further challenges faced by NASA projects. The second page of our project assessments highlights key challenges facing that project that have or could affect project performance. For this year's report, we identified challenges across the projects we reviewed in the categories of launch, contractor, development partner, design, technology, schedule, and integration and test. These challenges do not represent an exhaustive or exclusive list and are based on our definitions and assessments, not those of NASA.

To supplement our analysis, we relied on our work over past years examining acquisition issues across multiple agencies. These reports cover such issues as contracting, program management, acquisition best practices, and cost estimating. We also have an extensive body of work related to challenges NASA has faced with specific system acquisitions, financial management, and cost estimating. This work provided the historical context and basis for large parts of the general observations we made about the projects we reviewed.

Data Limitations

NASA provided preliminary estimated life-cycle cost ranges and associated schedules for the eight projects that had not yet entered implementation, which are generally established at KDP-B. NASA formally establishes cost and schedule baselines, committing itself to cost and schedule targets for a project with a specific and aligned set of planned mission objectives, at KDP-C, which follows a preliminary design review. KDP-C reflects the life-cycle point where NASA approves a project to leave the formulation phase and enter into the implementation phase. NASA explained that preliminary estimates are generated for internal planning and fiscal year budgeting purposes at KDP-B, which occurs midstream in the formulation phase, and hence, are not considered a formal commitment by the agency on cost and schedule for the mission deliverables. Due to changes that occur to a project's scope and technologies between KDP-B and KDP-C, the estimates of project cost and schedule can be significantly altered between the two KDPs.

We conducted this performance audit from April 2017 to May 2018 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Appendix II: Major NASA Projects Assessed in GAO's 2018 Report

In 2018, we assessed 26 major NASA projects. Figure 11 shows the preliminary launch readiness data and cost estimates for projects in the formulation phase, and the current launch readiness dates and cost estimates for projects in the implementation phase.

Figure 11: Cost and Schedule of Major NASA Projects Assessed in GAO's 2018 Report by Phase

Phase	Acronym	Project name	Preliminary launch readiness date	Preliminary cost estimate (in millions)
Formulation	DART	Double Asteroid Redirection Test	Dec 2020 – May 2021	$247.7 – $290.7
	Clipper	Europa Clipper	July 2023	$3,100 – $4,000
	LBFD	Low Boom Flight Demonstrator	March 2022	$390+
	Lucy	Lucy	Oct – Nov 2021	$914 – $984
	PACE	Plankton, Aerosol, Cloud, ocean Ecosystem	Aug 2022 – Apr 2023	$805 – $850
	Psyche	Psyche	August 2022	$907.3 – $957.3
	Restore-L	Restore-L	June – Dec 2020	$626 – $753
	WFIRST	Wide-Field Infrared Survey Telescope	2024 – 2026	$3,200 – $3,800

Phase	Acronym	Project name	Current launch readiness date	Current cost estimate (in millions)
Implementation	EGS	Exploration Ground Systems	June 2020	$3,230.7
	GRACE-FO	Gravity Recovery and Climate Experiment Follow-On	May 2018	$431.9
	ICESat-2	Ice, Cloud, and Land Elevation Satellite-2	October 2018	$1,063.6
	ICON	Ionospheric Connection Explorer	No earlier than June 2018	$252.7
	InSight	Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport	May 2018	$828.9
	JWST	James Webb Space Telescope	May 2020	$8,825.4
	L9	Landsat 9	November 2021	$885.0
	LCRD	Laser Communications Relay Demonstration	November 2019	$262.7
	Mars 2020	Mars 2020	July 2020	$2,458.2
	NISAR	NASA Indian Space Research Organisation Synthetic Aperture Radar	September 2022	$896.9
	PSP	Parker Solar Probe[a]	August 2018	$1,548.2
	Orion	Orion Multi-Purpose Crew Vehicle[b]	April 2023	Under revision
	RBI	Radiation Budget Instrument (canceled)	December 2019	$304.8
	SGSS	Space Network Ground Segment Sustainment[c]	June 2021	$1,320.8
	SLS	Space Launch System	June 2020	$9,843.2
	SWOT	Surface Water and Ocean Topography	April 2022	$754.9
	TESS	Transiting Exoplanet Survey Satellite	April 2018	$336.7
	CCP	Commercial Crew Program[d]	Jan - Feb 2019	$6,968.4

Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-18-280SP

Note: The life cycle for NASA space flight projects consists of two phases—formulation, which takes a project from concept to preliminary design, and implementation, which includes building, launching, and operating the system, among other activities. For projects in implementation, the current launch readiness date and cost estimate are the project's established cost and schedule baseline or the latest cost estimate and schedule if the project has experienced cost or schedule growth above the project's baseline.

[a]In May 2017, NASA renamed the Solar Probe Plus project as the Parker Solar Probe project.

[b]NASA officials said they are revising the Orion program's life-cycle cost estimate and expect to complete a new estimate in June 2018. The new cost is expected to be over the program's cost baseline of $11,283.5 million.

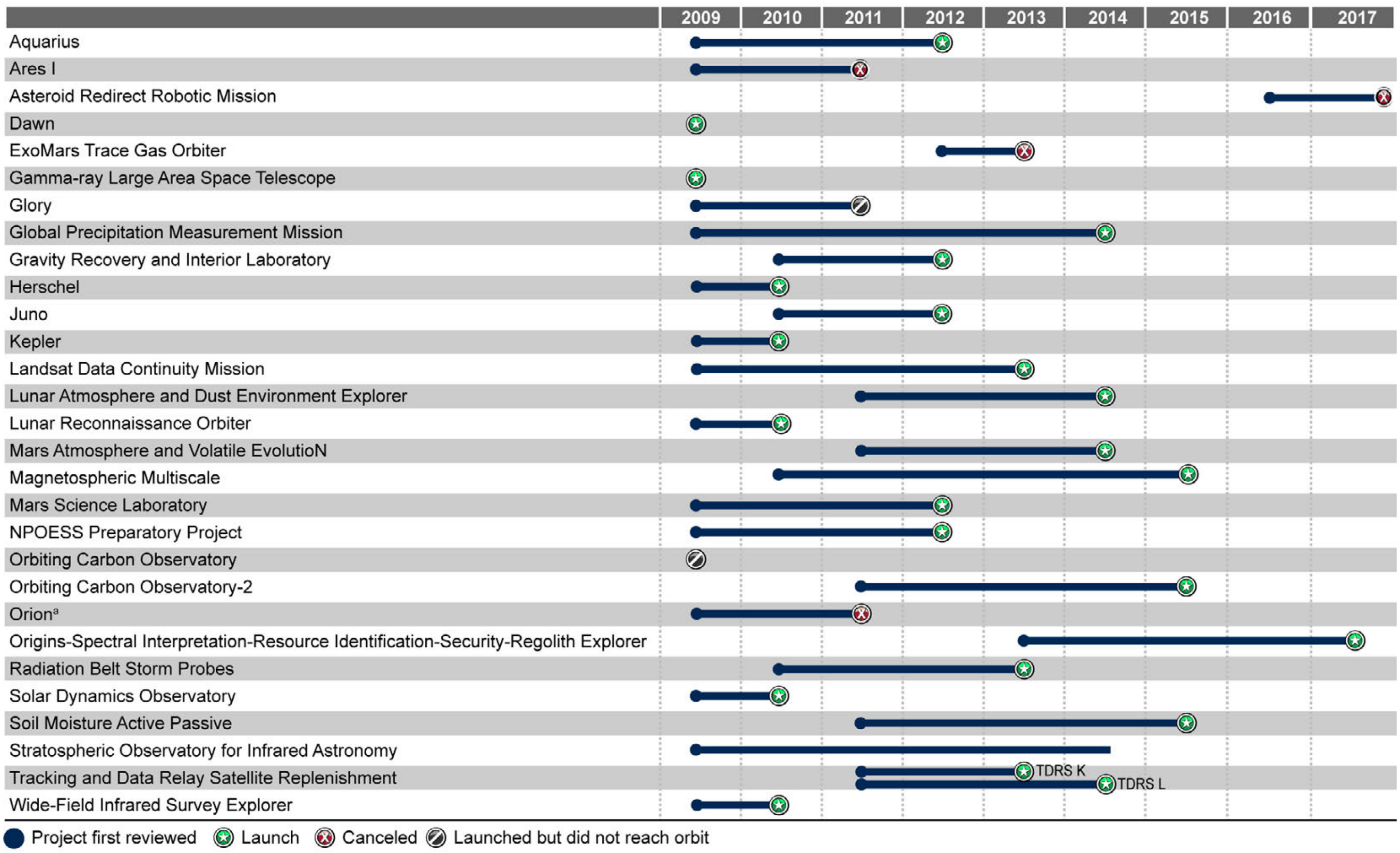
[c]In 2016, NASA reclassified the Space Network Ground Segment Sustainment (SGSS) as a hybrid sustainment effort, rather than a major project. A hybrid sustainment effort still includes development work. As a result, we continue to include SGSS in our assessment. The SGSS project reported costs are up through its first operational readiness review at the end of fiscal year 2019, and its schedule is under review.

[d]The launch readiness date for the Commercial Crew Program is for the certification reviews for Boeing and SpaceX. The Commercial Crew Program is implementing a tailored version of NASA's space flight project life cycle, but it is currently completing development activities typically associated with implementation.

Appendix III: Major NASA Projects Reviewed in GAO's Annual Assessments

We have reviewed 55 major National Aeronautics and Space Administration (NASA) projects or programs since our initial review in 2009. See figure 12 below for a list of projects included in our assessments from 2009 to 2017. These projects were not included in the 2018 review because they launched, were canceled, or launched but failed to reach orbit.

Figure 12: Major NASA Projects Reviewed in GAO's Annual Assessments from 2009-2017

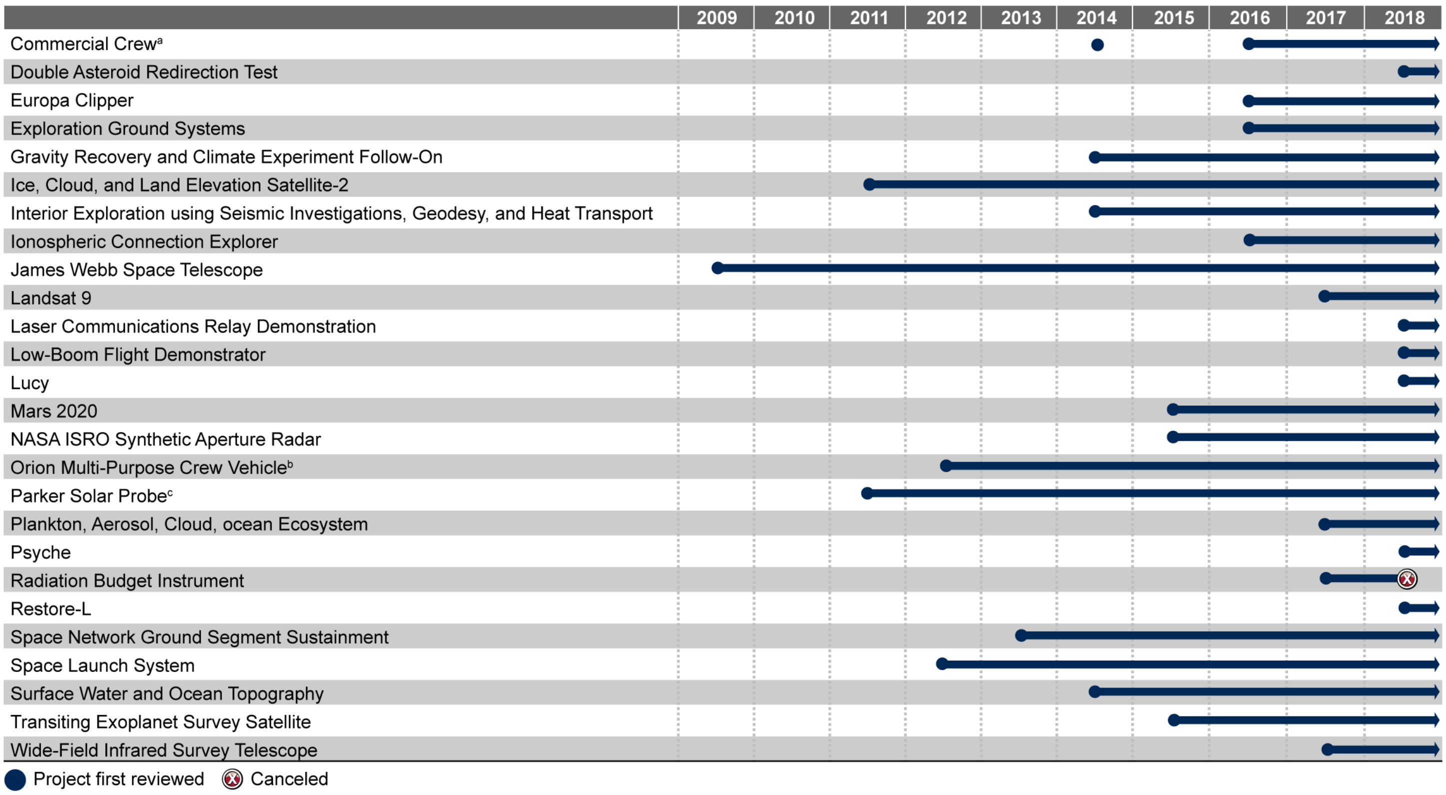


Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-18-280SP

[a]In 2014, NASA adopted Orion as the common name for Orion MPCV; the project did not change. This Orion project stems from the original Orion project that was canceled in June 2011 when the Constellation program was canceled after facing significant technical and funding issues. During the closeout process for the Constellation program, NASA identified elements of the Ares I and Orion projects that would be transitioned for use on the new Space Launch System and Orion Multi-Purpose Crew Vehicle programs.

See figure 13 below for a list of projects included in our 2018 assessment, including when the projects were first included in the review, and projects that were canceled during the review.

Figure 13: Major NASA Projects Reviewed in GAO's 2018 Assessment



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-18-280SP

[a]A bid protest was filed on September 26, 2014, after NASA awarded Commercial Crew contracts. GAO issued a decision on the bid protest on January 5, 2015, which was after our review of projects had concluded; therefore, we excluded the Commercial Crew Program from the 2015 review.

[b]In 2014, NASA adopted Orion as the common name for Orion MPCV; the project did not change. This Orion project stems from the original Orion project that was canceled in June 2011 when the Constellation program was canceled after facing significant technical and funding issues. During the closeout process for the Constellation program, NASA identified elements of the Ares I and Orion projects that would be transitioned for use on the new Space Launch System and Orion Multi-Purpose Crew Vehicle programs.

[c]In May 2017, NASA renamed the Solar Probe Plus project as the Parker Solar Probe project.

Appendix IV: Technology Readiness Levels

Table 4: Characteristics of Technology Readiness Levels

Technology readiness level	Description	Hardware	Demonstration environment
1. Basic principles observed and reported.	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties.	None (paper studies and analysis).	None.
2. Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be invented. The application is speculative and there is no proof or detailed analysis to support the assumption. Examples are still limited to paper studies.	None (paper studies and analysis).	None.
3. Analytical and experimental critical function and/or characteristic proof of concept.	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.	Analytic studies and demonstration of nonscale individual components (pieces of subsystem).	Lab.
4. Component and/or breadboard. Validation in laboratory environment.	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of ad-hoc hardware in a laboratory.	Low fidelity breadboard. Integration of nonscale components to show pieces will work together. Not fully functional or form or fit but representative of technically feasible approach suitable for flight articles.	Lab.
5. Component and/or breadboard validation in relevant environment.	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so that the technology can be tested in a simulated environment. Examples include high-fidelity laboratory integration of components.	High-fidelity breadboard. Functionally equivalent but not necessarily form and/or fit (size, weight, materials, etc.). Should be approaching appropriate scale. May include integration of several components with reasonably realistic support elements/subsystems to demonstrate functionality.	Lab demonstrating functionality but not form and fit. May include flight demonstrating breadboard in surrogate aircraft. Technology ready for detailed design studies.
6. System/subsystem model or prototype demonstration in a relevant environment.	Representative model or prototype system, which is well beyond the breadboard tested for technology readiness level 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in simulated realistic environment.	Prototype. Should be very close to form, fit, and function. Probably includes the integration of many new components and realistic supporting elements/subsystems if needed to demonstrate full functionality of the subsystem.	High-fidelity lab demonstration or limited/restricted flight demonstration for a relevant environment. Integration of technology is well defined.

Technology readiness level	Description	Hardware	Demonstration environment
7. System prototype demonstration in a realistic environment.	Prototype near or at planned operational system. Represents a major step up from technology readiness level 6, requiring the demonstration of an actual system prototype in a realistic environment, such as in an aircraft, vehicle, or space. Examples include testing the prototype in a test bed aircraft.	Prototype. Should be form, fit, and function integrated with other key supporting elements/subsystems to demonstrate full functionality of subsystem.	Flight demonstration in representative realistic environment such as flying test bed or demonstrator aircraft. Technology is well substantiated with test data.
8. Actual system completed and "flight qualified" through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this technology readiness level represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.	Flight qualified hardware.	Developmental Test and Evaluation in the actual system application.
9. Actual system "flight - proven" through successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last "bug fixing" aspects of true system development. Examples include using the system under operational mission conditions.	Actual system in final form.	Technology assessed as fully mature. Operational Test and Evaluation in operational mission conditions.

Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-18-280SP

Appendix V: Elements of a Sound Business Case

The development and execution of a knowledge-based business case for the National Aeronautics and Space Administration's (NASA) projects can provide early recognition of challenges, allow managers to take corrective action, and place needed and justifiable projects in a better position to succeed. Our prior work of best practice organizations shows the risks inherent in NASA's work can be mitigated by developing a solid, executable business case before committing resources to a new product's development.[1] In its simplest form, a knowledge-based business case is evidence that (1) the customer's needs are valid and can best be met with the chosen concept and that (2) the chosen concept can be developed and produced within existing resources—that is, proven technologies, design knowledge, adequate funding, adequate time, and adequate workforce to deliver the product when needed. A program should not be approved to go forward into product development unless a sound business case can be made. If the business case measures up, the organization commits to the development of the product, including making the financial investment. The building of knowledge consists of information that should be gathered at these three critical points over the course of a program:

- When a project begins development, the customer's needs should match the developer's available resources—mature technologies, time, and funding. An indication of this match is the demonstrated maturity of the technologies required to meet customer needs—referred to as critical technologies. If the project is relying on heritage—or pre-existing—technology, that technology must be in the appropriate form, fit, and function to address the customer's needs within available resources. The project will generally enter development after completing the preliminary design review, at which time a business case should be in hand.
- Then, about midway through the project's development, its design should be stable and demonstrate it is capable of meeting performance requirements. The critical design review takes place at that point in time because it generally signifies when the program is

[1]GAO, *Defense Acquisitions: Key Decisions to be Made on Future Combat System,* GAO-07-376 (Washington, D.C.: Mar. 15, 2007); *Defense Acquisitions: Improved Business Case Key for Future Combat System's Success,* GAO-06-564T (Washington, D.C.: Apr. 4, 2006); *NASA: Implementing a Knowledge-Based Acquisition Framework Could Lead to Better Investment Decisions and Project Outcomes,* GAO-06-218 (Washington, D.C.: Dec. 21, 2005); and *NASA's Space Vision: Business Case for Prometheus 1 Needed to Ensure Requirements Match Available Resources,* GAO-05-242 (Washington, D.C.: Feb. 28, 2005).

ready to start building production-representative prototypes. If project development continues without design stability, costly redesigns to address changes to project requirements and unforeseen challenges can occur.

- Finally, by the time of the production decision, the product must be shown to be producible within cost, schedule, and quality targets and have demonstrated its reliability, and the design must demonstrate that it performs as needed through realistic system-level testing. Lack of testing increases the possibility that project managers will not have information that could help avoid costly system failures in late stages of development or during system operations.

Appendix VI: Comments from the National Aeronautics and Space Administration

National Aeronautics and Space Administration

Office of the Administrator
Washington, DC 20546-0001

April 13, 2018

Ms. Cristina T. Chaplain
Director
Contracting and National Security Acquisitions
United States Government Accountability Office
Washington, DC 20548

Dear Ms. Chaplain:

The National Aeronautics and Space Administration (NASA) appreciates the opportunity to comment on the Government Accountability Office (GAO) draft report entitled "NASA: Assessments of Major Projects" (GAO-18-280SP). This assessment provides NASA with a valued independent perspective on our major acquisitions. We appreciate the open and constructive dialogue between NASA and the GAO engagement team, and we look forward to continuing to work with the GAO to identify and address any challenges that may enable cost and schedule improvements in our current and future projects.

This year's report represents the tenth annual iteration of the GAO's legislatively mandated assessment of NASA's major acquisitions. The GAO has provided NASA with several highly valued insights into various aspects of our acquisition approaches since the inaugural report's issuance in 2009, many of which have resulted in programmatic improvements and enhancements. However, the number of projects in this year's assessment portfolio is 36 percent higher than the average for this engagement. This growth may be attributed to a greater number of major spaceflight development projects in NASA's portfolio, but another driver has been the expansion of the legislative mandate to include potential major projects in formulation; technology demonstrations; and communications, tracking, and infrastructure refreshment activities. We are pleased the GAO makes a dedicated effort to minimize disruption to projects wherever possible; however, there are times where disruption is unavoidable, particularly with regard to projects earlier in their life cycles prior to confirmation. While NASA appreciates the clear demonstrated value in this recurring engagement, it is equally important to recognize the growing administrative burden that is necessary to respond to GAO inquiries with valid, accurate, and timely information.

NASA appreciates the GAO's recognition of alternative approaches to managing different types of projects, such as technology demonstration spacecraft and experimental aircraft. The GAO has established best practices regarding the maturation of technologies to Technology Readiness Level 6 (TRL-6) by the Preliminary Design Review (PDR) for science and human exploration missions, and we strive to achieve this technology maturation schedule on our spaceflight missions per the NASA Procedural Requirement

(NPR) 7120.5E policy. As the GAO has now incorporated technology demonstration projects into the audit, it is important to remember that the purpose of these activities is to mature specific new technologies to TRL-6 or higher by the end of their demonstration phase in a relevant environment. As such, at PDR for these technology demonstration projects, it is anticipated that technologies would not necessarily be at TRL-6 unlike for science and human exploration missions. NASA looks forward to working with the GAO to ensure a common understanding of the ways our approach to these types of projects differ from the typical NPR 7120.5E approach.

NASA is in agreement with the GAO that there are several large, complex projects in development that comprise a large relative share of the total current major project portfolio. We also recognize some development challenges exist in these projects that have resulted in recently revised cost and schedule plans in some instances. As we work to mitigate cost, schedule, and technical risk in these critical development efforts, we would like to take this opportunity to highlight the overall positive trending of our cost and schedule estimation practices over the past twenty years. When taken in aggregate, NASA's cost and schedule performance has markedly improved, moving from 45 percent average development cost growth against established baselines in the pre-cost confidence level era in the early 2000s, to less than 2 percent average development growth since the advent of the Joint Cost and Schedule Confidence Level (JCL) policy implementation in 2009. We are continuing to assess and advance the Agency's programmatic capabilities across the cost-estimating, pricing, scheduling, and earned value management communities, as well as any strategic workforce implications or augmentations required to support future mission needs. NASA looks forward to continued maturation and application of our cost and schedule estimation practices and tools as additional large acquisitions continue along their life cycles in the years ahead.

The majority of work on NASA's new deep space exploration system is on track. As a percentage of overall effort, we are seeing specific areas of targeted challenges consistent with a first-time design, development, test, and build of a human spacecraft system for deep space, which offer future opportunity for subsequent builds. NASA is using lessons learned from these experiences to drive efficiencies into overall production and operations planning. With NASA's multi-mission approach to deep space exploration, we have hardware in production for the first and second missions, and we are gearing up for the third flight. As teams complete hardware for one flight, they move on to the next set of flights. Extreme focus on early flights can be harmful to future missions in a multi-flight program, and focusing solely on the first flights of Exploration Mission 1 (EM-1) for the Space Launch System (SLS) and EM-2 for Orion can impact the ability to deliver a human deep space exploration system for use in the decades to come. Taking the time to effectively resolve first-time build challenges up-front leads to short-term schedule and cost challenges but yields significant benefits for out-year flights.

After a thorough schedule analysis in 2017, NASA updated the EM-1 launch date and provided the required Congressional notification per the 2005 NASA Authorization Act, Section 103. The notification included updated cost and schedule estimates for the SLS and Exploration Ground Systems (EGS) programs through EM-1 because these programs are baselined to the EM-1 launch date. An updated cost estimate for Orion was not included in the initial notification because this program is baselined through EM-2, a different development duration than the SLS EM-1 baseline. As part of NASA's normal budgeting process, Orion is refining its EM-2 baseline cost estimate to incorporate the new schedule planning for EM-1 and account for post-EM-1 activities. NASA will provide the results of this update when it is complete.

NASA would like to thank the GAO for continuing to work with project subject-matter experts to consider and incorporate technical corrections as part of this audit. We appreciate the consideration of these comments, which is important for an accurate and balanced presentation of the projects' technical status. We look forward to working with the GAO to ensure the technical review process continues to add value in the future.

NASA greatly appreciates the ongoing dialogue with the GAO on this critical engagement and is committed to working jointly to address any questions or concerns related to this effort. Please contact Kevin M. Gilligan at (202) 358-4544 if you have any questions or require additional information.

Sincerely,

Stephen G. Jurczyk
Associate Administrator (Acting)

Appendix VII: GAO Contact and Staff Acknowledgments

GAO Contact

Cristina Chaplain, (202) 512-4841 or chaplainc@gao.gov.

Staff Acknowledgments

In addition to the contact named above, Molly Traci, Assistant Director; Andrea M. Bivens; Lorraine Ettaro; Lisa L. Fisher; Laura Greifner; Kristine R. Hassinger; Erin Kennedy; Joy Kim; Jose A. Ramos; Carrie Rogers; Daniel R. Singleton; Juli Steinhouse; Ryan Stott; Roxanna T. Sun; Alyssa Weir; and Kristin Van Wychen made significant contributions to this report.

GAO's Mission

The Government Accountability Office, the audit, evaluation, and investigative arm of Congress, exists to support Congress in meeting its constitutional responsibilities and to help improve the performance and accountability of the federal government for the American people. GAO examines the use of public funds; evaluates federal programs and policies; and provides analyses, recommendations, and other assistance to help Congress make informed oversight, policy, and funding decisions. GAO's commitment to good government is reflected in its core values of accountability, integrity, and reliability.

Obtaining Copies of GAO Reports and Testimony

The fastest and easiest way to obtain copies of GAO documents at no cost is through GAO's website (https://www.gao.gov). Each weekday afternoon, GAO posts on its website newly released reports, testimony, and correspondence. To have GAO e-mail you a list of newly posted products, go to https://www.gao.gov and select "E-mail Updates."

Order by Phone

The price of each GAO publication reflects GAO's actual cost of production and distribution and depends on the number of pages in the publication and whether the publication is printed in color or black and white. Pricing and ordering information is posted on GAO's website, https://www.gao.gov/ordering.htm.

Place orders by calling (202) 512-6000, toll free (866) 801-7077, or TDD (202) 512-2537.

Orders may be paid for using American Express, Discover Card, MasterCard, Visa, check, or money order. Call for additional information.

Connect with GAO

Connect with GAO on Facebook, Flickr, Twitter, and YouTube.
Subscribe to our RSS Feeds or E-mail Updates. Listen to our Podcasts.
Visit GAO on the web at https://www.gao.gov.

To Report Fraud, Waste, and Abuse in Federal Programs

Contact:

Website: https://www.gao.gov/fraudnet/fraudnet.htm

Automated answering system: (800) 424-5454 or (202) 512-7470

Congressional Relations

Orice Williams Brown, Managing Director, WilliamsO@gao.gov, (202) 512-4400, U.S. Government Accountability Office, 441 G Street NW, Room 7125, Washington, DC 20548

Public Affairs

Chuck Young, Managing Director, youngc1@gao.gov, (202) 512-4800
U.S. Government Accountability Office, 441 G Street NW, Room 7149
Washington, DC 20548

Strategic Planning and External Liaison

James-Christian Blockwood, Managing Director, spel@gao.gov, (202) 512-4707
U.S. Government Accountability Office, 441 G Street NW, Room 7814, Washington, DC 20548