United States Government Accountability Office

Report to Congressional Committees

May 2019

NASA

Assessments of Major Projects

GAO-19-262SP

GAO Highlights

Highlights of GAO-19-262SP, a report to congressional committees

Why GAO Did This Study

This report provides GAO's annual snapshot of how well NASA is planning and executing its major acquisition projects. GAO previously found that, as of February 2018, the cost and schedule performance of major projects was deteriorating, with 9 of 17 projects in development reporting cost or schedule growth. GAO also found that NASA was likely to continue to see cost and schedule growth, as new, large projects were entering the portfolio while others were taking longer to launch than planned.

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 11th annual assessment. This report assesses (1) the cost and schedule performance of NASA's major projects and (2) the maturity of critical technologies, among other issues. This report also includes assessments of 21 of NASA's 24 major projects, each with a life-cycle cost of over $250 million using 2018 data. This report does not assess what effect, if any, the government shutdown that ended in January 2019 had on performance. To conduct its review, GAO analyzed cost, schedule, technology maturity, and other data; reviewed project status reports; and interviewed NASA officials.

What GAO Recommends

In prior reports, GAO has made related recommendations that NASA generally agreed with; 14 of these are not yet fully addressed. NASA generally agreed with the findings in this report.

View GAO-19-262SP. For more information, contact Cristina T. Chaplain at (202) 512-4841 or chaplainc@gao.gov.

May 2019

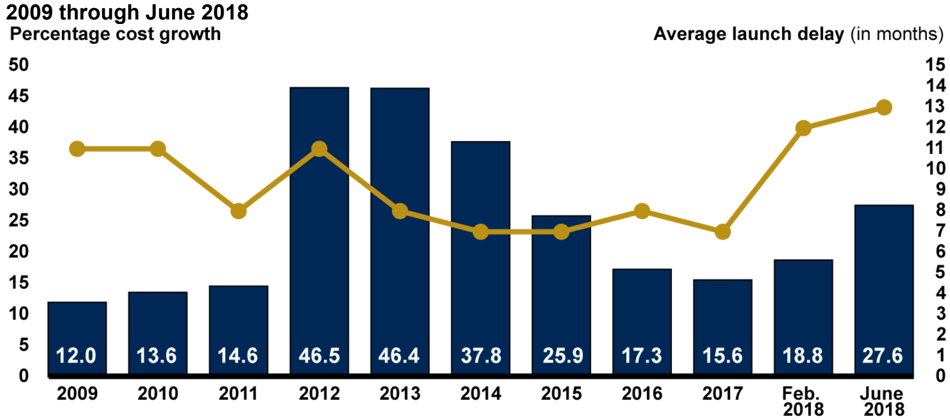
NASA

Assessments of Major Projects

What GAO Found

The cost and schedule performance of the National Aeronautics and Space Administration's (NASA) portfolio of major projects continues to deteriorate. For this review, cost growth was 27.6 percent over the baselines and the average launch delay was approximately 13 months, the largest schedule delay since GAO began annual reporting on NASA's major projects in 2009. See figure.

Development Cost Performance and Average Launch Delay for Major NASA Projects from 2009 through June 2018



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-19-262SP

Note: Data is as of June 2018 with some exceptions. For example, data was updated for projects that held decision reviews subsequent to that date but before the end of the calendar year 2018.

This deterioration in cost and schedule performance is largely due to integration and test challenges on the James Webb Space Telescope (see GAO-19-189 for more information). The Space Launch System program also experienced significant cost growth due to continued production challenges. Further, additional delays are likely for the Space Launch System and its associated ground systems. Senior NASA officials stated that it is unlikely these programs will meet the launch date of June 2020, which already reflects 19 months of delays. These officials told GAO that there are 6 to 12 months of risk associated with that launch date.

GAO found some subjectivity in the processes NASA uses to identify and assess critical technologies—those that are required for the project to successfully meet customer requirements—which could understate the development risk that its major projects face. The average number of critical technologies NASA reported increased slightly in 2019, but remains low compared to historical data. However, GAO found inconsistencies in how projects identify critical technologies. For example, the Lucy project determined that operating its solar array in a previously unexplored environment did not warrant identifying it as a critical technology, while the Ionospheric Connection Explorer (ICON) project did identify a technology as critical because of its use in a new environment. NASA is planning to clarify its guidance on technology readiness, among other measures. GAO will continue to monitor NASA's efforts in this area.

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Abbreviations

AIM	Asteroid Impact Monitor
ASI	Italian Space Agency
CCP	Commercial Crew Program
CNES	Centre National d'Etudes Spatiales
DART	Double Asteroid Redirection Test
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
EVMS	Earned Value Management System
GRACE-FO	Gravity Recovery and Climate Experiment Follow-On
GSLV	Geosynchronous Satellite Launch Vehicle
HARP-2	Hyper Angular Rainbow Polarimeter
HEOMD	Human Exploration and Operations Mission Directorate
ICESat-2	Ice, Cloud, and Land Elevation Satellite-2
ICON	Ionospheric Connection Explorer
IMAP	Interstellar Mapping and Acceleration Probe
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
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
LIDAR	Light Detection and Randing
NASA	National Aeronautics and Space Administration
NEXT-C	NASA's Evolutionary Xenon Thruster-Commercial
NISAR	NASA ISRO Synthetic Aperture Radar
NPR	NASA Procedural Requirements
OCI	Ocean Color Instrument
Orion	Orion Multi-Purpose Crew Vehicle
PACE	Plankton, Aerosol, Cloud ocean Ecosystem
PDR	preliminary design review
PIXL	Planetary Instrument for X-ray Lithochemistry

PSP	Parker Solar Probe
RBI	Radiation Budget Instrument
REASON	Radar for Europa Assessment and Sounding: Ocean to Near-surface
SADA	Solar Array Drive Assembly
SCaN	Space Communication and Navigation
SCS	Sampling and Caching Subsystem
SDO	Solar Dynamics Observatory
SLS	Space Launch System
SGSS	Space Network Ground Segment Sustainment
SHERLOC	Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals
SLS	Space Launch System
SPEXone	Spectro-Polarimeter for Planetary Exploration
SRON	Netherlands Institute for Space Research
STMD	Space Technology Mission Directorate
SWOT	Surface Water and Ocean Topography
SwRI	Southwest Research Institute
TESS	Transiting Exoplanet Survey Satellite
USRA	Universities Space Research Association
WFIRST	Wide-Field Infrared Survey Telescope

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U.S. GOVERNMENT ACCOUNTABILITY OFFICE
441 G St. N.W.
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May 30, 2019

Congressional Committees

The National Aeronautics and Space Administration (NASA) is planning to invest about $63 billion over the life-cycle of its current portfolio of 24 major projects, which we define as those projects or programs that have a life-cycle cost of 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 in view of NASA's persistent cost growth and schedule delays in the majority of its major projects.[1] This report includes assessments of NASA's key projects across mission areas, such as the Space Launch System (SLS) for human exploration, Mars 2020 for planetary science, and the Plankton, Aerosol, Cloud ocean Ecosystem (PACE) for Earth science.

The explanatory statement of the House Committee on Appropriations accompanying the Omnibus Appropriations Act, 2009 included a provision for us to prepare project status reports on selected large-scale NASA programs, projects, and activities.[2] This is our 11th 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 (3) the stability of project designs at key points in the development process. This report also includes individual assessments of 21 of the 24 major NASA projects in NASA's current portfolio. 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 complete individual project assessments for three projects that launched during our review.

To complete our annual assessments, we typically compare cost and schedule performance of NASA's portfolio across each of our reporting

[1]GAO, *High-Risk Series: Substantial Efforts Needed to Achieve Greater Progress on High-Risk Areas*, GAO-19-157SP (Washington, D.C.: Mar. 6, 2019).

[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 as major projects as NASA does not use the term "large scale."

periods. The reporting period is the year we issue our report, and we have typically used cost and schedule data that NASA provided to us early in that calendar year. For example, for our last assessment, we based the 2018 reporting period on data NASA provided to us in January and February 2018.[3] Due to the partial government shutdown, which occurred between December 2018 and January 2019 due to a lapse in appropriations for fiscal year 2019, data included in this report is current as of December 2018, unless otherwise noted. This report does not assess the effects, if any, of the partial government shutdown on the cost or schedule of the projects in the portfolio.

To assess the cost and schedule performance, technology maturity, and design stability of NASA's major projects, we obtained information on these areas from project officials using data questionnaires, analyzed projects' monthly status reports and other documentation, and interviewed NASA project and headquarters officials. There are 24 major projects in total, but the information available depends on where a project is in its life cycle.[4] For the 17 projects in the implementation phase, we compared current cost and schedule estimates as of June 2018 to their original cost and schedule baselines, identified the number of critical technologies being developed, and assessed their technology maturity against GAO-identified acquisition best practices. If a project had a major decision event, such as establishing a cost and schedule baseline, before the end of December 2018, we included that data in our analysis. In addition, NASA provided an updated cost estimate for the Space Launch System as of September 2018 that we included in our analysis.

We also examined a subset of the 24 major projects—six projects that had not yet held a preliminary design review as of the beginning of our review—to provide observations on the extent to which technology risk across NASA's major projects is reported. We selected one of these projects, Europa Clipper, for a more in depth review of how the project identified and evaluated its critical technologies compared against best practices in GAO's exposure draft Technology Readiness Assessment

[3]GAO-18-280SP.

[4]Six 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. A seventh project, 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.

Guide.[5] We selected this project from our subset of six projects for several reasons, including its high life-cycle cost estimate and because the project was approaching its preliminary design review, which is the point when projects are expected to have matured their critical technologies. While the case study provides us with a more in-depth understanding of NASA's process for selecting and evaluating critical technologies, we cannot generalize findings from this case study to all of the major projects in NASA's portfolio.

To assess the stability of project designs at key points in the development process, 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. Twelve projects completed a critical design review before December 2018 and were included in this analysis. 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. Finally, to conduct our 21 individual 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 2018 to May 2019 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.

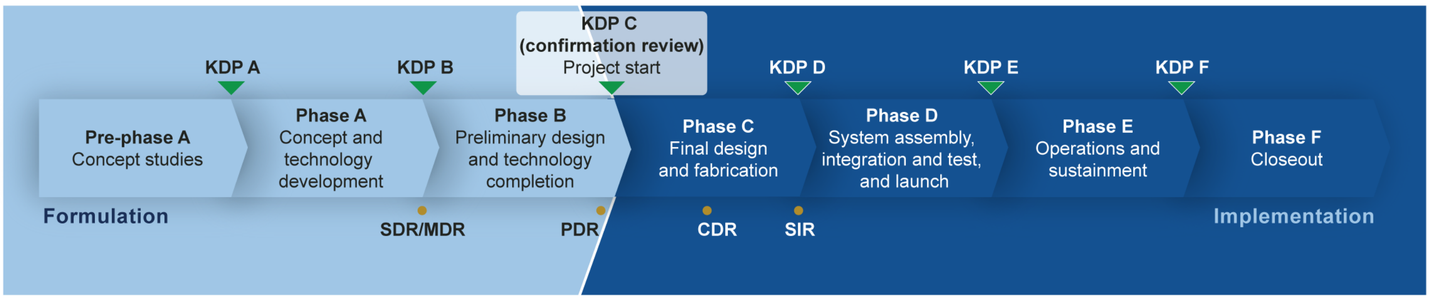
Background

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

[5] GAO, *GAO Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects – Exposure Draft*, GAO-16-410G (Washington, D.C.: Aug. 11, 2016).

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



Management decision reviews

KDP = key decision point

Technical reviews

- SDR/MDR = system definition review/mission definition review
- PDR = preliminary design review
- CDR = critical design review
- SIR = system integration review

Source: GAO presentation of National Aeronautics and Space Administration information. | GAO-19-262SP

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 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 the 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 effects of cost and schedule to date on the estimate, 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.[6]

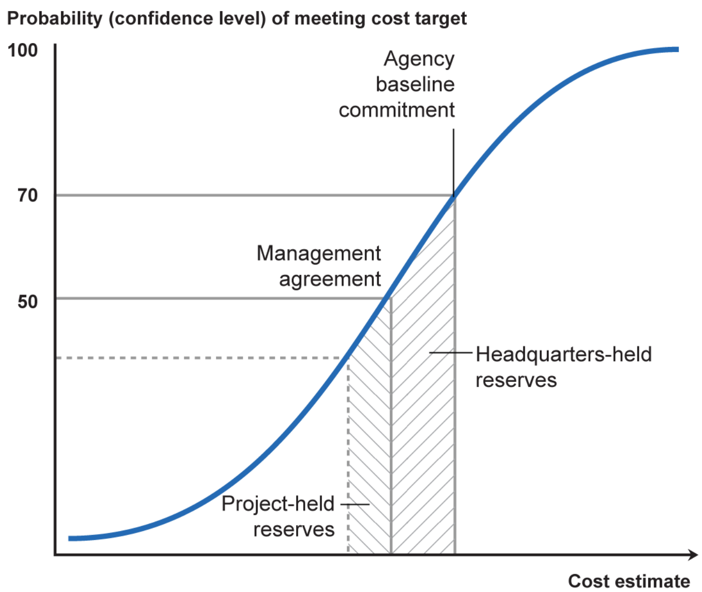
The management agreement and agency baseline commitment include cost and schedule reserves held at the project and NASA headquarters level, respectively.[7] Cost reserves are for costs that are expected to be incurred—for instance, to address project risks—but are not yet allocated to a specific part 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

[6]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.

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

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. The total amount of cost and schedule reserves held at the project level varies based on where the project is in its life cycle. 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-19-262SP

Six NASA centers or laboratories are responsible for managing 23 NASA major projects. Of these, three centers or laboratories manage 17 of the 23 major projects and require or recommend that projects hold a certain level of cost and schedule reserves at key project milestones.[8] 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 24th 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 stated that they plan to use a mix of center policies in managing the LBFD acquisition.

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 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, which includes final delivery of all remaining project deliverables and safe decommissioning/disposal of space flight systems and other project assets.

NASA Projects Reviewed in GAO's Annual Assessment

NASA's portfolio of major projects covers a range of project types including satellites equipped with advanced sensors for studying the Earth, a rover that plans to collect soil and rock samples on Mars, telescopes for exploring the universe, and spacecraft for transporting humans and cargo beyond low-Earth orbit. When NASA determines that

[8]NASA, Goddard Procedural Requirements 7120.7B, *Funded Schedule Margin and Budget Margin for Flight Projects* (Sept. 17, 2018); Marshall Procedural Requirements 7120.1, *Marshall Space Flight Center Engineering and Program/Project Management Requirements* (Oct. 20, 2016); and Jet Propulsion Laboratory, *Flight Project Practices, Rev. 12* (Dec. 14 2017). 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), Double Asteroid Redirect Test (DART), and Interstellar Mapping and Acceleration Probe (IMAP) projects and has guidelines for schedule reserves, but not for cost reserves.

a project will have an estimated life-cycle cost of more than $250 million, we include that project in our annual review.

This report reviews a total of 24 major projects and includes individual assessments of 21 of those major NASA projects (see table 1). We did not include an individual assessment for three projects that launched during the course of our review. One project is being assessed for the first time this year: Interstellar Mapping and Acceleration Probe (IMAP). For a list of the 24 projects and their current cost and schedule estimates, see appendix II. Appendix III provides a list of all the projects that we have reviewed from 2009 to 2019 in our series of annual reports.

Table 1: Major NASA Projects Reviewed in GAO's 2019 Assessment

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

Source: GAO. | GAO-19-262SP

[a]The IceSat-2, InSight, and Parker Solar Probe projects launched in 2018.

Over the past 7 years, we have issued several reports assessing NASA's progress acquiring specific large projects and programs in more depth.[9] For example, we found in July 2016 that all three human spaceflight programs—the Orion Multi-Purpose Crew Vehicle (Orion), 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.[10] 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 November 2018 launch readiness date.[11] 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 June 2017, NASA notified Congress of its assessment of the EM-1 schedule. Subsequently, in December 2017, NASA approved a new EM-1 schedule of December 2019 with 6 months schedule reserve to extend the date to June 2020.

We have also reported for several years on the James Webb Space Telescope (JWST) project, which has experienced significant cost increases and schedule delays and has now been replanned twice.[12] Prior to being approved for development, cost estimates for JWST ranged from $1 billion to $3.5 billion, with expected launch dates ranging from

[9]See Related GAO Products at the end of this report.

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

[11]GAO-17-414.

[12]A replan is a process generally driven by changes in program or project cost parameters, such as if development cost growth is 15 percent or more of the estimate in the baseline report or a major milestone is delayed by 6 months or more from the baseline's date. A replan does not require a new project baseline to be established. A rebaseline is a process initiated if the NASA Administrator determines the development cost growth is more than 30 percent of the estimate provided in the baseline of the report, or if other events make a rebaseline appropriate. When the NASA Administrator determines that development cost growth is likely to exceed the development cost estimate by 15 percent or more, or a program milestone is likely to be delayed from the baseline's date by 6 months or more, NASA must submit 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. 51 U.S.C §30104(e)(2)(reporting requirement).

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, 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. Between September 2017 and June 2018, the project's planned launch date was delayed three times, culminating in another independent review and a replan with a new project cost estimate of $9.663 billion and a new launch date of March 2021.

In March 2019, we found that before the JWST project enters its final phase of integration and test, it must conduct a review to determine if it can launch within its cost and schedule commitments.[13] As part of this review, the project is not required to update its joint cost and schedule confidence level analysis, but government and industry cost and schedule experts have found it is a best practice to do so. We recommended that the NASA Administrator should direct the JWST project office to conduct a joint cost and schedule confidence level analysis prior to its system integration review. NASA concurred with the recommendation.

[13]GAO, *James Webb Space Telescope: Opportunity Nears to Provide Additional Assurance That Project Can Meet New Cost and Schedule Commitments,* GAO-19-189 (Washington, D.C.: Mar. 26, 2019).

Affordability of NASA's Portfolio Will Be Strained as Cost and Schedule Performance Continues to Deteriorate and New Projects Begin

The cost and schedule performance of NASA's portfolio of major projects continues to deteriorate. Since we last reported in May 2018, cost growth has increased to 27.6 percent and the average launch delay is approximately 13 months, the largest schedule delay we have ever reported.[14] This deterioration in cost and schedule performance is largely due to the replan of the JWST project as a result of spacecraft integration and test challenges. Cost growth in the past year was further driven by the SLS program, stemming from continued production challenges with the SLS core stage—which functions as the SLS's fuel tank and structural backbone. In its fiscal year 2019 budget request, NASA did not request funding for two major projects yet were proceeding with planned work on them. If Congress continues to fund these projects along with other ongoing major projects, NASA will have to increase its annual funding request for major projects in future years or make other funding trade-offs as part of its annual budget request.

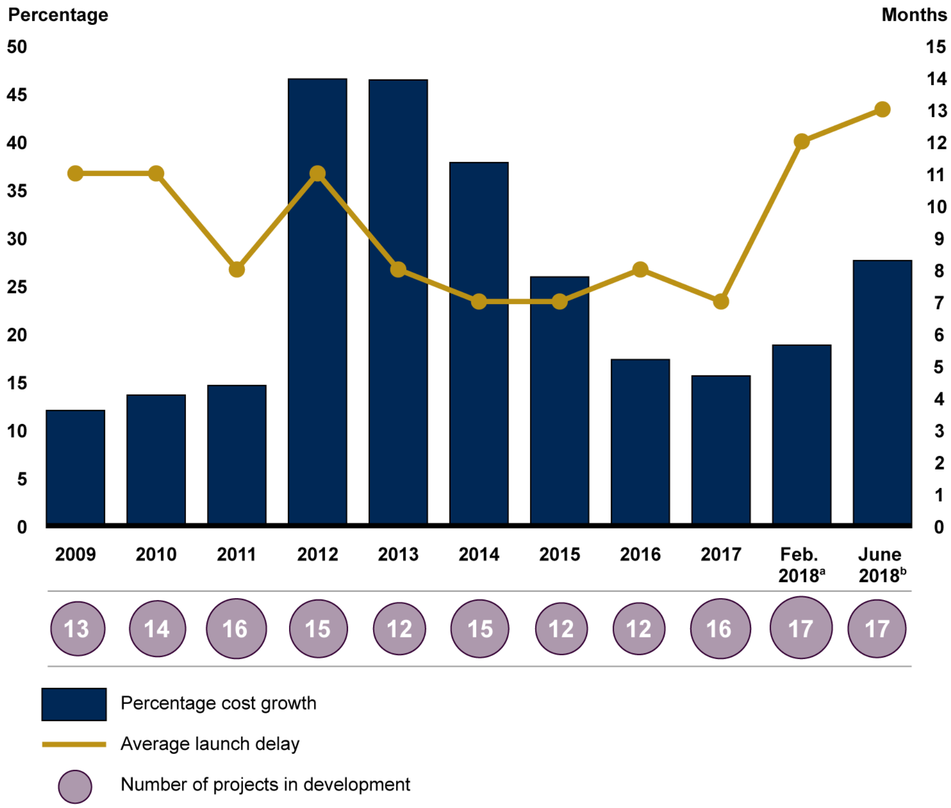
NASA Cost and Schedule Performance Continues to Deteriorate with Further Growth Likely

The cost and schedule performance of NASA's portfolio of major projects continues to deteriorate. Since our last assessment, overall portfolio cost growth was 27.6 percent, up from 18.8 percent.[15] At that time, we also found that 18.8 percent may not represent the total cost growth for the portfolio. This was because the Orion program—one of the largest projects in the portfolio—did not have an updated cost estimate and project officials expected cost growth. In June 2018, the Orion program provided an updated cost estimate, which is included in the analysis in this report. The average launch delay increased to approximately 13 months, up from 12 months since we last reported and is the longest launch delay we have reported since our first assessment in 2009 (see figure 3).

[14] GAO-18-280SP.

[15] GAO-18-280SP.

Figure 3: Development Cost Performance and Average Launch Delay for Major NASA Projects from 2009 through June 2018



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-19-262SP

[a]In February 2018, we were not able to determine the full extent of portfolio cost growth because NASA did not have an updated cost estimate for the Orion program at that time. The June 2018 data reflects the updated estimate.

[b]Data are as of June 2018 with the exception of projects that held decision reviews subsequent to that date but before the end of the calendar year 2018. Those projects include Double Asteroid Redirection Test, Lucy, Low Boom Flight Demonstrator, and Space Network Ground Segment Sustainment. The decision memorandum for Space Network Ground Segment Sustainment received final signatures in February 2019; however, the reviews were held prior to December 2018. In addition, for projects that launched in 2018, we used the final development cost data from the project's Key Decision Point E memorandum, which may have occurred after June 2018.

Cost and schedule performance deteriorated largely due to the most recent replan of the JWST project in response to spacecraft integration and test challenges, among other factors. As we found in March 2019, to develop a new schedule for JWST's replan, NASA took into account the remaining integration and test work and added time to address other potential threats to the schedule, including about 6 months to address an integration and test anomaly that occurred on the spacecraft in 2018.[16] As a result of the replan, the project had a 10-month launch delay beyond the 19-month delay since our last assessment and an $813.8 million cost increase.[17] When JWST is excluded from the above analysis, the average schedule delay was approximately 9 months.

Cost growth since our last assessment was further driven by the SLS program, stemming from continued production challenges with the SLS core stage—which functions as the SLS's fuel tank and structural backbone.[18] According to program officials, Boeing underestimated both the complexity of engine section assembly and the time and manpower that would be needed to complete the effort, which has contributed to cost growth.

In addition to JWST and SLS, four other projects—SGSS, ICON, Mars 2020, and Orion—experienced cost growth since we last reported in May 2018.[19] ICON also experienced a schedule delay. The remaining 11 major projects stayed within cost and schedule estimates since we last reported. Of these projects, Parker Solar Probe, which launched in August 2018, completed technology development having spent approximately $40 million less than its cost baseline. Table 2 provides data on the cost and schedule performance of the 17 major projects in development that have cost and schedule baselines since our last assessment.[20]

[16]GAO-19-189.

[17]GAO-18-280SP.

[18]GAO-18-280SP.

[19]GAO-18-280SP.

[20]GAO-18-280SP.

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

Overall Performance	Project	Confirmation Date Year	Changes between Last GAO Assessment and Current Assessment Cost (millions)	Changes between Last GAO Assessment and Current Assessment Schedule (months)	Cumulative Performance from Original Baseline through June 2018 Cost (millions)	Cumulative Performance from Original Baseline through June 2018 Schedule (months)
Lower than expected cost	PSP[a]	2014	-$35.1	0	-$40.5	0
Within baseline	SWOT	2016	$0.0	0	$0.0	0
	Landsat 9	2017	$0.0	0	$0.0	0
	Lucy	2018	$0.0	0	$0.0	0
	LBFD	2018	$0.0	0	$0.0	0
	DART	2018	$0.0	0	$0.0	0
Higher than expected cost	ICON	2014	$2.2	6	$2.2	14
	Mars 2020	2016	$37.7	0	$48.4	0
	NISAR	2016	$0.0	0	$22.0	0
	Orion (EM-2)	2015	$530.7	0	$379.0	0
Replan[b]	InSight [a]	2014	-$25.2	0	$106.5	26
	EGS (EM-1)	2014	$0.0	0	$421.4	19
	SLS (EM-1)	2014	$880.8	0	$1028.6	19
Rebaseline[b]	JWST	2008	$813.8	10	$4,421.5	81
	ICESat-2[a]	2012	-$28.5	-1	$177.8	16
	SGSS	2013	$167.6	0	$589.2	48
Under revision	LCRD[c]	2017	TBD	0	TBD	0
Total:			**$2344**	**15**	**$7156.1**	**223**

Legend: PSP: Parker Solar Probe; DART: Double Asteroid Redirection Test; SWOT: Surface Water and Ocean Topography; NISAR: NASA Indian Space Research Organisation – Synthetic Aperture Radar; ICON: Ionospheric Connection Explorer; InSight: Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport; LCRD: Laser Communications Relay Demonstration; SLS: Space Launch System; EM-1: Exploration Mission 1; ; ICESat-2: Ice, Cloud, and Land Elevation Satellite-2; EGS: Exploration Ground Systems; SGSS: Space Network Ground Segment Sustainment; EM-2: Exploration Mission 2; JWST: James Webb Space Telescope; Orion: Orion Multi-Purpose Crew Vehicle.

Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-19-262SP

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

NASA provided data to GAO in June 2018, with the exception of projects that held decision reviews subsequent to that date but before the end of the calendar year 2018. Those projects include DART, Lucy, LBFD, and SGSS. The decision memorandum for SGSS received final signatures in February 2019; however, the reviews were held prior to December 2018. In addition, NASA provided an updated cost estimate based on data as of September 2018 for the Space Launch System program. Finally, for projects that launched in 2018, we used the final development cost data from the project's Key Decision Point E memorandum, which may have occurred after June 2018.

[a]InSight, IceSat-2, and Parker Solar Probe projects launched in 2018.

[b]A replan is a process generally driven by changes in program or project cost parameters, such as if development cost growth is 15 percent or more of the estimate in the baseline report or a major milestone is delayed by 6 months or more from the baseline's date. NASA replanned the SLS

program when 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 the NASA Administrator determines that development costs increase by 30 percent or more or if other events make a rebaseline appropriate. When the NASA Administrator determines that development cost growth is likely to exceed the development cost estimate by 15 percent or more, or a program milestone is likely to be delayed from the baseline's date by 6 months or more, NASA must submit 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. 51 U.S.C § 30104(e)(2)(reporting requirement).

[c]LCRD is expected to undergo a replan based on schedule delays from its mission partner.

Beyond JWST and SLS, reasons projects experienced cost increases or schedule delays include the following:

- Mars 2020 experienced cost growth in multiple areas, including new developments such as the Sampling and Caching Subsystem (SCS) that will collect and cache Martian soil and rock samples and the Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals (SHERLOC) that will search for organics and minerals that have been altered by watery environments. SHERLOC and SCS faced technical challenges that resulted in increased costs.
- ICON experienced schedule delays and associated cost growth due to issues with its Pegasus launch vehicle, not with the observatory portion of the project. The project missed its latest launch date due to anomalous telemetry from the launch vehicle. In November 2018, the project convened a Failure Review Board to investigate the anomaly. Project officials noted that the ICON observatory was completed on schedule and within cost. As of December 2018, the program had not rescheduled the launch date.
- The Orion program completed an updated cost estimate, which includes a 5.6 percent development cost increase. Program officials explained that the major drivers of this cost growth were the slip of the EM-1 launch date, which reflected delays in the delivery of the service module; Orion contractor underperformance; and NASA directed scope increases, including purchasing EM-2 avionics. Furthermore, as we found in 2018, NASA officials told us that new hardware and development challenges contributed to increased cost for the program.[21]
- The SGSS project completed a cost estimate through its final acceptance review. As we found last year, NASA had only approved

[21]GAO-18-280SP.

the SGSS project's cost estimate through the initial operational readiness review, currently planned for September 2019.[22] As a result, the $167.6 million increase in table 2 represents the additional costs for the SGSS project for the time between the initial operational readiness review to final acceptance review, which is currently scheduled for November 2020.

We found three challenges in measuring the cost and schedule performance of the portfolio this year. First, the cost growth and schedule delays are likely an underestimate for the portfolio for two reasons.

- The LCRD instrument is a hosted payload on an Air Force Space Test Program mission, and NASA is assessing the impact of continued delays with the spacecraft bus to LCRD's cost and schedule. According to officials, the contractor—with whom the Air Force holds the contractual relationship—has experienced technical challenges refurbishing the existing spacecraft bus to meet the requirements of one of the other, non-NASA payloads. The full extent of the delay and cost increases will not be known until the Air Force provides the LCRD project with the contractor's updated schedule and finalizes a new cost-sharing agreement with its mission partners. At that time, the LCRD project will be able to complete a new estimate of its schedule and associated costs.
- Although the Orion project provided a revised cost estimate in June 2018, this cost estimate assumes a launch date of September 2022, which is 7 months earlier than the program's baseline date of April 2023—the commitment date between NASA, Congress and OMB. Subsequently, program officials told us that its cost projections fund one of those seven months. However, the estimate is still not complete as it does not account for all costs that NASA would incur if the program executes to its committed baseline date of April 2023. We continue to follow up with NASA on this through other ongoing work.

Second, the human spaceflight programs continue to experience challenges executing to cost and schedule commitments but the extent of those challenges are not yet captured in our assessment. In November 2018—within 1 year of announcing a delay for the first mission—senior NASA officials acknowledged that the revised June 2020 launch date is unlikely. These officials told us that there are 6 to 12 months of risk associated with this date. This means that additional delays beyond the

[22] GAO-18-280SP.

19 months of delays captured in our analysis for SLS and ground systems are likely.

Finally, the SLS and EGS projects are performing development work for missions beyond EM-1 that is not captured in the portfolio analysis because NASA has not established baselines for those efforts. We cannot assess cost and schedule performance as part of our portfolio analysis until NASA establishes baselines for these efforts. To that end, we have made recommendations in the past on the need for NASA to baseline the programs' costs for capabilities beyond the first mission; however, a significant amount of time has passed without NASA taking steps to fully implement these recommendations. For example, in May 2014, we recommended that because NASA intends to use increased capabilities of the SLS, Orion, and ground support efforts well into the future, that it should establish baselines for those efforts.[23] NASA partially agreed with the recommendation but has not taken action. In our February 2019 high-risk report, we reported that the agency has not taken action on several recommendations related to understanding the long-term costs of its human exploration programs.[24] Further, we found there was a lack of transparency in major project cost and schedules, especially for the human spaceflight programs. As we noted in the high risk report, without transparency into these estimates, both NASA and Congress have limited data to inform decision making.[25]

NASA Will Continue to be Challenged to Budget for Planned Major Projects Given Competing Priorities

In its fiscal year 2019 budget request, NASA did not request funding for two major projects—WFIRST and PACE—but was proceeding with planned work on these projects while waiting for a final appropriation decision. The two projects together will require almost $3 billion over the next five years, according to NASA documents. Further, in May 2018, NASA reported selecting the Interstellar Mapping and Acceleration Probe project to begin formulation and implementation with a life-cycle cost cap of $565 million, which was not yet categorized as a major project in NASA's fiscal year 2019 budget request.

[23]GAO, *NASA: Actions Needed to Improve Transparency and Assess Long-Term Affordability of Human Exploration Programs*, GAO-14-385 (Washington, D.C.: May 8, 2014).

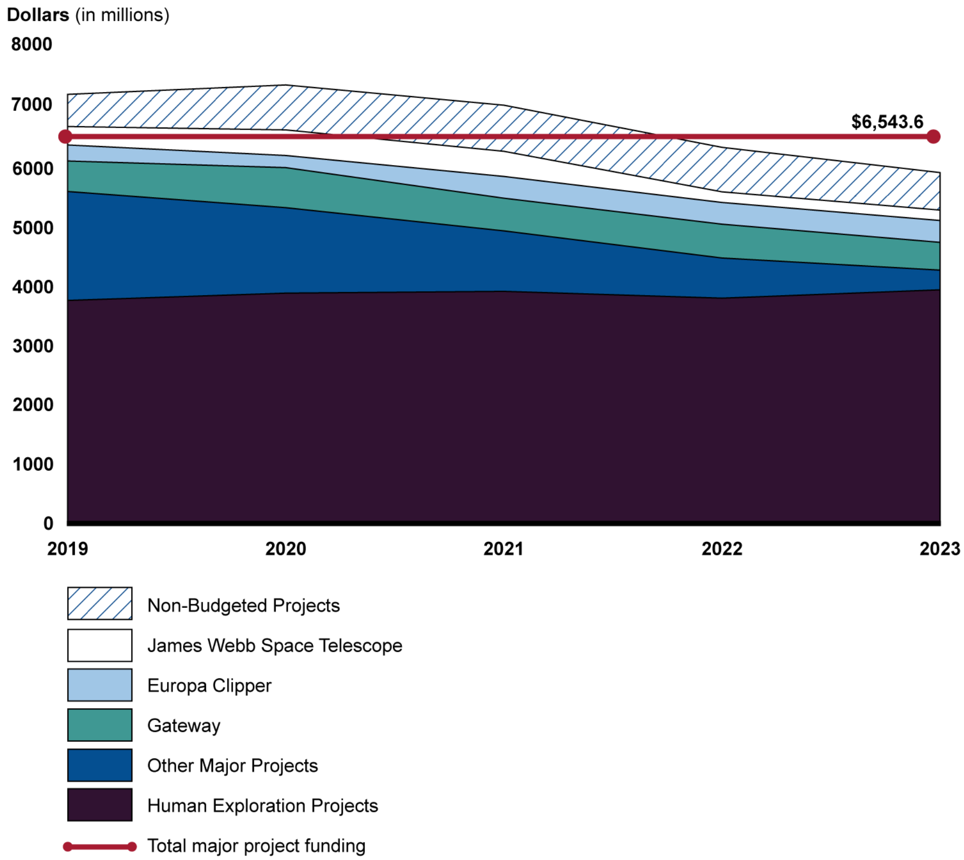
[24]GAO-19-157SP.

[25]GAO-19-157SP.

Continuing these efforts along with other ongoing major projects—including funding for a new Gateway that NASA envisions as a staging point for missions to the Moon and deep space—will result in NASA having to either increase its annual funding request for major projects or continue to make funding trades between projects as part of the annual budget request. For example, in its fiscal year 2020 budget request, NASA again did not request funding for WFIRST and PACE. Agency officials stated that they have difficulty managing the portfolio of major projects—particularly in conducting longer range planning—with continuing funding uncertainties. Further, officials stated that they receive direction from Congress to fund certain projects that may not be in the agency's longer-range planning. We have previously found that the agency has faced difficulties in executing its plans due to budget uncertainty.[26] As seen in figure 4, assuming NASA's future budget requests align with its budget request for fiscal year 2019, NASA's potential commitments exceed its topline major-project budget until fiscal year 2022, when a minimal wedge of available funding—approximately $344 million— for new requests begins to open up.

[26]GAO, *NASA: Assessments of Major Projects*, GAO-14-338SP (Washington, D.C.: Apr. 15, 2014).

Figure 4: Five-Year Budget Profile for NASA Major Projects Assuming a Flat Budget (Fiscal Years 2019-2023)



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-19-262SP

As the figure illustrates, NASA is currently managing a portfolio of programs that costs more than what its planned annual budget request can support, and this trend will continue, assuming its budget requests stay on the same trajectory. Our previous work on Department of Defense acquisitions shows that when agencies commit to more programs than resources can support, unhealthy competition for funding is created among programs. This situation can lead to inefficient funding adjustments, such as moving money from one program to another or deferring costs to the future.[27] We have also found similar conditions at the Coast Guard. In July 2018, we found that the Coast Guard's funding plans over the next 5 years for its portfolio of major acquisitions exceeds average budget requests in the last several years.[28] To address funding constraints, the Coast Guard has been in a reactive mode by making prioritization decisions through the annual budget process without identifying how trade-off decisions made in the current budget cycle will affect the future of the acquisition portfolio. As a result, the Coast Guard has continued to defer planned acquisitions to future years and left a number of operations capability gaps unaddressed that could affect future operations.

NASA might also find the available funding in the out years could quickly be consumed by additional demands in funding. This would exacerbate the amount of time that NASA will continue to operate in its current predicament, where its typical level of budget request does not support the number of projects in its portfolio. Examples of possible demands for that future funding include the following:

- **Cost growth to existing large projects:** 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.[29] The current portfolio of major projects includes six projects in that phase, meaning these projects are at risk of future cost growth or schedule delays. Further, some major projects will soon set cost and schedule baselines that may exceed preliminary estimates, requiring more funding than originally envisioned. For example, the Europa Clipper project planned to hold its confirmation review and set cost and schedule baselines in October 2018 following its preliminary design review; however, due to ongoing design challenges, the project now plans to hold the review in fall 2019. The project indicated in a cost exercise in preparation for its confirmation

[27]GAO, *DOD Acquisition Outcomes: A Case for Change*, GAO-06-257T (Washington, D.C.: Nov. 15, 2005); *Space Acquisitions: DOD Needs to Take More Action to Address Unrealistic Initial Cost Estimates of Space Systems,* GAO-07-96 (Washington, D.C.: Nov. 17, 2006); and *Defense Acquisitions: A Knowledge-Based Funding Approach Could Improve Major Weapon System Program Outcomes*, GAO-08-619 (Washington, D.C.: July 2, 2008).

[28]GAO, Coast Guard Acquisitions: Actions Needed to Address Longstanding Portfolio Management Challenges. GAO-18-454 (Washington, D.C.: July 24, 2018).

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

review that its costs would increase above preliminary estimates. Project officials explained that the expected cost increase is the result of conducting a more detailed cost estimate.

- **New lunar efforts:** The proposed fiscal year 2019 budget for the Gateway project already accounts for over $2.7 billion, or about 9 percent of NASA's major-project budget, over the next 5 years. The proposed budget for lunar efforts in addition to Gateway is more than $3 billion over the next 5 years, which officials indicated may include several new major projects with life-cycle costs over $250 million.
- **New projects joining the portfolio:** The $6.5 billion flat budget line illustrated in figure 4 does not include funding for new projects or projects that have not yet been proposed. For example, the latest decadal survey for astronomy and astrophysics, conducted by the National Research Council in 2010 to identify priorities for the agency over the next 10 years, proposes a gravity-wave observatory that would detect the mergers of black holes, among other objectives. With a proposed 50 percent cost-share between NASA and the European Space Agency, the project is estimated to cost NASA $1.5 billion over 9.5 years. NASA officials agreed that the future budget is unlikely to support the $1.5 billion estimated cost for the above project, or about $750 million for the agency's share of the project. As a result, NASA officials stated they are only planning to spend $400 million over the next decade for the project, which NASA stated can be accommodated within its major project portfolio. Further, NASA officials stated that demand on future funding could be mitigated because the agency includes projected funding in its budget for future missions. This projected funding is not reflected in the $6.5 billion flat budget line illustrated in the figure above. However, this planned funding may be budgeted to other agency priorities until new projects are confirmed and later appropriated funding through the budget process.

Subjectivity in Identifying and Assessing Critical Technologies Could Understate Risk

Subjectivity in the processes NASA uses to identify and assess critical technologies could understate the development risk that its major projects face. The average number of critical technologies NASA reported increased slightly when comparing data from January 2018 to December 2018 because two of the new projects in the portfolio reported one or more critical technologies. However, the number remains low compared to data we collected in 2009 and 2010. While this decline may be an indication that recent projects are taking on less technology risk than their predecessors, we also found inconsistencies in the portfolio on how projects identify critical technologies, and these inconsistencies may affect comparisons. A study completed by NASA in 2016 also found subjectivity in how projects identify critical technologies. This study team also reported that projects may interpret technology readiness levels differently because guidance and definitions are spread throughout several documents. Most of NASA's major projects in development reported that they matured their technologies to the level recommended by best practices by their preliminary design review—continuing a trend since 2013. 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.

NASA Projects Continue to Report Lower Numbers of Critical Technologies than Prior Years, but NASA Plans to Address Inconsistent Identification

Complex acquisition efforts require the development of cutting-edge technologies and their integration into large and complex systems; NASA refers to such technologies as critical or new technologies. Such acquisition efforts may also use existing technologies, but in new applications or environments, which NASA refers to as heritage technologies. Our product development best practices do not make this distinction. We generally describe critical technologies as those that are required for the project to successfully meet customer requirements, which can include both existing and new technology. Further, according to GAO's Technology Readiness Assessment Guide, heritage technologies can become critical if being used in a different form, fit, or function.[30] Additionally, the Guide notes that determining a technology is not critical is problematic when technologies are being applied in a different operational environment, particularly when used in a novel way.

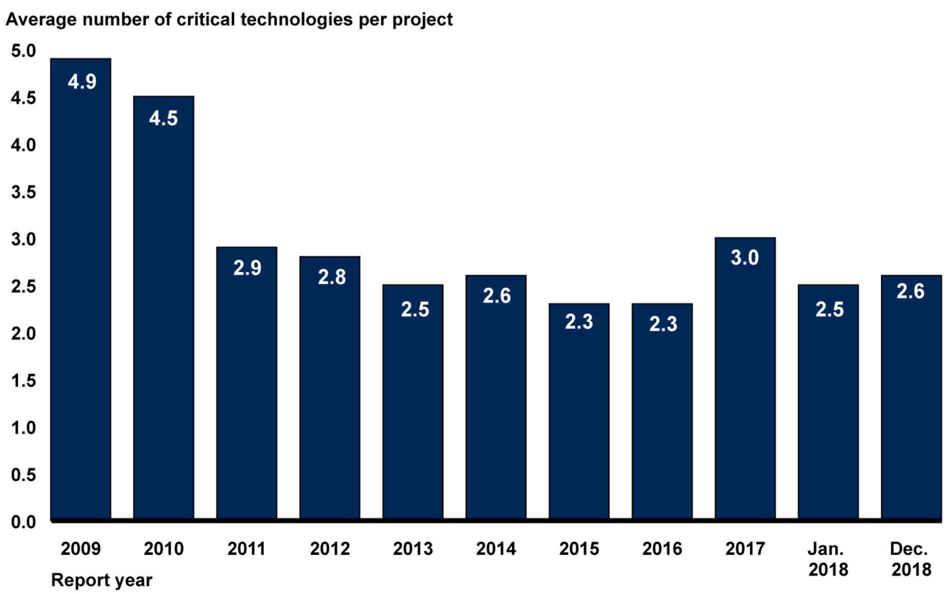
According to GAO's Technology Readiness Assessment Guide, critical technologies must be identified to achieve a comprehensive evaluation of technological risk. Failing to identify all critical technologies, including those with which there is prior experience but which the project plans to use in a new or novel manner, increases risk of overruns in cost and schedules and performance shortfalls. While underreporting technical risks can hinder decision makers' full understanding of a project's progress, correctly identifying critical technologies may better position the government to have realistic discussions about how to mitigate potential risks. For example, NASA projects are required to document new technologies as part of the project's Formulation Agreement, which establishes the technical and acquisition work to be conducted during the

[30] GAO-16-410G.

formulation phase and defines schedule and funding requirements for that work. Further, projects' independent standing review boards determine whether projects' new technologies are developed to an adequate state of readiness, or back-up options are identified, in order to successfully complete preliminary design reviews. If projects do not comprehensively identify critical technologies, NASA loses insight at key decision reviews about potential cost and schedule impacts if there are risks associated with the maturity of those technologies.

Over the past 8 years, projects have self-reported 3 or fewer critical technologies on average. This represents a marked decrease from the 4.9 and 4.5 average numbers of critical technologies reported in 2009 and 2010 respectively (see figure 5).

Figure 5: Average Number of Critical Technologies Reported by NASA's Major Projects in Development from 2009 through December 2018



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-19-262SP

Note: Includes all projects that held both a preliminary design review (PDR) and project confirmation by December 2018, except for the Restore-L project. The Restore-L project held PDR by this timeframe, but has continued to delay its confirmation review.

The 17 projects in the current portfolio that were in development as of December 2018 reported an average of 2.6 critical technologies, a slight increase compared to last year's average of 2.5 critical technologies. We removed three projects from our analysis because two of them—Gravity Recovery And Climate Experiment-Follow On (GRACE-FO) and

Transiting Exoplanet Survey Satellite (TESS)—launched in 2018 and the third, Radiation Budget Instrument (RBI), was canceled that same year. Of these three, RBI had reported having 3 critical technologies while GRACE-FO and TESS both reported having zero. We added three projects—DART, LBFD, and Lucy—that were in development as of December 2018. Of the three, DART and LBFD reported three and one critical technologies respectively, while Lucy reported zero.

We have previously observed that the decline in the average number of critical technologies from 2009 and 2010 may be an indication that recent projects are taking on less technology risk than their predecessors by incorporating fewer new critical technologies into their design.[31] While this may still be the case, our analysis also found that inconsistencies in how projects across the portfolio identify critical technologies have the potential to affect a comparison of the average number of technologies from year to year.

For example, the Lucy project determined that increasing the size of its solar array and operating it in a previously unexplored environment did not warrant identifying the solar array as a critical technology. In contrast, the ICON project reported that its interferometer is a critical technology because it is being used in a different application, even though it is not a new technology. In addition, the Europa Clipper project identified no critical technologies, but many of the project's nine heritage technologies require modifications to meet mission requirements. Europa Clipper project officials explained that they classified some of those heritage technologies as "new," in part because they will operate in a new or novel environment, but do not use the terminology "critical." Though the technologies were identified as heritage, the Lucy and Europa Clipper projects will have development work to adapt the technologies for their purposes. While not all heritage technologies that require development work should be identified as critical, these examples illustrate the subjectivity that exists in making these decisions.

In 2016, a NASA technology readiness assessment study team—made up of 19 senior and experienced managers in the fields of systems development and technology selection—found that the identification of critical technologies is subject to interpretation across centers and

[31]GAO, *NASA: Assessments of Selected Large-Scale Projects*, GAO-13-276SP (Washington, D.C.: Apr. 17 2013).

projects. The team found that this was due, in part, to a lack of clear technology definitions, including what qualifies as a critical technology. For example, it found a lack of consistency in determining what should be considered new or heritage technology as opposed to what is standard engineering development. The study team defines standard engineering development as slight modifications to technologies, as long as the modification is within the technology's original design intention or demonstrated capability. The study team further stated that correctly identifying technologies allows projects to better understand cost and schedule impacts of new technology risk and to plan with more confidence.

In December 2018, NASA established a corrective action plan in order to address recent cost and schedule growth experienced by several high-profile missions as well as NASA's inclusion on GAO's High Risk list. In response to a recommendation made by the study team, one of the initiatives that NASA plans to implement is to create a Technology Readiness Assessment Best Practices Document. This document is intended to capture the technology readiness assessment information that is scattered throughout the agency, provide links to governing documents, and document best practices across the agency. If further study team recommendations are implemented as part of this document, the document would include adding a step in the technology readiness assessment process to classify technology as either new, engineering, or heritage, and providing guidance on the use of critical technology. We will continue to monitor NASA's efforts in this area.

GAO Assessment of NASA's Process to Identify Critical Technologies for the Europa Clipper Project

To get a better sense of how NASA identifies critical technologies, we compared the Europa Clipper project's process to the best practices in GAO's Technology Readiness Assessment Guide.[a] We found that the Europa Clipper project's process for identifying critical technologies had both strengths and weaknesses. With respect to strengths, the project did consider the technologies' operational environments and whether the application of existing technologies was new or novel. For example, the project identified the Mapping Imaging Spectrometer for Europa cryocooler technology as "new" because its performance had not been demonstrated for the Europa mission radiation environment, among other things.

The Europa Clipper project, however, did not demonstrate that it used a rigorous, objective, reliable, and documented approach based on a work breakdown structure—which can be thought of as an illustration of the work that will satisfy a program's requirements—or other key program documents to initially identify critical technology candidates or why some technologies were selected and others were not. For example, though project officials told us that they identified new technologies in instrument proposals and early assessments, they did not provide documentation of these proposals and assessments, and we were therefore unable to confirm how this occurred. Further, using instrument proposals alone would not have been sufficient to ensure that all of the project's technologies were considered when determining the project's new technologies. For example, instrument proposals would not have included technology related to the spacecraft, if applicable. Project officials told us that spacecraft subsystems generally would not include critical technologies, but agreed that the process for determining that for Europa Clipper was not documented.

Additionally, though officials said they used a flow chart with clear criteria to determine if a technology was new, engineering development, or heritage, the project did not provide documentation to show if or how this process was carried out for the various technologies. They also told us that as more information became available in the course of the project's evaluation process, some technologies initially identified as new, such as the Europa Imaging System detector, were reclassified as engineering development. However, officials did not provide documentation or further explanation of how or why this change occurred. A best practice is to annotate a work breakdown structure, or a logical alternative such as a program risk register, and then list critical technologies with the reasons why other technologies were not selected. This allows anyone who participates in the technology readiness assessment to see an account of how the critical technologies were systematically determined rather than through an undocumented or arbitrary selection process.

[a]GAO, *GAO Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects – Exposure Draft*, GAO-16-410G (Washington, D.C.: Aug. 11, 2016).

NASA Projects Reported Generally Maintaining Technology Maturity, but NASA Has Identified Steps That Could Address Differing Assessments of Technology Readiness Levels

We found that most of NASA's major projects in development—10 of 16 projects—met the best practice of maturing all technologies to a technology readiness level 6 by their preliminary design review, which is generally consistent with the past several years. We did not include the LBFD project, which is a flight demonstration, because the project does not intend to mature its technologies until it reaches the operations phase. 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.[32]

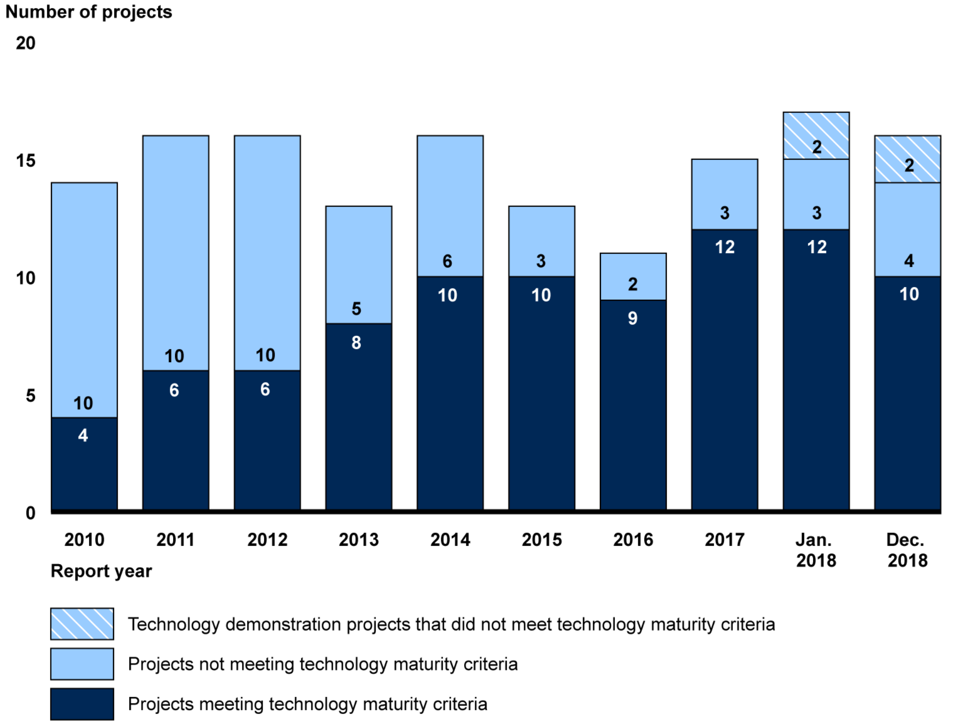
We have previously reported that allowing technology development to carry over into product development increases the risk that significant problems will be discovered late in development. Addressing such problems may require more time, money, and effort to fix because they may require more extensive retrofitting and redesign as well as retesting.[33] Figure 6 depicts NASA's major projects in development, including two technology demonstration projects that did not meet the best practice. The LCRD and Restore-L projects are technology demonstration projects managed by Goddard Space Flight Center, whose policy does not require technology demonstrations to mature all of their technologies to technology readiness level 6 by preliminary design review.[34] 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. Appendix IV provides a description of technology readiness levels, which are the metrics used to assess technology maturity.

[32]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.

[33]GAO, *Defense Acquisitions: Improvements Needed in Space Systems Acquisition Management Policy,*GAO-03-1073 (Washington, D.C.: Sept. 15, 2003).

[34]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.

Figure 6: Number of NASA's Major Projects Attaining Technology Maturity by Preliminary Design Review from 2010 through December 2018



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-19-262SP

Note: Includes projects that completed preliminary design review and identified critical or heritage technologies. By the end of 2018, 17 of 24 NASA major projects had held this review and identified critical or heritage technologies. However, this analysis does not include the LBFD project, as it is a flight demonstration project that does not intend to reach maturity until the operations phase.

Of the two projects we added to our technology maturity analysis this year—DART and Lucy—only Lucy matured its technologies to a technology readiness level 6. The DART project matured six of seven technologies; however, NASA's Evolutionary Xenon Thruster-Commercial (NEXT-C) technology, which is managed outside of the DART project, did not reach technology readiness level 6 by the time of the project preliminary design review in April 2018.[35] Of the six projects that did not

[35]NEXT-C is a project managed at Glenn Research Center under the Discovery Program and will provide electric propulsion for DART. The DART mission will be the first time this technology will fly operationally and, if successful, serve as qualification for future deep space missions. However, the NEXT-C team was unable to fully mature the thruster's propulsion processing unit prior to DART's preliminary design review, which had been delayed 2 months to allow for more time to mature the NEXT-C technology.

meet the best practice, two—LCRD and Mars 2020—had technologies identified by the project as heritage and critical, and two—JWST and Restore-L—had only heritage technologies that were not matured to a technology readiness level 6 by the preliminary design review.

In addition to a lack of clear technology definitions, the NASA study team we discussed above also found different interpretations of technology readiness levels used across different projects. The study team found this was due in part to minimal guidance spread across four documents that did not reference each other. The team also found that technology is often estimated to be at a higher level of maturity than it actually is, as the assessments are frequently self-performed by the project and are not always independently validated. As a result, officials may lack a true understanding of technology risks and their impacts on the project, which in turn can lead to cost and schedule growth.

We found one instance where a project may not have fully considered the implications of not having yet demonstrated components as an integrated system when assessing maturity levels. The LCRD project rated its lunar laser communications demonstration technology at a technology readiness level 9 based on the maturity of its individual components. However, technology readiness level 9 is defined as "actual system has been proven in successful mission operations," and the LCRD technology had not yet been demonstrated as an integrated system. NASA policy includes the "weakest link" concept, in which the maturity of the system can be determined by the technology readiness level of its least mature component. According to the NASA study team report, though, the correct interpretation of the "weakest link" concept is that while the system can be rated no higher than the technology readiness level of its least mature component, the difficulty of integration must also be taken into account when determining the maturity of the system. As a result, the maturity of the total system may be lower than the maturity of the least mature component. While we acknowledge the use of "weakest link" in determining the technology readiness level of the system as a whole, our analysis indicates that the project initially did not take into account possible difficulties during integration of the components. However, project officials later acknowledged that a technology readiness level of 6 would have been more appropriate. Officials stated that one component of the technology could have been accurately assessed as a technology readiness level 9; however, two others had not yet been demonstrated operationally.

NASA is taking steps to address some of the concerns that both we and the study team highlighted in this area through its December 2018 corrective action plan initiative to create a Technology Readiness Assessment Best Practices Document. As the study team recommended in its report, this document will consolidate processes, guidance, and best practices that are currently scattered throughout the agency into a single reference source, as well as provide links to governing documents. Based on further recommendations from the study team, this best practices document could also include an updated technology readiness levels table in order to increase consistency and reduce ambiguity. We will continue to monitor NASA's efforts in this area.

GAO Assessment of NASA's Process to Evaluate Critical Technologies for the Europa Clipper Project

To get a better sense of how NASA evaluates critical technologies, we compared the Europa Clipper project's process to the best practices in GAO's Technology Readiness Assessment Guide.[a] We found that the Europa Clipper project's process for evaluating critical technologies was generally stronger than its process for identifying critical technologies. For example, the project determined consistent definitions of the technology readiness levels and the evidence needed to achieve the designated category before the assessment. In addition, the assessment team interviewed testing officials to determine whether the test results and testing environment were sufficient and acceptable.

However, the project did not provide documentation of all pertinent information related to the analysis, such as how the starting technology readiness levels for any of the project's new technologies were determined. Some technologies were assigned a specific technology readiness level near the beginning of the project, while others were evaluated as simply "less than 6." As a result, the credibility of the assigned technology readiness levels is decreased. According to project officials, completion of the necessary tests to achieve technology readiness level 6 is more relevant than the starting technology readiness level. GAO's *Technology Readiness Assessment Guide* states that having the necessary information is important so that the assessment team can make a credible determination of the technology readiness level from the supporting documentation.

[a]GAO, GAO Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects – Exposure Draft, GAO-16-410G (Washington, D.C.: Aug. 11, 2016).

NASA Has Maintained Improvements in Design Stability at Key Design Review, but Most Projects Continue to Experience Changes after That Review

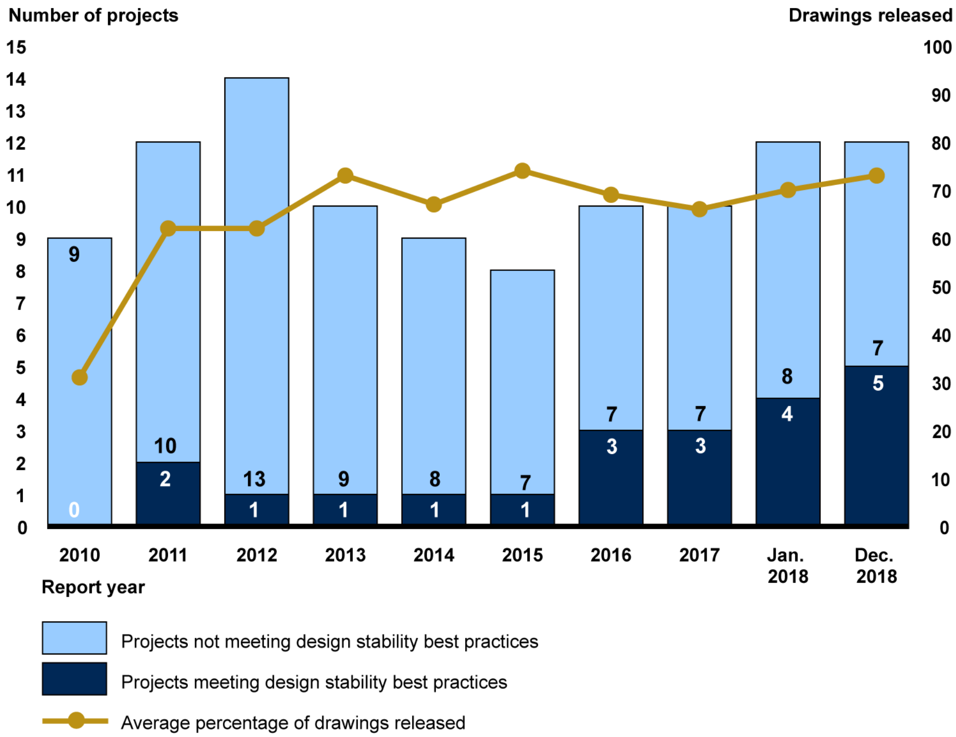
Most projects have not demonstrated a stable design at the project's critical design review, but more are doing so now than several years ago. In addition, the average percentage of released drawings for the portfolio has remained generally consistent with the past 5 years. Our work on product development best practices shows that releasing at least 90 percent of engineering drawings by the time of the critical design review lowers the risk of projects experiencing design changes and manufacturing problems that can lead to cost and schedule growth. Further, many of NASA's major projects—including several of those that did not demonstrate a stable design at critical design review—continue to experience late design changes. Design changes after the critical design review can be costly to the project in terms of time and funding because hardware may need to be reengineered or reworked as a result.

NASA Has Maintained Improvements in the Number of Projects with Stable Design

NASA has maintained the number of projects with stable designs at critical design review, but most projects still do not meet the best practice. The critical design review is the time in the project's life cycle when NASA assesses the integrity of the project design and its ability to meet mission requirements. 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 manufacturing problems and 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 before December 2018, only five met the best practice of releasing 90 percent of their current projected engineering drawings by the time of the review (see figure 7). This is an improvement over the past 8 years. In addition, the average percentage of released drawings for the portfolio at critical design review is 73 percent, which has remained generally consistent with the past 5 years.

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



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-19-262SP

Since we last reported, we added three projects and removed three projects from our analysis.[36] All three projects we added to the analysis—Landsat 9, NISAR, and SWOT—met the best practice for percentage of engineering drawings released at critical design review. Two projects—GRACE-FO and TESS—launched last year and were removed from our analysis of design drawings. A third project—RBI—was canceled. Of these three projects, two—GRACE-FO and RBI—had met the best practice and one, TESS, had not.

Similar to our previous report, five of the seven projects that did not meet the best practice released fewer than 60 percent of engineering drawings

[36]GAO-18-280SP.

by critical design review.[37] For example, we found that Orion held its critical design review in October 2015 with only 53 percent of its current expected design drawings released, significantly lower than the best practice of 90 percent. Orion did not release 90 percent of its expected drawings until 2017, about two years after its critical design review.

The average percentage of design drawings released by critical design review may increase in the future, as the two projects that currently have the lowest percentages of releasable drawings, PSP and InSight, with 31 and 51 percent of drawings released respectively, launched in 2018 and will be exiting the portfolio next year.

NASA Design Drawing Growth Is Relatively Steady, but Late Design Drawing Growth Still Occurs

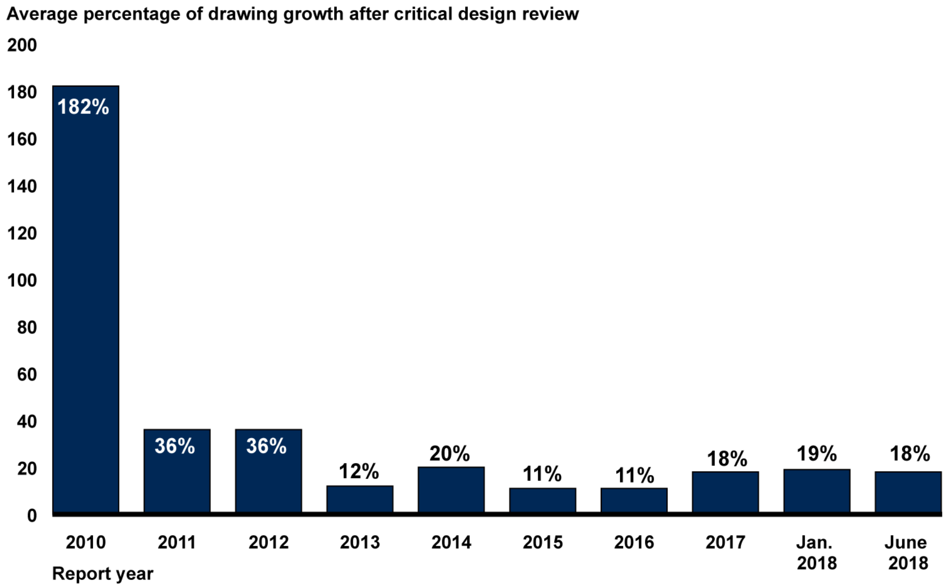
The number of design drawings projects expected at their respective critical design reviews compared to the updated number of design drawings projects expected as reported in data received by GAO each year—referred to as design drawing growth—has remained relatively steady. However, some projects continue to experience late growth. If a project experiences a large amount of engineering 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 re-engineered or reworked as a result.

The average percentage of drawing growth for projects past critical design review decreased slightly, from 19 percent to 18 percent (see figure 8). Of the 11 projects included in this year's analysis, 9 experienced design drawing growth after their critical design review, ranging from 1 to 52 percent. This is an improvement from last year, when 11 out of 12 projects experienced design drawing growth. Further, 6 of 8 of the projects that did not meet the best practice of releasing 90 percent of their design drawings by critical design review then had late design drawing growth of 15 percent or higher.[38] The projects that had the most late drawing growth—JWST and InSight—were among the projects that had released the lowest percentage of drawings prior to the critical design review, at 56 and 51 percent respectively. This analysis also removed the GRACE-FO, RBI, and TESS projects for reasons discussed above.

[37] GAO-18-280SP.

[38] We did not collect drawing growth data on the NISAR project since it held critical design review after our data collection ended for this particular analysis.

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



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-19-262SP

Notes: 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.

The NISAR project is not included in the above analysis because it held its critical design review in October 2018.

Three of the projects in the portfolio—Mars 2020, Orion, and LCRD—have experienced design drawing growth ranging from 1 to 8 percent since last year's report. For example, Mars 2020 experienced drawing growth related to the Sample and Caching Subsystem and mechanical subsystems. This is an area that we will continue to monitor as part of our annual assessments.

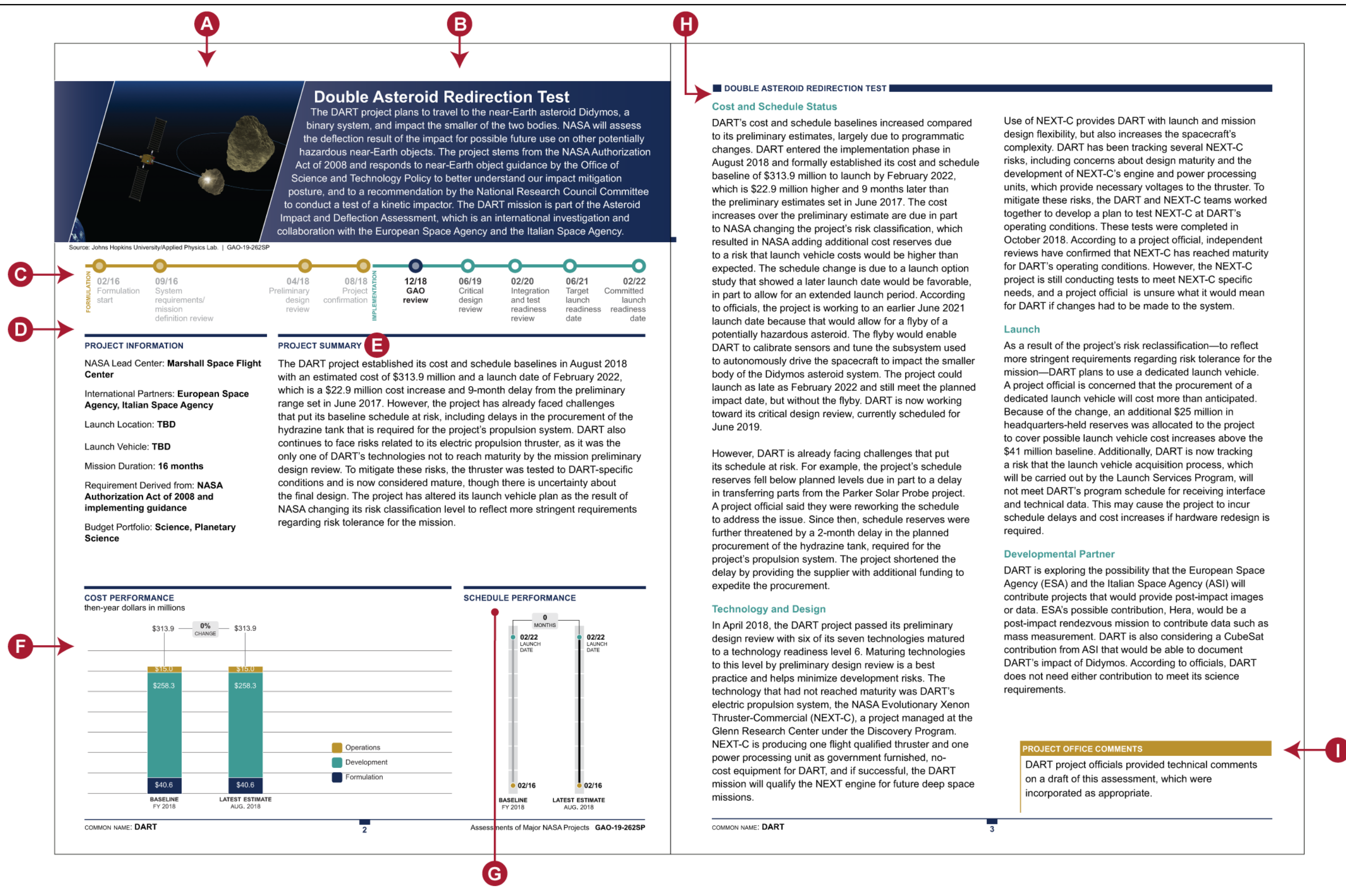
Project Assessments

In the following section, we summarize the individual assessments of the 21 projects we reviewed in a two-page or one-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, and a brief narrative describing the current status of the project.[39] Nineteen assessments describe the challenges we identified, as well as challenges that we have identified in the past. 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. Two of the assessments do not provide an in-depth review of program challenges because the projects had few, if any, challenges to report. The information presented in these assessments was obtained from NASA documentation, answers to our questionnaire by NASA officials, interviews with project staff, and includes our analysis of project cost and schedule information. 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 9 for an illustration of a sample assessment layout.

[39]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 9: Illustration of a Sample Project Assessment



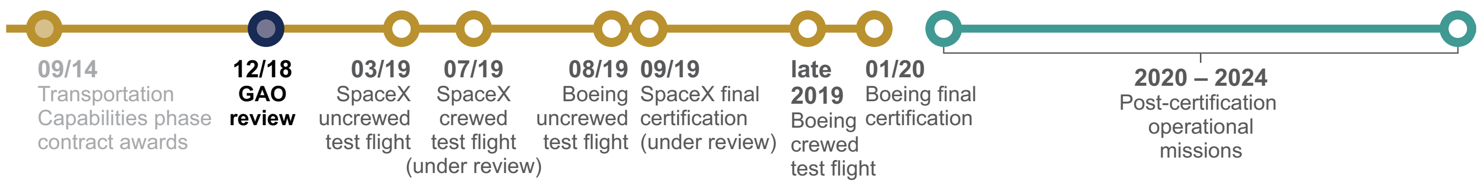
- **A** Illustration of the spacecraft, instrument, aircraft, launch vehicle, or ground system.
- **B** General description of the mission's objectives.
- **C** Timeline identifying key dates for the project including when the project began formulation, held major design reviews, began implementation, 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** **Cost:** For projects in formulation, the preliminary cost estimate. For projects in implementation, the approved cost baseline and latest estimate.
- **G** **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.
- **H** 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.
- **I** **Project Office Comments:** General comments provided by the cognizant project office.

Source: GAO analysis. | GAO-19-262SP

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 the ISS.

Source: NASA. | GAO-19-262SP



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: **Low Earth Orbit and Spaceflight Operations, Space Transportation**

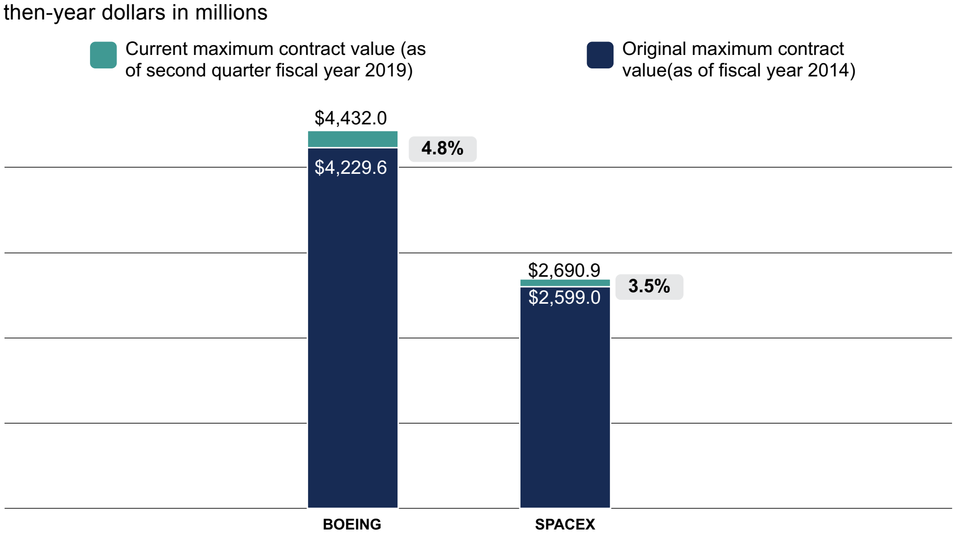
[a]Blue Origin and Sierra Nevada Corporation do not have contracts for the current phase and therefore were not included in this assessment.

PROJECT SUMMARY

Both of the Commercial Crew Program's contractors have made progress developing and testing their crew transportation systems. However, each continues to experience schedule delays. Both contractors' test flights have slipped to 2019 while the final certification reviews have been delayed. Given concerns that additional program delays could lead to a gap in access to the ISS, NASA announced that it planned to buy two additional seats on the Russian Soyuz to allow for a U.S. crew presence on the ISS through September 2020. Additionally, both contractors continue to work through crew transportation system design issues. Specifically, the program is tracking risks related to each contractor's parachute systems and launch vehicle engines. Lastly, both contractors have modified their original plans to submit evidence verifying that they have met Commercial Crew Program requirements. These new plans have deferred submitting verification evidence from the uncrewed test flight to the crewed test flight, which could add additional risk to the program's schedule.

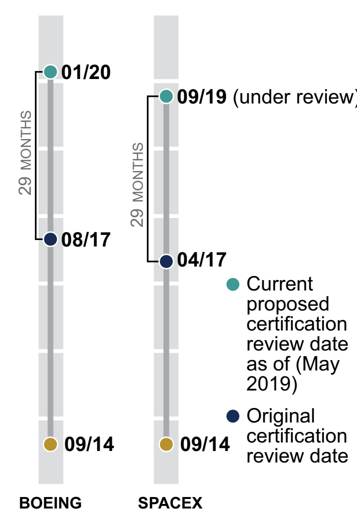
COST PERFORMANCE[b]

then-year dollars in millions



[b]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 and testing their crew transportation systems, including the March 2019 SpaceX uncrewed test flight. A SpaceX official told us this test flight significantly reduced its schedule risk. However, each contractor continues to experience schedule delays to final certification, a process that the program uses to ensure that each system meets its requirements for human spaceflight. In July 2018, we found that Boeing expected NASA to certify its crew transportation system in January 2019 while SpaceX planned on reaching this milestone in February 2019[1]. Since that report, both contractors have further delayed certification: Boeing has delayed the milestone an additional twelve months to January 2020 and SpaceX has delayed the milestone an additional 7 months to September 2019, though that date is under review. NASA noted that much work remains, and cautioned that these schedules may change as the contractors prepare for test flights. In February 2019, given concerns that additional program delays could lead to a gap in access to the ISS, NASA announced that it planned to buy two additional seats on the Russian Soyuz to allow for a U.S. presence on the ISS through September 2020.

Design

Both contractors have faced challenges completing parachute system qualification testing that could further delay certification. In August 2018, both contractors' parachute systems experienced anomalies during qualification testing. In both instances, the program is working with the contractor to investigate the causes of the anomalies. SpaceX's parachute system sustained unexpected damage. SpaceX modified the design and according to a SpaceX official, completed two additional tests in January 2019. The program approved the new design for the uncrewed test flight. For Boeing, a device intended to help the crew capsule land on an optimum angle failed to deploy, but a Boeing official told us that the main test objectives were met. Boeing continues to investigate its anomaly, and has remanufactured the failed part to support the remaining qualification testing. The program estimates that the total work needed to address these risks may affect the schedule of the crewed test flight for both SpaceX and Boeing.

The program is also tracking risks associated with each contractor's launch vehicle engines, which could delay test flights. For Boeing, the launch vehicle engine position during ascent deviated from commands for a 2018 launch, but the launch vehicle provider stated that it achieved all mission objectives. The program has insight into the launch vehicle manufacturer's ongoing investigation. A set of corrective actions will be implemented for the uncrewed flight test. The program estimates that the time needed to resolve this risk could delay Boeing's uncrewed test flight. For SpaceX, NASA is continuing to assess a risk where SpaceX's launch vehicle engines' design had previously resulted in turbine cracking. To mitigate the turbine cracking risk, SpaceX conducted additional qualification testing and developed an operational strategy that, to date, resulted in no cracks. The program has accepted this operational strategy for the uncrewed test flight, and continues to work with SpaceX on a final resolution for the crewed test flight.

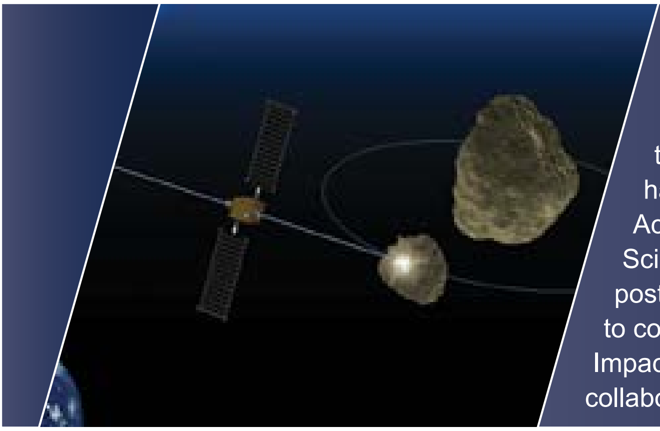
Other Issues to Be Monitored

The contractors' plans to defer final submission of some verification evidence to the crewed test flight, the last major test event before certification, could increase schedule risk. As of September 2018, the contractors were generally on schedule for meeting ISS requirements before their uncrewed test flights. However, both contractors have deferred Commercial Crew program requirements from the uncrewed test flight to the crewed test flight. According to officials, in January 2018, with approval from the program, the contractors modified their plans and deferred submitting verification evidence from before the uncrewed test flight to before the crewed test flight. Program officials told us that the contractors proposed deferring submitting verification evidence because they were having difficulties meeting the original targets for the uncrewed test flight. Boeing officials stated that the certification work deferred is for capabilities introduced on the crewed test flight.

PROJECT OFFICE COMMENTS

NASA's Commercial Crew Program, Boeing, and SpaceX continue to develop the systems that will return human spaceflight to the United States. Both commercial partners are conducting flight tests and considerable integrated system testing in 2019 to prove designs and the ability to meet NASA's safety and mission requirements for crewed flights to the ISS. The Commercial Crew Program, Boeing, and SpaceX reviewed a draft of this assessment and provided technical comments, which were incorporated as appropriate.

[1]GAO, NASA Commercial Crew Program: Plan Needed to Ensure Uninterrupted Access to the International Space Station, GAO-18-476 (Washington, D.C.: July 11, 2018).



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 possible future use on other potentially hazardous near-Earth objects. The project stems from the NASA Authorization Act of 2008 and responds to near-Earth object guidance by the Office of Science and Technology Policy to better understand our impact mitigation posture, and to a recommendation 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 investigation and collaboration with the European Space Agency and the Italian Space Agency.

Source: Johns Hopkins University/Applied Physics Lab. | GAO-19-262SP

FORMULATION
- 02/16 Formulation start
- 09/16 System requirements/ mission definition review
- 04/18 Preliminary design review
- 08/18 Project confirmation

IMPLEMENTATION
- **12/18 GAO review**
- 06/19 Critical design review
- 02/20 Integration and test readiness review
- 06/21 Target launch readiness date
- 02/22 Committed launch readiness date

PROJECT INFORMATION

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

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

Launch Location: **TBD**

Launch Vehicle: **TBD**

Mission Duration: **16 months**

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

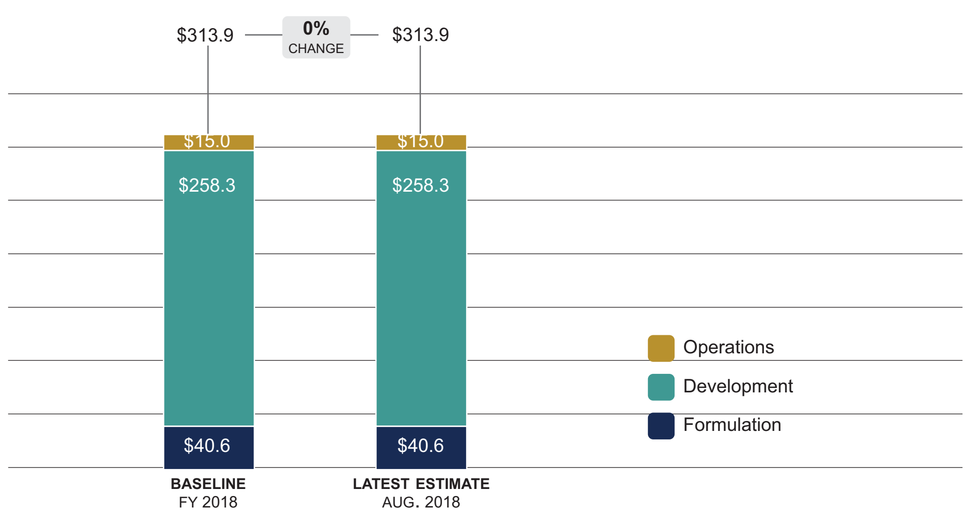
Budget Portfolio: **Science, Planetary Science**

PROJECT SUMMARY

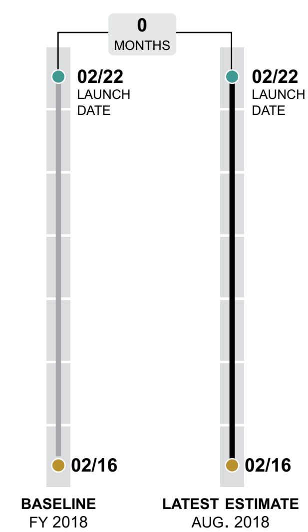
The DART project established its cost and schedule baselines in August 2018 with an estimated cost of $313.9 million and a launch date of February 2022, which is a $22.9 million cost increase and 9-month delay from the preliminary range set in June 2017. However, the project has already faced challenges that put its baseline schedule at risk, including delays in the procurement of the hydrazine tank that is required for the project's propulsion system. DART also continues to face risks related to its electric propulsion thruster, as it was the only one of DART's technologies not to reach maturity by the mission preliminary design review. To mitigate these risks, the thruster was tested to DART-specific conditions and is now considered mature, though there is uncertainty about the final design. The project has altered its launch vehicle plan as the result of NASA changing its risk classification level to reflect more stringent requirements regarding risk tolerance for the mission.

COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

DART's cost and schedule baselines increased compared to its preliminary estimates, largely due to programmatic changes. DART entered the implementation phase in August 2018 and formally established its cost and schedule baseline of $313.9 million to launch by February 2022, which is $22.9 million higher and 9 months later than the preliminary estimates set in June 2017. The cost increases over the preliminary estimate are due in part to NASA changing the project's risk classification, which resulted in NASA adding additional cost reserves due to a risk that launch vehicle costs would be higher than expected. The schedule change is due to a launch option study that showed a later launch date would be favorable, in part to allow for an extended launch period. According to officials, the project is working to an earlier June 2021 launch date because that would allow for a flyby of a potentially hazardous asteroid. The flyby would enable DART to calibrate sensors and tune the subsystem used to autonomously drive the spacecraft to impact the smaller body of the Didymos asteroid system. The project could launch as late as February 2022 and still meet the planned impact date, but without the flyby. DART is now working toward its critical design review, currently scheduled for June 2019.

However, DART is already facing challenges that put its schedule at risk. For example, the project's schedule reserves fell below planned levels due in part to a delay in transferring parts from the Parker Solar Probe project. A project official said they were reworking the schedule to address the issue. Since then, schedule reserves were further threatened by a 2-month delay in the planned procurement of the hydrazine tank, required for the project's propulsion system. The project shortened the delay by providing the supplier with additional funding to expedite the procurement.

Technology and Design

In April 2018, the DART project passed its preliminary design review with six of its seven technologies matured to a technology readiness level 6. Maturing technologies to this level by preliminary design review is a best practice and helps minimize development risks. The technology that had not reached maturity was DART's electric propulsion system, the NASA Evolutionary Xenon Thruster-Commercial (NEXT-C), a project managed at the Glenn Research Center under the Discovery Program. NEXT-C is producing one flight qualified thruster and one power processing unit as government furnished, no-cost equipment for DART, and if successful, the DART mission will qualify the NEXT engine for future deep space missions.

Use of NEXT-C provides DART with launch and mission design flexibility, but also increases the spacecraft's complexity. DART has been tracking several NEXT-C risks, including concerns about design maturity and the development of NEXT-C's engine and power processing units, which provide necessary voltages to the thruster. To mitigate these risks, the DART and NEXT-C teams worked together to develop a plan to test NEXT-C at DART's operating conditions. These tests were completed in October 2018. According to a project official, independent reviews have confirmed that NEXT-C has reached maturity for DART's operating conditions. However, the NEXT-C project is still conducting tests to meet NEXT-C specific needs, and a project official is unsure what it would mean for DART if changes had to be made to the system.

Launch

As a result of the project's risk reclassification—to reflect more stringent requirements regarding risk tolerance for the mission—DART plans to use a dedicated launch vehicle. A project official is concerned that the procurement of a dedicated launch vehicle will cost more than anticipated. Because of the change, an additional $25 million in headquarters-held reserves was allocated to the project to cover possible launch vehicle cost increases above the $41 million baseline. Additionally, DART is now tracking a risk that the launch vehicle acquisition process, which will be carried out by the Launch Services Program, will not meet DART's program schedule for receiving interface and technical data. This may cause the project to incur schedule delays and cost increases if hardware redesign is required.

Developmental Partner

DART is exploring the possibility that the European Space Agency (ESA) and the Italian Space Agency (ASI) will contribute projects that would provide post-impact images or data. ESA's possible contribution, Hera, would be a post-impact rendezvous mission to contribute data such as mass measurement. DART is also considering a CubeSat contribution from ASI that would be able to document DART's impact of Didymos. According to officials, DART does not need either contribution to meet its science requirements.

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, and understanding the formation of its surface features. We did not assess the proposed 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-19-262SP

FORMULATION
- 06/15 Formulation start
- 01/17 System requirements/ mission definition review
- 08/18 Preliminary design review
- **12/18 GAO review**
- 06/19 Delta preliminary design review
- 09/19 Project confirmation

IMPLEMENTATION
- 05/20 Critical design review
- 03/21 System integration review
- 07/23 Projected 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**

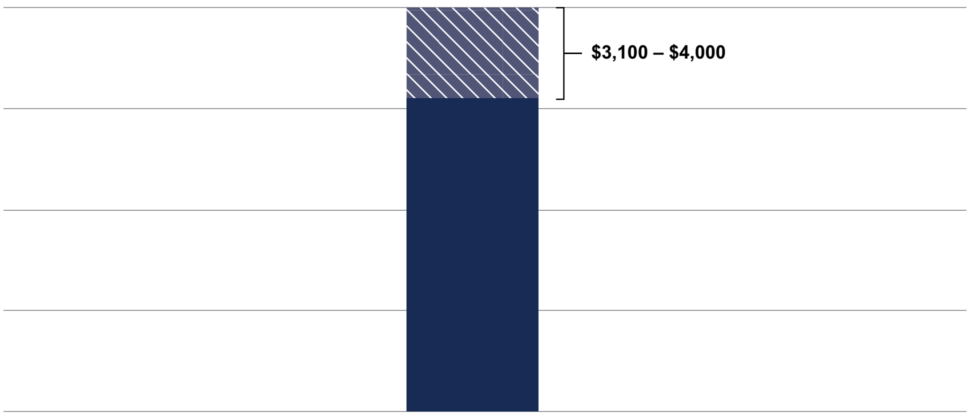
Budget Portfolio: **Science, Planetary Science**

PROJECT SUMMARY

The Europa Clipper project is now working to a July 2023 launch date, as opposed to the accelerated launch schedule of June 2022 that it was previously working towards. Following the project's preliminary design review in August 2018, significant design work related to the solar array and other areas of concern remain open. As a result, the project does not expect to complete its preliminary design review until June 2019. Due to these ongoing design challenges, the project has also delayed its confirmation review from October 2018 to fall 2019. Prior to the launch delay, project officials told us that costs were expected to increase above preliminary estimates. As part of its decision to delay the project's confirmation review, NASA's program management council directed the project to examine its requirements in order to reduce complexity and cost risk, which may affect the project's science capabilities. The Consolidated Appropriations Act, 2016 states that the project shall use NASA's Space Launch System (SLS) as its launch vehicle, but project officials told us that NASA has not made a final decision on the launch vehicle.

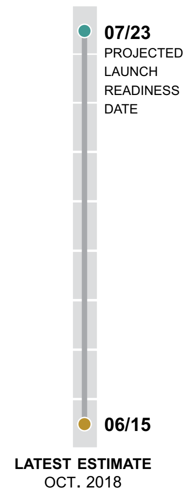
PRELIMINARY COST[a]

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 project planned to hold its confirmation review and set cost and schedule baselines in October 2018 following its preliminary design review; however, due to ongoing design challenges, the project now plans to hold the review in fall 2019. In addition, the project is now working to a July 2023 launch date—instead of its previously planned launch date of June 2022—given continued workforce shortages at the Jet Propulsion Laboratory. The project has been below planned staffing levels by an average of 22 full time equivalents, or about 7 percent of planned levels, since it entered the preliminary design and technology completion phase in February 2017. These shortages have affected several areas including avionics, system integration and test, and instruments.

A cost exercise in preparation for the confirmation review indicated costs would increase above preliminary estimates, if confirmed at the review. Project officials explained that the expected cost increase is the result of conducting a more detailed cost estimate. As part of its decision to delay the project's confirmation review, NASA's program management council directed the project to examine its requirements in order to reduce complexity and cost risk, which may affect the project's science capabilities. We found in 2018 that the project has a process in place to manage instrument costs with options to descope an instrument entirely or in part to prevent cost growth. Agency officials reported that NASA has not descoped any instruments to date but at least one instrument is near the 20 percent cost growth threshold.

The project currently holds 84 days of schedule reserves, which is below its plan of 108 days. Further, the project's 9 percent cost reserves is below its plan of 25 percent. The project's expected cost increase at the confirmation review would have brought the project reserves in line with requirements, if the launch date were held to the previous plan of June 2022.

Technology and Design

The project held its preliminary design review in August 2018 with all of its reported technologies matured to technology readiness level 6, a best practice, but significant design work remains. As a result, the project does not expect to complete its preliminary design until June 2019. The design for mounting the Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON) instrument antennas on the solar array has generated significant performance concerns for both the instrument and the solar array. The project is working with the solar array vendor to test potential design changes, which could increase cost and schedule risk.

The project had previously taken steps to address schedule delays associated with solar array development by changing the materials it planned to use, reassessing integration and test plans, and changing from an in-house build to a vendor with solar array experience. Project officials stated that if the solar array is further delayed, they could opt to integrate it for the first time at the launch site. Current plans are to integrate the solar array prior to environmental testing at JPL and de-integrate for transport to the launch site. Officials noted that integrating for the first time at the launch site would increase risk of late discovery of solar array issues.

Launch

The Consolidated Appropriations Act, 2016 states that the project shall use NASA's Space Launch System (SLS), but NASA officials told us that a final decision about the launch vehicle has not been made. As a result, the project continues to maintain compatibility with multiple launch vehicles including SLS and the Delta IV Heavy. The project is tracking a risk that if the formal selection decision is delayed beyond the critical design review, significant resources will be required to maintain compatibility with multiple launch vehicles, which could threaten cost and schedule.

If NASA selects SLS as the launch vehicle, the Human Exploration and Operations (HEO) mission directorate, which is developing SLS, has agreed to only require the Europa Clipper project to be responsible for the cost equivalent to the Delta IV Heavy. The remaining SLS cost is to be covered by the HEO mission directorate.

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-19-262SP

PROJECT INFORMATION

NASA Lead Center: **Kennedy Space Center**

International Partner: **None**

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

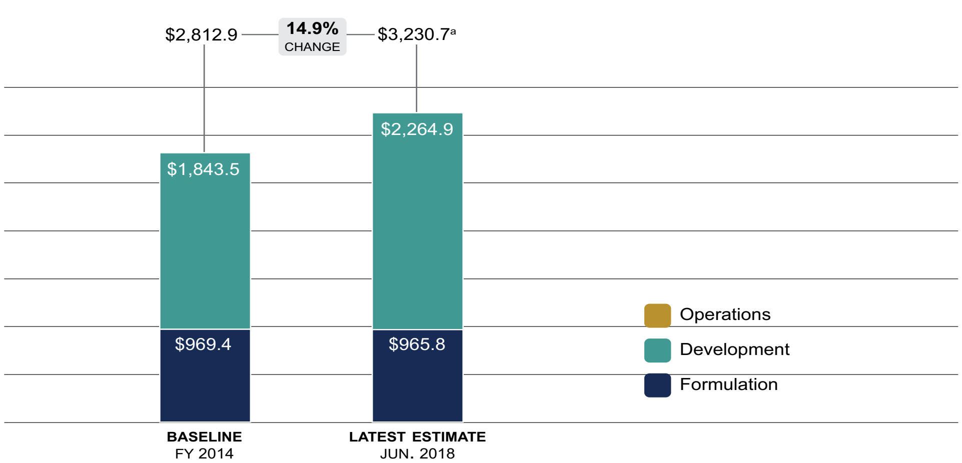
Budget Portfolio: **Exploration, Exploration Systems Development**

PROJECT SUMMARY

Less than one year after announcing a new launch readiness date for Exploration Mission-1 (EM-1)—December 2019 with 6 months of reserve to June 2020—senior NASA officials acknowledged that the revised December 2019 launch date is unachievable. Moreover, senior officials stated there are 6 to 12 months of schedule risk associated with the June 2020 date, which means the first launch may occur as late as June 2021. Since NASA established the new date range for EM-1, the program has had ongoing construction challenges with the Mobile Launcher. For example, construction on the Mobile Launcher resulted in a 5-month delay in moving the mobile launcher to the Vehicle Assembly Building and as a result, delayed the start of multi-element verification and validation testing. According to officials, however, the program has made progress on two software developments—that represent the program's critical path—by implementing process improvements such as iterative testing. With respect to costs, the EGS program continues to operate within costs established for the June 2020 launch date.

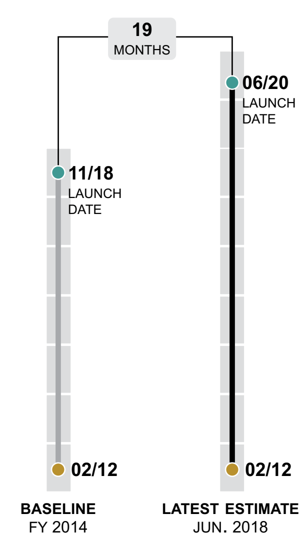
COST PERFORMANCE

then-year dollars in millions



[a]Assumes June 2020 launch date.

SCHEDULE PERFORMANCE



Cost and Schedule Status

Less than one year after announcing a new launch readiness date for EM-1—December 2019 with 6 months of reserve to June 2020—senior NASA officials acknowledged that the revised December 2019 launch date is unachievable. Moreover, senior officials stated there are 6 to 12 months of schedule risk associated with the June 2020 date, which means the first launch may occur as late as June 2021. Since NASA established the new EM-1 launch date range, the program has had ongoing construction challenges with the Mobile Launcher. For example, installation of the liquid hydrogen tail service mast umbilical was delayed due to hydrogen leaks discovered at disconnect points during testing. Additionally, the Mobile Launcher schedule deteriorated due to problems with finalizing construction work prior to moving it to the Vehicle Assembly Building. According to officials, construction work had not progressed to the point desired to move the Mobile Launcher so officials decided it should remain at the construction site. This resulted in a 5-month delay to the start of multi-element verification and validation, a test process to ensure that systems at Kennedy Space Center can operate together to successfully process and launch the integrated SLS and Orion Systems. With respect to costs, the EGS program continues to operate within costs established for the June 2020 launch date, but any delays beyond June 2020 will result in cost overruns.

Technology

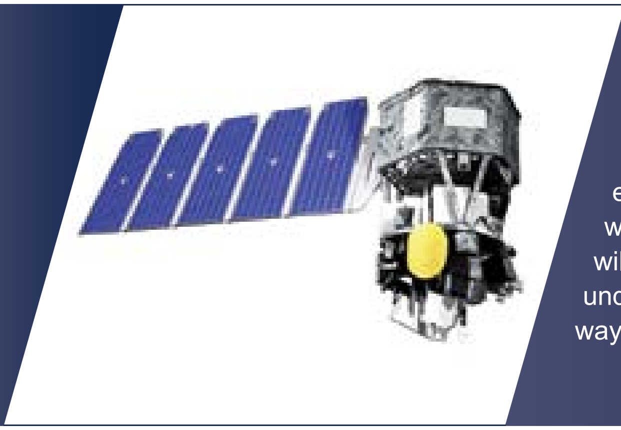
The EGS program also has made some progress on its two major software development efforts—Spaceport Command and Control System (SCCS), which will operate and monitor ground equipment, and Ground Flight Application Software (GFAS), which will interface with flight systems and ground crews. According to program officials, these software development efforts, which represent the EGS critical path, have improved since the recent implementation of process improvement initiatives. For example, the program implemented iterative integration testing, which involves conducting tests on smaller segments of software throughout the development process instead of waiting to conduct testing when a software release is fully complete. According to officials, these efforts allow the program to identify and correct errors earlier in the software development process. Officials indicated that these changes have also resulted in lower numbers of issues found in each software release. Officials acknowledged that delays within the SLS and Orion programs are providing flexibility to the EGS program, including the software development schedule. However, late deliveries from Orion and SLS could limit the amount of time EGS has post-delivery to integrate and test software components from each of the three programs while staying within the June 2020 launch window.

Integration and Test

Senior NASA officials stated that included in the 6-12 months of risk to the June 2020 launch date is a risk that it will take more time for the EGS program to complete integrated test and checkout procedures after SLS and Orion components arrive than the program currently has in its schedule. Officials explained that this risk is based on a schedule risk analysis that considered factors such as historical pre-launch integrated test and check out delays and the learning curve associated with a new vehicle. Our prior work has shown that the integration and test phase often reveals unforeseen challenges leading to cost growth and schedule delays.

PROJECT OFFICE COMMENTS

According to officials, the EGS program has made progress on its two major software development efforts (SCCS and GFAS), which represent the EGS critical path. Although there have been some delays on the Mobile Launcher, completion of the Mobile Launcher is not expected to affect the launch schedule for EM-1. EGS officials also provided technical comments on a draft of this assessment, which were incorporated as appropriate.



Source: University of California, Berkeley. | GAO-19-262SP

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

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**

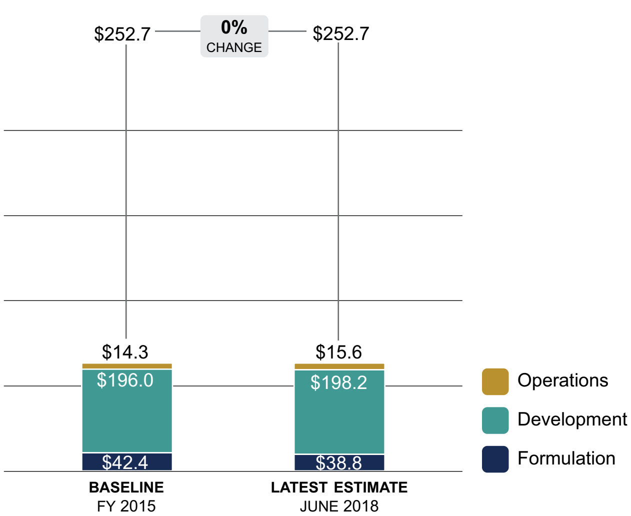
Next Major Project Event: **Launch**

PROJECT SUMMARY

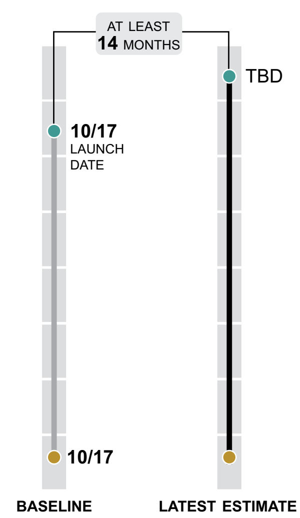
The ICON project missed its committed launch readiness date and several other subsequent launch dates due to a series of delays related to its launch vehicle, and as a result, the project's cost and schedule are under review. After issues with its Pegasus launch vehicle caused the project to miss its baseline launch date of October 2017, the project set a new launch date of June 2018. However, the project missed that launch date due to anomalous telemetry from the Pegasus launch vehicle while en route to the Kwajalein, Marshall Islands launch site. At the time, the project identified a launch vehicle component within the actuator system—the system responsible for steering the launch vehicle—as the cause of the anomalous telemetry. After missing the June 2018 launch date, the ICON project changed its launch location from the Marshall Islands to Cape Canaveral Air Force Station, Florida to take advantage of launch opportunities in the fall of 2018. However, the project was unable to take advantage of the fall and winter opportunities at Cape Canaveral due to the recurrence of anomalous telemetry from the launch vehicle. In November 2018, the project convened a Failure Review Board to investigate the anomaly and transport the observatory in the Pegasus fairing back to Vandenberg Air Force base in California. As of February 2019, testing of the launch vehicle continues in an effort to identify the root cause.

COST PERFORMANCE

then-year dollars in millions



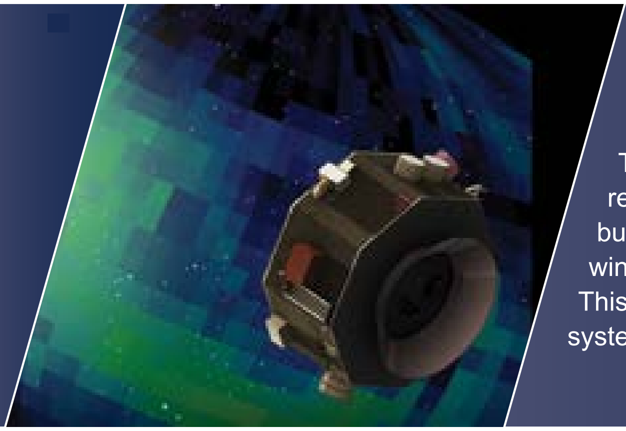
SCHEDULE PERFORMANCE[a]



[a] As of December 2018, the ICON project's launch date had not been determined. Depending on the outcome of the launch vehicle investigation and the selected launch date, the project's total lifecycle costs may increase.

PROJECT OFFICE COMMENTS

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



Interstellar Mapping and Acceleration Probe

The Interstellar Mapping and Acceleration Probe (IMAP) mission will help researchers better understand the boundary where the heliosphere—the bubble created by a constant flow of particles from our Sun, called the solar wind—collides with interstellar medium, or material from the rest of the galaxy. This boundary limits the amount of harmful cosmic radiation entering the solar system, and IMAP will collect and analyze particles that make it through.

Source: NASA. | GAO-19-262SP

PROJECT INFORMATION

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

Mission Duration: **2 years**

Requirement Derived from: **2013 Heliophysics Decadal Survey**

Budget Portfolio: **Science, Heliophysics**

Next Major Project Event: **Preliminary Design and Technology Completion Phase (planned December 2019)**

CURRENT STATUS

In May 2018, NASA selected the IMAP project from a 2017 competitive announcement of opportunity. IMAP will be the fifth Solar Terrestrial Probe program and was the highest priority mid-size mission in the 2013 Heliophysics Decadal Survey. The IMAP project plans to include 10 instruments, which are intended to measure atoms, ions, magnetic fields, and solar wind particles. Several of these proposed instruments include international contributions, which will be baselined at the project's confirmation review. The spacecraft design is based on heritage designs from other heliophysics projects, including Parker Solar Probe and the Van Allen Probes.

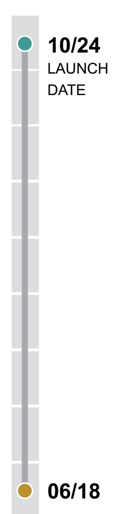
The project is currently working toward a launch date of October 2024 and the mission reports a cost-cap of $565 million, which does not include international contributions or launch services. During the current phase, concept and technology development, the project will continue to refine project-level requirements, as well as the mission, spacecraft, and payload architecture. The project is planning to enter the preliminary design phase in January 2020 and hold its confirmation review, the point at which NASA will approve a cost and schedule baseline, in March 2021.

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. This figure does not include any contributions nor the launch vehicle cost.*

PRELIMINARY SCHEDULE



PROJECT OFFICE COMMENTS

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

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.

Source: NASA. | GAO-19-262SP

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**

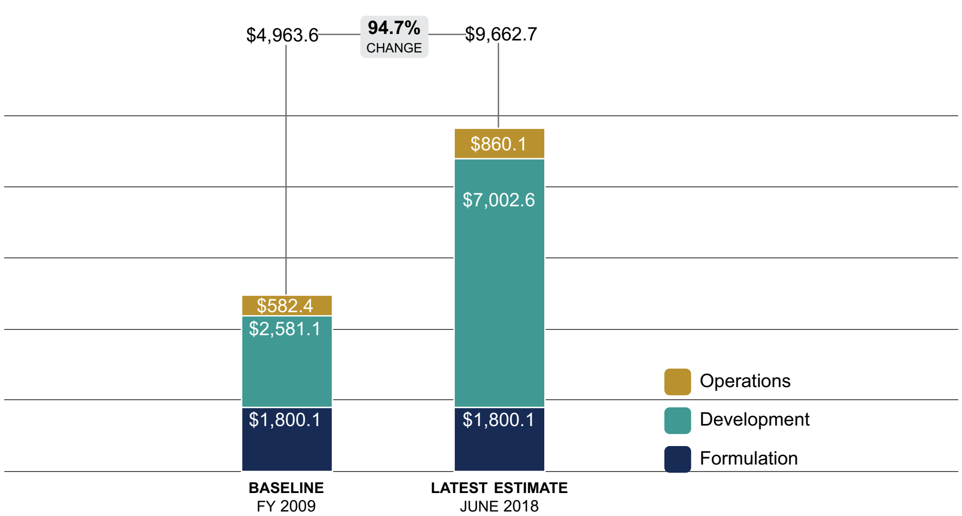
Budget Portfolio: **Science, Astrophysics**

PROJECT SUMMARY

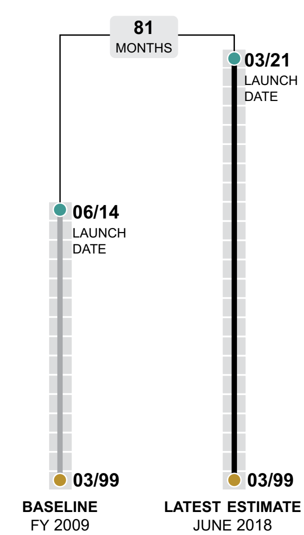
The JWST project has experienced additional cost growth of about $828 million and schedule delays of 29 months over its prior cost and schedule commitments, which were established in 2011. The project experienced a series of delays in 2017 and 2018 primarily due to spacecraft element integration challenges and various technical and workmanship issues during integration and test. As a result of these delays, NASA established a new cost commitment of $9.7 billion and launch readiness date of March 2021 for the project in June 2018. The JWST project also re-established its cost and schedule reserves in June 2018 and has since used a total of about 3 months of its schedule reserves primarily due to delays associated with addressing a design issue on the cover of the sunshield and spacecraft element vibration testing. The project's ability to execute to its new schedule will be tested as it progresses through the remainder of challenging integration and test work, including integration and test of the JWST observatory, which is expected to begin in September 2019.

COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The JWST project has experienced additional cost growth of about $828 million and schedule delays of 29 months over its prior cost and schedule commitments, which were established in 2011. The project experienced a series of delays primarily due to spacecraft element integration challenges and various technical and workmanship issues during integration and test. As a result of the delays, NASA established a new cost commitment of $9.7 billion and launch readiness date of March 2021 for the project in June 2018. These new cost and schedule commitments represent a total of 95 percent of cost growth and 81 months of schedule delays since the project's cost and schedule baselines were first established in 2009. In addition, the cost growth resulted in the project exceeding an $8 billion cap on the formulation and development costs that Congress established for the project in 2011. The JWST project re-established its cost and schedule reserves in June 2018 consistent with NASA center policy.

Design

The JWST project has completed repairs to address a design issue with fasteners on part of the membrane cover assembly—used to cover the sunshield membrane when in the stowed position to provide thermal protection during launch—but the repairs proved more difficult than anticipated. This resulted in the use of schedule reserves and delayed the start of spacecraft element vibration testing. During acoustics testing in April 2018, the project found that fasteners on part of the assembly had come loose due to a design change made to prevent the fasteners from damaging the sunshield membrane. The design change caused the nuts to not lock properly. The project incorporated time into its new schedule to make the necessary repairs, but needed to use 4.5 weeks of schedule reserves to address unanticipated technical challenges. These challenges included needing additional time to repair tears and pin holes in the covers discovered after the covers were removed. As a result of these delays, the project restarted spacecraft element vibration testing in November 2018 about a week later than planned.

Subsequently, the project used about another 8.5 weeks of schedule reserves primarily due to delays during spacecraft element vibration testing. The testing took longer than anticipated because the project needed to update its test parameters based on new launch vehicle data, and conduct additional vibration analysis and testing during part of the test period. The project updated its analysis and added additional testing for membrane release devices—which help hold down the sunshield membrane during launch—because the project had not accounted for prior design changes that it made to the membrane cover assemblies. The additional analysis and testing was needed to ensure that the devices would not be damaged during testing. As a result of the additional analysis and testing, project officials said they plan to add mass dampers to part of the sunshield structure during observatory integration and test to reduce vibrations.

Integration and Test

The project's ability to execute to its new schedule will be tested as it progresses through the remainder of challenging integration and test work. For example, the project has several first-time and challenging integration and test activities remaining. The project plans to integrate the completed telescope and spacecraft elements in September 2019 and begin testing the full observatory in the final integration phase, which includes another set of challenging environmental tests. Our prior work has shown that integration and testing is the phase in which problems are most likely to be found and schedules tend to slip.

Further, the project has technical issues and risks that it must continue to mitigate during the remaining phases of integration and test. For example, the project continues to work to mitigate a design issue on the sunshield membrane tensioning system—which helps deploy the sunshield and maintain its correct shape. The project and the relevant contractor determined that a design modification was necessary to fully mitigate a design issue discovered in October 2017, after one of the sunshield's six membrane tensioning systems experienced a snag when conducting folding and deployment exercises on the sunshield. The design solution includes modifying clips used to progressively release the cable tension and adding guards to control the excess cable.

PROJECT OFFICE COMMENTS

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

Landsat 9

Landsat 9 is the next satellite in the Landsat-series program, which for over 40 years has provided 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 effort 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: Northrop Grumman Innovation Systems (artist rendering). | GAO-19-262SP

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**

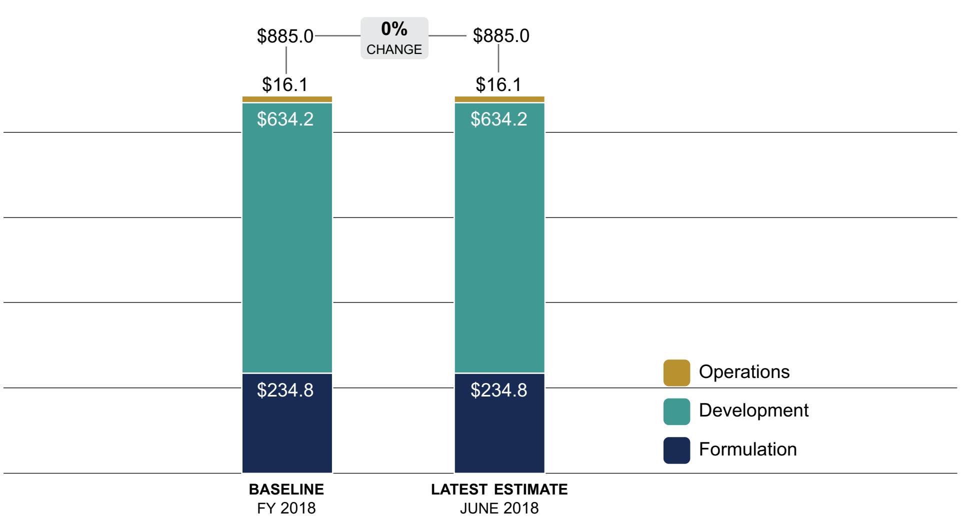
Budget Portfolio: **Science, Earth Science**

PROJECT SUMMARY

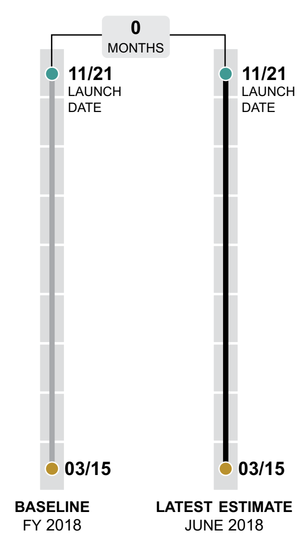
The Landsat 9 project continues to work toward a launch readiness date of December 2020 due to direction in the Explanatory Statement accompanying the Consolidated Appropriations Act, 2016. This date is 11 months earlier than the project's November 2021 baseline launch readiness date. Officials stated that this earlier date is aggressive due to a challenging spacecraft development schedule. The project is working to mitigate these challenges by adding staff to support spacecraft integration and testing and conducting regular schedule reviews, among other things. The project held its critical design review in April 2018 with about 93 percent of its design drawings released, which is greater than the best practice of releasing 90 percent of design drawings by this milestone. However, only about 81 percent of the project's spacecraft design drawings were released by that time. The project is working toward its system integration review currently planned for August 2019.

COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The Landsat 9 project continues to work toward a launch readiness date of December 2020, which is 11 months earlier than the project's November 2021 baseline launch readiness date. The project is working to the earlier December 2020 date due to direction in the Explanatory Statement accompanying the Consolidated Appropriations Act, 2016. According to officials, this launch date will help ensure that the Landsat program is able to maintain two Landsat satellites on-orbit simultaneously and provide expanded science data, which is a goal of the scientific community but not a requirement of the program.

The project's standing review board is concerned that the December 2020 launch readiness date is aggressive due to a challenging spacecraft development schedule. Specifically, there are conflicts over resources needed for spacecraft development, such as personnel and facilities, that pose a significant schedule risk. In addition, the standing review board is concerned that procurement and internal manufacturing delays will affect the spacecraft's assembly, integration, and testing schedule. Officials explained that the project is working to mitigate these risks by buying additional integration and testing equipment and adding staff to support spacecraft integration and testing. To further address delays, the project also has weekly meetings with facility management, conducts regular schedule reviews, and the spacecraft contractor has added a program expeditor to identify and remove schedule roadblocks. According to project officials, these efforts have helped to improve the schedule data they receive from the contractor.

Project officials stated that they had difficulty receiving credible schedule data for the solar array drive assembly (SADA). The project is working with the Joint Polar Satellite System-2 (JPSS-2) project, which is using the same solar array drive assembly, to address concerns about the subcontractor's schedule performance. For example, the JPSS-2 project has a lead systems engineer on site with the subcontractor to help develop better schedule data. As of November 2018, the SADA has completed vibration and thermal vacuum testing. Project officials report the SADA is currently on schedule for delivery in early 2019.

In April 2018, the project recalculated its joint cost and schedule confidence level—the likelihood the project will meet its cost and schedule estimate—to be 50 percent for the December 2020 launch date. This meets NASA's policy for a confidence level tied to a launch date, which is earlier than the baseline schedule. The project is holding schedule reserves below the planned level. The project is working toward its system integration review currently planned for August 2019.

Design

Landsat 9 held its critical design review in April 2018 with about 93 percent of the project's total design drawings released for its two instruments and the spacecraft, which is greater than the best practice of releasing 90 percent of design drawings by this time. However, spacecraft design drawings lagged behind the best practice, with only about 81 percent of drawings released at that time. Our work on product development best practices has shown 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.

PROJECT OFFICE COMMENTS

In commenting on a draft of this assessment, Landsat 9 project officials stated that all project elements are making progress 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-19-262SP

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**

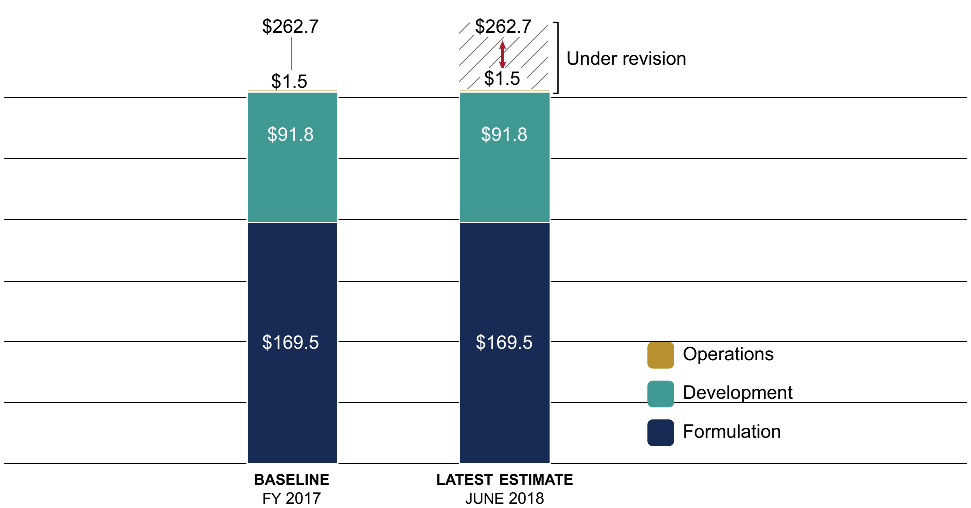
Budget Portfolio: **Space Technology, Research and Development**

PROJECT SUMMARY

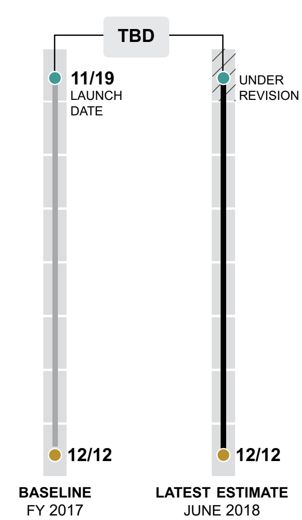
The LCRD instrument will be hosted on an Air Force satellite, and that satellite has experienced delays. Due to challenges with the spacecraft bus, the mission will not be able to launch until August 2020 at the earliest, according to officials. This will require the project to revise its cost and schedule. The full extent of the project's cost increases is not yet known as the contractor has yet to provide an updated cost and schedule estimate. Furthermore, the project is in the process of addressing issues with components that could delay or increase the cost of delivering the instrument on-time for integration and will require additional testing. For example, the project may need to remove one of its flight modems for rework and retesting and is investigating potential cracking of flight isolators, which may need to be redesigned.

COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The LCRD project is assessing the extent to which spacecraft delays will affect its cost and schedule. The LCRD instrument will be a payload on an Air Force Space Test Program satellite and NASA is assessing the impact of continued delays with the spacecraft on LCRD's cost and schedule. According to officials, the contractor—with whom the Air Force holds the contractual relationship—has experienced technical challenges refurbishing the existing spacecraft bus to meet the requirements of one of the other, non-NASA, payloads. NASA has a cost-sharing agreement with the Air Force related to the spacecraft, so the LCRD program's costs increase any time the contract costs associated with the spacecraft increase, according to officials.

As of November 2018, NASA was planning to deliver the LCRD instrument in July 2019 for integration. However, the Air Force and NASA were assessing the extent of delays with the spacecraft bus, and did not anticipate the launch would occur until August 2020 at the earliest—13 months after NASA plans to deliver the LCRD instrument for integration. The full extent of the delay and cost increases will not be known until the Air Force provides the LCRD project with the contractor's updated schedule and finalizes a new cost-sharing agreement with its mission partners. At that time, the LCRD project will be able to complete a new estimate of its schedule and associated costs.

Integration and Test

In addition to delays with the spacecraft bus, the LCRD project is also addressing integration and test issues within its own project that could affect the delivery schedule of the LCRD instrument. For example, one of the flight modems—a key LCRD component that sends and receives commands and data—was shutting down due to an issue with its power supply. The project is tracking the possibility that this component will need to be removed from the flight panel, reworked, and retested, which would adversely affect the LCRD instrument's delivery schedule and cost. In addition, the project is in the process of addressing potential cracking of flight isolators, which are shock absorbers designed to protect the instruments from vibration during space flight. The project is assessing whether to proceed with an identical design or a completely different design for the isolators. Goddard Space Flight Center personnel are removing the existing isolators and sending them to the vendor for additional testing. The program is awaiting a cost estimate for redesigned isolators.

Further, the spacecraft bus may pose technical challenges for LCRD. The project has identified a risk that accommodation of the various payloads on the Air Force satellite may result in the necessity to make design changes to LCRD. For example, the project recently identified that LCRD electromagnetic interference is outside what the Air Force will allow. Therefore, the project may need to modify existing hardware in order to meet Air Force requirements. The project is currently evaluating ways to reduce these risks and coordinating with the contractor to resolve the identified technical issues but will need to obtain waivers from the Air Force in order to continue forward without meeting requirements. According to project officials, the electromagnetic interference risk has gone down in criticality over time but they do not expect they will be able to close the risk until after system-level testing is complete.

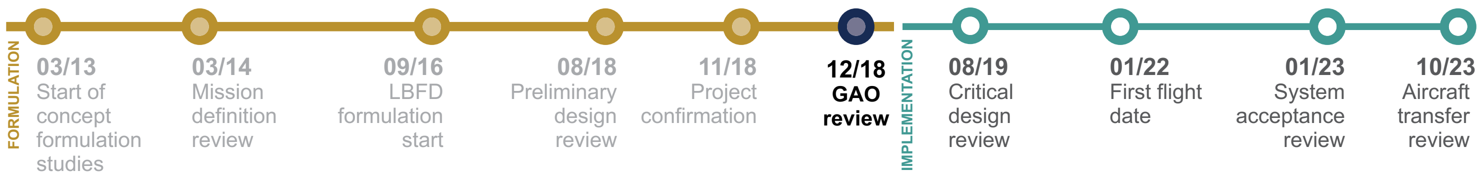
PROJECT OFFICE COMMENTS

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

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. In particular, the LBFD project plans to generate key data to allow for the development of internationally accepted standards, such as noise standards, that are needed to open the market to supersonic flight. The project plans to turn over the flight-demonstration aircraft to the Commercial Supersonic Technology project to gather community responses to the flights and to create a database to support development of international noise rules for supersonic flight.

Source: Lockheed Martin. | GAO-19-262SP



PROJECT INFORMATION

NASA Lead Center: **None**

International Partner: **None**

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

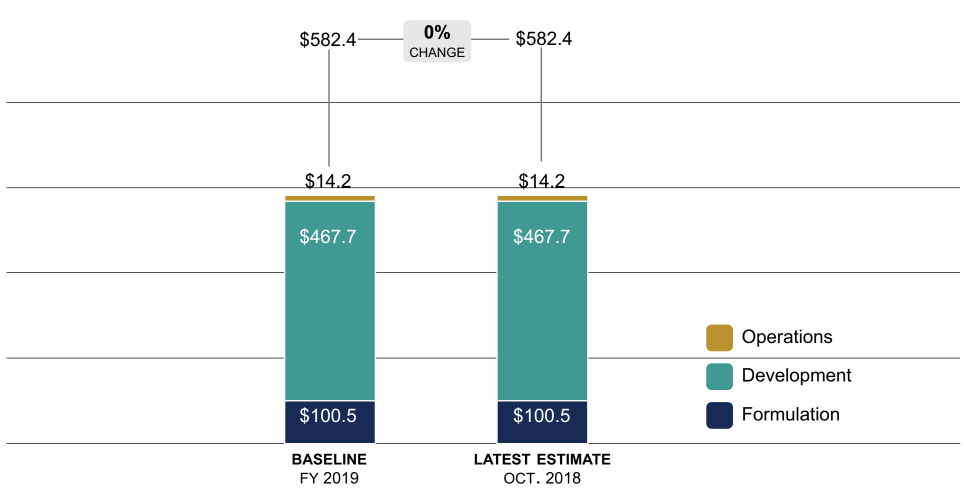
Budget Portfolio: **Aeronautics, Integrated Aviation Systems Program**

PROJECT SUMMARY

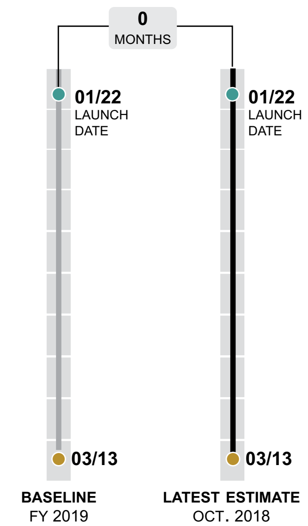
The LBFD project entered the implementation phase in November 2018 and formally established its cost and schedule baselines. The project set a baseline life-cycle cost of $582.4 million and a first flight date of January 2022. The project completed the final preliminary design review in August 2018. The LBFD project has identified one technology, the design tools used to create the aircraft's outer shape, as being key to the low boom. Because this is a technology demonstration project, project officials do not expect the technology to reach a technology readiness level 6—at which point technologies have been demonstrated in a relevant environment—until the aircraft is actually built and flown. The LBFD project is using a virtual project office that includes personnel from various NASA centers. The virtual project office model may highlight an organizational structure that could be beneficial for future projects, but it is too soon to tell.

COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The LBFD project entered the implementation phase in November 2018 and formally established its cost and schedule baselines. The project set a baseline life-cycle cost of $582.4 million and a first flight date of January 2022. Program officials explained that the first flight is a key milestone for the project, but part of verifying the air worthiness of the project also includes completing the envelope expansion process. During this process, the project will systematically fly the aircraft faster and higher until LBFD demonstrates acceptable acoustic characteristics. Project officials explained that development ends once this process is complete, which is captured in the system acceptance review. The project is planning to hold that system acceptance review in January 2023.

Project officials further explained that another key milestone for this aeronautics project is aircraft transfer review. This review confirms that the project is ready to transfer the aircraft to the Flight Demonstration and Capabilities Project, which is responsible for conducting community response testing. The project is planning to conduct this review in October 2023. The costs associated with community response testing are not included in the LBFD project cost estimate.

Technology and Design

The LBFD project has identified one technology, the design tools used to create the aircraft's outer shape, as being key to the low boom. Because this is a technology demonstration project, project officials do not expect the technology to reach a technology readiness level 6—at which point technologies have been demonstrated in a relevant environment—until the aircraft is actually built and flown. As such, the project assessed these design tools as a technology readiness level 5—meaning that the basic components have been integrated and tested in a simulated environment—at the preliminary design review held after the project's development contract was awarded. In addition, the project is tracking the development of the external vision system, which includes cameras and monitors to provide forward visibility to the pilot, as a risk. According to officials, external vision system components have been used in flight environments, but these components have not been demonstrated in a high performance research aircraft environment. Officials noted that the external vision system is not necessary to fly the aircraft.

According to project officials, changes to the design of the aircraft's outer shape have been minimal since the preliminary design review held after the development contract was awarded. Because of more precise design knowledge regarding the aircraft's outer shape, the project was able to remove the fiber-optic sensing system requirement. This system was intended to give detailed measurements of changes in the aircraft's shape as it flies, but officials stated that the current design is sufficiently rigid that any such changes would be too small for the system to measure.

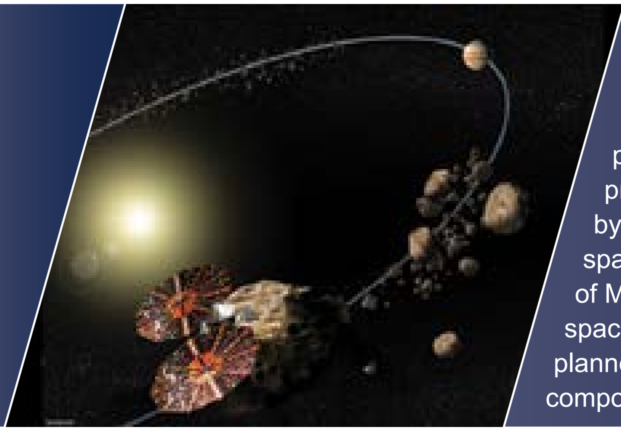
Other Issues to Be Monitored

The LBFD project is using a virtual project office that includes personnel from various NASA centers. Project officials stated that the virtual project management approach is going well but noted that the project has not had to deal with any major setbacks thus far that may test the approach. The virtual project office model may highlight an organizational structure that could be beneficial for future projects, but it is too soon to tell.

PROJECT OFFICE COMMENTS

The LBFD project was provided with a draft of this assessment and did not have any technical corrections or comments.

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-19-262SP

FORMULATION
- 12/16 Project selection
- 02/18 Spacecraft system requirements/ systems definition review
- 09/18 Preliminary design review
- 10/18 Project confirmation

IMPLEMENTATION
- **12/18 GAO review**
- 10/19 Critical design review
- 07/20 System integration review
- 11/21 Committed 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**

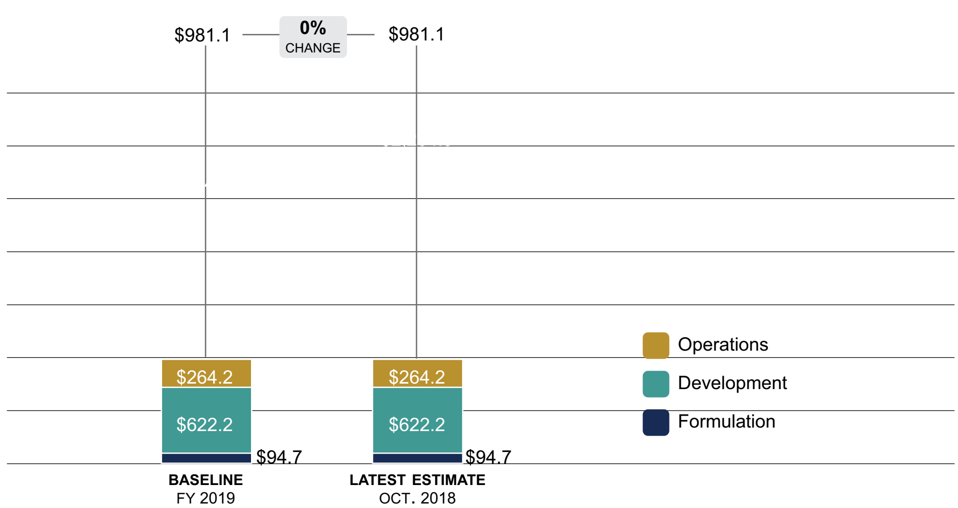
Budget Portfolio: **Science, Planetary Science**

PROJECT SUMMARY

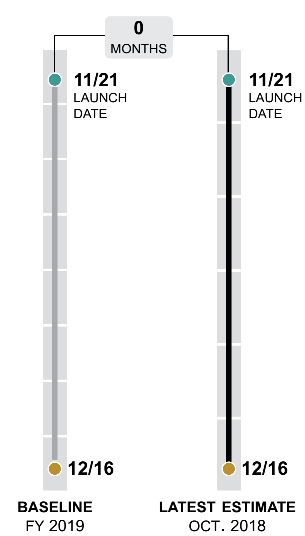
In October 2018, the Lucy project entered the implementation phase and formally established cost and schedule baselines of $981.1 million and November 2021, respectively. The project is currently holding cost and schedule reserves consistent with NASA center policy. Lucy held its preliminary design review in September 2018, at which time the project's standing review board identified concerns that the project's instruments are near the critical path—the schedule with the least amount of reserve that drives the schedule for the entire project—and that the launch schedule is optimistic relative to similar missions. The project is tracking risks that could affect its ability to achieve its baseline science requirements, including spacecraft positioning and potential damage to the instruments from a switch anomaly.

COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The Lucy project entered the implementation phase and formally established its cost and schedule baselines in October 2018. The project set a baseline life-cycle cost of $981.1 million and a launch date of November 2021, which is within the project's preliminary cost estimate of $914 million to $984 million and projected launch readiness date of October to November 2021. NASA calculated the project's joint cost and schedule confidence level, the likelihood a project will meet its cost and schedule estimate, at 70 percent as generally required by NASA policy. However, the project's standing review board joint confidence level analysis noted that the project may need another $27 million to meet the launch window at a 50 percent confidence level. The project is currently holding cost and schedule reserves consistent with NASA center policy. The project plans to hold its next major milestone—the critical design review—in October 2019.

Technology and Design

Lucy held its preliminary design review in September 2018 with its one reported heritage technology, the UltraFlex solar array, matured to the level recommended by best practices. The project is tracking a risk related to this technology, however, as analyses indicate that the degradation of the UltraFlex solar array will be greater than expected due to the radiation environment during Lucy's three planned Earth gravity assists. The solar array has not previously operated in this environment. To counteract the degradation, the project is planning to increase the size of the solar array from 6.3 to 7.1 meters, which adds mass to the spacecraft. Project officials stated that this increase in size is engineering work that does not require new technology development. Additionally, the project is concerned that the solar array vendor may not be able to meet project testing specifications related to outgassing that occurs during testing. The project continues to review the vendor's capability to meet project specifications and gauge the sensitivity of the instruments.

At the preliminary design review, the project's standing review board noted that the project's instruments are near the critical path—the schedule with the least amount of reserve that drives the schedule for the entire project—but that the project was not tracking risks related to late delivery of the instruments. Additionally, the board was concerned that the launch schedule is optimistic relative to similar missions. Project officials stated that they are tracking instrument performance closely and maintaining an instrument risk database.

The project is also tracking risks to its ability to achieve baseline science requirements. For example, the project is concerned that uncertainty in the shape of the target asteroid will mean that the spacecraft cannot position itself accurately to collect data. The project is running simulations of encounters with various potential asteroid shapes and using ongoing Earth-bound observations to increase knowledge of potential shapes. The project is also concerned that a switch anomaly could result in power being applied to both sides of an instrument, instead of one side at a time. The project continues to research the potential for instrument damage from such a scenario.

PROJECT OFFICE COMMENTS

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

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. The Mars 2020 rover 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.

Source: NASA/JPL-Caltech. | GAO-19-262SP

FORMULATION
- 11/13 Formulation start
- 10/14 System requirements/ mission definition review
- 02/16 Preliminary design review
- 06/16 Project confirmation

IMPLEMENTATION
- 02/17 Critical design review
- 02/18 System integration review
- **12/18 GAO review**
- 07/20 Committed launch readiness date

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), Italian Space Agency (Italy)**

Launch Location: **Eastern Range, FL**

Launch Vehicle: **Atlas V**

Mission Duration: **2 years**

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

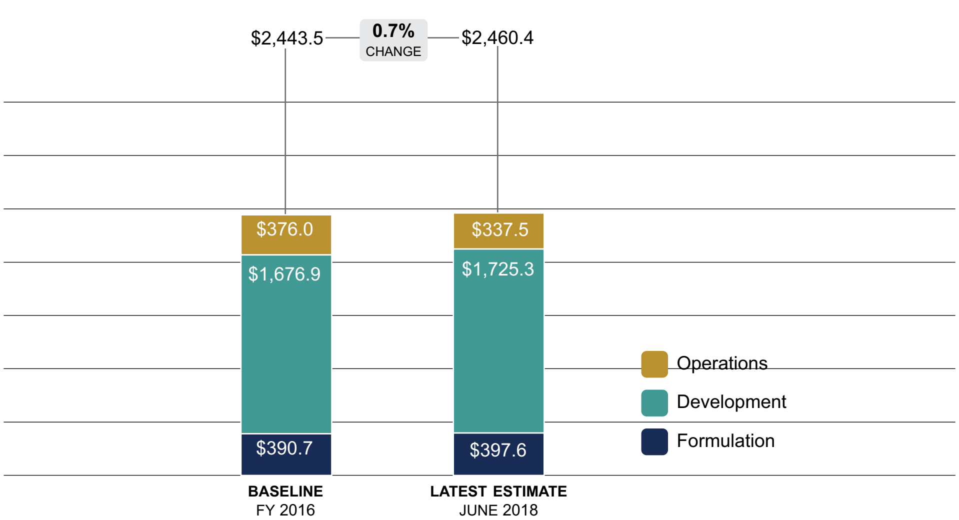
Budget Portfolio: **Science, Planetary Science**

PROJECT SUMMARY

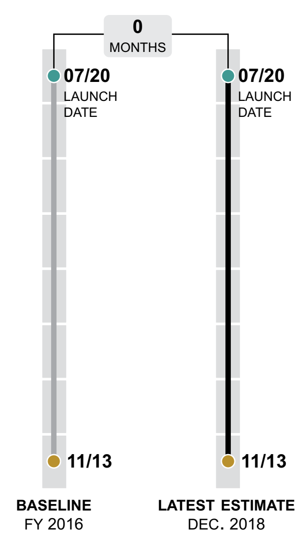
The Mars 2020 project has encountered cost growth and schedule delays due to technical and design challenges for some components and subsystems—including a new and highly complex development—but these delays have not affected the project's overall schedule. The project is also tracking a number of additional risks that could affect cost and schedule for these new and complex developments. For example, the project is tracking an aggregate risk for the Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals (SHERLOC) instrument. The risk is that, given SHERLOC's large number of new and challenging subassemblies, significant technical or programmatic problems could arise creating a ripple effect across the project that delays other activities such as system-level integration and testing. In May 2018, the project entered system assembly, integration, and test—the phase where problems are most commonly found and schedules tend to slip.

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 $16.9 million in cost growth due to technical challenges with two contributed instruments—a technology demonstration instrument that will demonstrate the ability to produce oxygen on Mars and an entry, descent, and landing instrument contributed by the Space Technology Mission Directorate and the Human Exploration and Operations Mission Directorate. Through the use of headquarters-held cost reserves, the project plans to address cost growth in other areas including new developments such as the Sample and Caching Subsystem (SCS), which will collect and cache Martian soil and rock samples and is the project's most complicated development. As of December 2018, the project has no cost reserves, which is below its plan of 20 percent.

According to officials, the project has experienced schedule performance degradation on some of the project's new and challenging developments, but the project's overall schedule has not been affected to date. Project officials reported that the project is holding schedule reserves above the JPL guidelines, but continued instrument-level performance problems could begin to affect the project-level schedule. If this occurs, project officials told us that the project could deliver instruments later in integration and test or descope problematic instruments to meet its planned launch date. The final option would be to wait 26 months—until September 2022—for the next planetary launch window to open. In May 2018, the project entered system assembly, integration, and test—the phase where problems are most commonly found and schedules tend to slip.

Design and Technology

The Mars 2020 project is rebuilding two components after they sustained damage during testing. First, in April 2018, the Mars 2020 heat shield suffered significant damage during a test activity. According to officials, a combination of factors including workmanship issues and test conditions may have contributed to the cracked heat shield. The project is building a redesigned heat shield with delivery expected to support Mars 2020's launch readiness date at a cost of approximately $10 million.

Second, the mast unit optical box of the SuperCam, an instrument that will investigate chemical compositions of rock and soil from a distance, was overheated and damaged beyond repair during testing. The Centre National d'Estudes Spatiales (CNES) is contributing the mass unit for SuperCam. The project is pursuing a new build for recovery, as opposed to upgrading a qualification unit, and expects to begin integration and test for the new unit in May 2019. This timeframe is later than originally planned but, as of December 2018, the project's launch readiness date had not been affected.

The Mars 2020 project is also tracking several risks in aggregate on the SHERLOC and the Planetary Instrument for X-ray Lithochemistry (PIXL) instruments. The aggregate risk is that significant technical or programmatic problems could arise given the large number of new and challenging subassemblies creating a ripple effect across the project, and delay other areas such as assembly, test, and launch operations. For example, the project has experienced technical problems with the SHERLOC instrument that have delayed the start of its thermal-vacuum testing by 4 months. As a result, there are outstanding risks that will have to be addressed by extending thermal-vacuum testing or by deferring tests until the flight model is tested.

Other Issues to Be Monitored

The project has completed a series of parachute tests to determine whether it can fly with its heritage parachute or needs to use a strengthened parachute, and has decided to use the strengthened parachute. These tests were completed to help mitigate risks related, in part, to supersonic test failures observed on an unrelated project. The project completed its third supersonic parachute test in September 2018 and has no further supersonic parachute tests scheduled.

PROJECT OFFICE COMMENTS

In commenting on a draft of this assessment, Mars 2020 project officials stated the project has addressed several key schedule risk areas. Officials said the project has successfully qualified the super-sonic parachute, that all flight actuators have been delivered, and that the heatshield redesign is complete and on schedule. 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-19-262SP

FORMULATION
- 03/14 Formulation start
- 12/14 System requirements/ mission definition review
- 06/16 Preliminary design review
- 08/16 Project confirmation

IMPLEMENTATION
- 10/18 Critical design review
- **12/18 GAO review**
- 12/19 System integration review
- 12/21 Manifested launch readiness date
- 09/22 Committed launch readiness date

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**

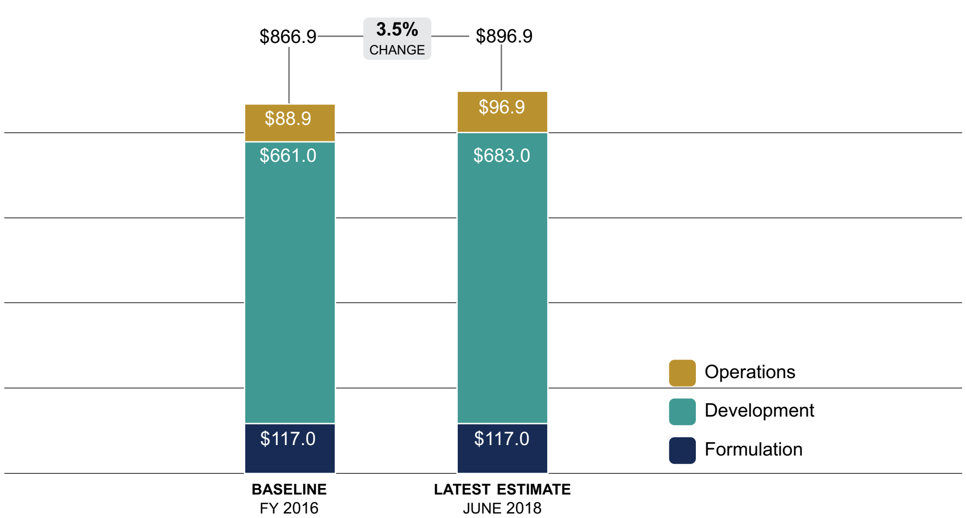
Budget Portfolio: **Science, Earth Science**

PROJECT SUMMARY

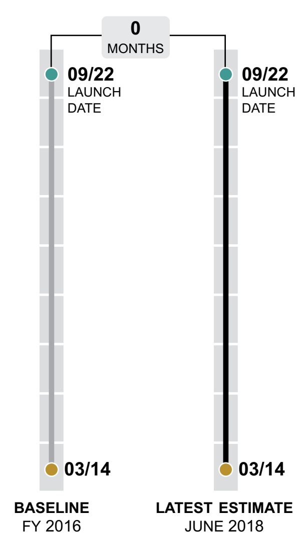
The NISAR project continues to operate within its schedule baseline but is not meeting its cost baseline due to $30 million in cost growth as the result of an increase in the scope of data collection for external data users. The project held its critical design review in October 2018 having released 93 percent of its design drawings meeting GAO's best practice of releasing 90 percent of design drawings by that review. At that time, the project expected the remaining design drawings to be complete by September 2019. The project is in the process of resolving a number of technical issues related to the failure of communication parts during qualification testing and deployment of the radar reflector while in orbit. NISAR will use a launch vehicle provided by ISRO, which must conduct an additional launch with a four-meter fairing, among other criteria, before it is qualified for use.

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. As we reported last year, the project experienced $30 million in cost growth due to plans to collect additional soil moisture and natural hazard data of value to other federal agencies and the science community, which were identified by an interagency working group.[1] The project is working toward its system integration review, currently planned for December 2019.

Technology and Design

The NISAR project held its critical design review with a stable design, which decreases the project's risk of cost growth and schedule delays during the integration and test phase. At this review, the project released about 93 percent of design drawings, meeting the best practice of releasing 90 percent of design drawings at this review.

The project is in the process of resolving several technical issues. For example, two communication parts failed qualification testing due to the manufacturer subjecting the parts to a temperature much higher than that encountered in normal operation. As a result, both parts have to be rebuilt. In addition, the project discovered a problem that could have caused the reflector to get stuck during deployment. The project is addressing this issue by changing the deployment sequence, making design changes that will prevent bolts from becoming stuck, and turning on heaters to increase the temperature of the instrument structure—further reducing the chance that the bolts will get stuck during deployment. Further testing is planned to verify that the problem is resolved. Finally, the project is tracking a separate but related risk that the radar reflector boom assembly—used to deploy the radar reflector when the spacecraft reaches orbit—could fail to deploy on orbit, which would also compromise science. The project has taken steps to mitigate this risk by making design changes, but additional testing is planned to reduce the risk that the project will encounter a failed boom deployment on orbit.

Launch Vehicle

The project will use a launch vehicle that Indian Space Research Organization (ISRO) is providing—the Geosynchronous Satellite Launch Vehicle (GSLV) Mark II—which must meet criteria that NASA and ISRO agreed upon before it may be used. ISRO must conduct an additional launch with a four-meter fairing, which is scheduled for the first quarter of 2019, to meet one of the agreed to criteria.

In addition, ISRO has recently made changes to the second stage of the launch vehicle, and the project is tracking ISRO's progress in ensuring that the launch vehicle meets all agreed-upon criteria.

PROJECT OFFICE COMMENTS

NISAR officials stated that $30 million in cost growth is not reflective of negative performance, but the result of implementing a recommendation from an interagency working group to adjust the scope of data collection to benefit key external data users who will benefit from access to NISAR data. In addition, NISAR officials stated that all costs within the NISAR project manager's control are currently meeting commitments. NISAR project officials also provided technical comments on a draft of this assessment, which were incorporated as appropriate.

[1] 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.

Source: NASA. | GAO-19-262SP

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**

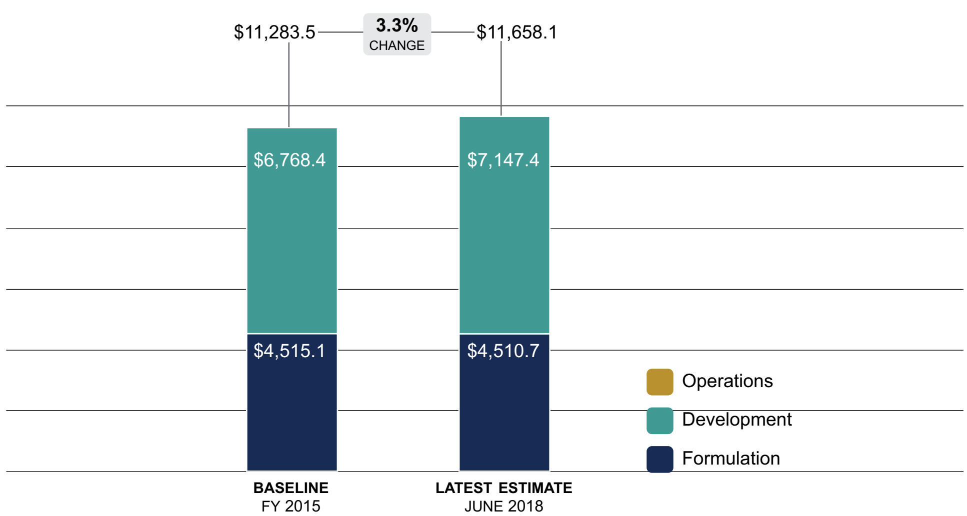
Budget Portfolio: **Exploration, Exploration Systems Development**

PROJECT SUMMARY

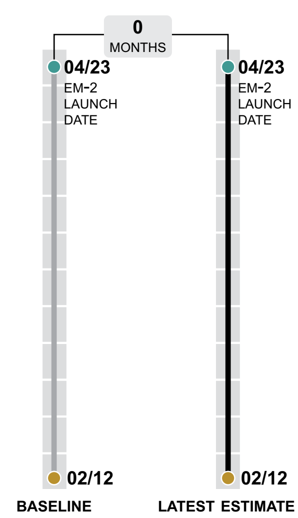
The Orion program can no longer support a June 2020 launch date for the first exploration mission, and according to program officials, recent delays are due to delivery delays with the service module, delays with the crew module, and contractor underperformance. Program officials told us that program and cross-program integration and test efforts are expected to take about 20 months from the delivery of the service module—which occurred in November 2018—to Exploration Mission (EM)-1 launch. As a result, the Orion program will not be ready to support an EM-1 launch before July 2020. Despite these delays to the first mission, program officials told us that the Orion program is working towards a September 2022 launch for the second mission, approximately 7 months before the committed EM-2 launch date of April 2023. The program has reported development cost growth of 5.6 percent, but the program's cost estimate only includes cost to the September 2022 launch date with 1 month of funded schedule margin, not the April 2023 launch date. Orion contractor estimates indicate that additional cost growth is likely.

COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The Orion program can no longer support a June 2020 EM-1 launch date, a revised date for the first mission that NASA announced in December 2017. This June 2020 launch date included 6 months of schedule reserve for possible manufacturing and production schedule risks that all three human spaceflight programs—Orion, SLS, and Exploration Ground Systems—might encounter while working toward this first integrated test flight. According to program officials, the recent delay is due to delivery delays for the service module, delays with the crew module, and contractor underperformance. Program officials told us that integration and test efforts are expected to take about 20 months from the delivery of the European service module (ESM)—which occurred in November 2018—to EM-1 launch. As a result, the Orion program will not be ready to support an EM-1 launch before July 2020. Despite these delays to the first mission, program officials told us that the Orion program is working toward a September 2022 launch for the second mission, approximately 7 months before the committed EM-2 launch date of April 2023.

The program has reported development cost growth of 5.6 percent; however, the program has not completed a cost estimate that supports its baseline schedule. The $379 million in development cost growth that the program reported is tied to a September 2022 EM-2 launch. Program officials stated that the cost increase includes 1 month of funded schedule margin, which would leave 6 months under the program's baseline without an associated cost estimate.

Integration and Test

NASA has experienced schedule delays with the service module and the crew module, both of which have threatened the EM-1 schedule. The European Space Agency delivered the European service module later than planned when the Orion program set its schedule baseline, and program officials stated that some of the delays leading right up to delivery resulted from failures during propulsion system testing as well as redesign of some power system components. Completion of the crew module has also been delayed due to a number of avionics component failures during testing. For example, one of the vehicle's global positioning system receivers failed to power up. In another, a part failed on one of the inertial measurement units—which would provide navigation information like vehicle rotation and acceleration. Program officials stated that they have addressed these issues and all of the affected hardware is reinstalled on the vehicle. The program is planning to conduct integrated testing of both the service and crew modules in 2019. Our prior work has shown that the integration and test phase often reveals unforeseen challenges that can lead to cost growth and schedule delays.

Contractor

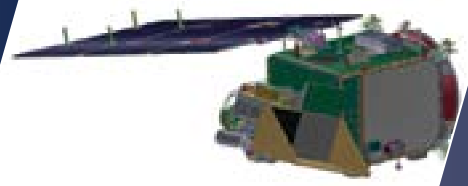
According to program officials—in addition to the ESM delays—the Orion prime contractor has been underperforming and is in the process of renegotiating the contract due to exceeding its period of performance. The contract through EM-2 was to run through December 2020, however—based on the current schedule—that is no longer possible. Further, in June 2018, Lockheed Martin's earned value management system indicates cost growth of about $759 million is likely. When asked how they plan to slow cost growth going forward, Orion contractor officials stated that they are working to address first-build issues to reduce risk on future mission hardware and also working with subcontractors to reduce component costs where possible.

Other Issues to Be Monitored

The program has completed key safety assessments, and according to program officials the first flight risk assessment will be prepared in 2020. NASA's June 2017 analysis found the probability of loss for the integrated SLS and Orion vehicles to be 1 in 140 for the first mission, which meets its objective for EM-1. Officials stated that, per NASA and industry best practices, this analysis assumed a level of system maturity that an unflown SLS vehicle and an unflown Orion crew module have not yet attained. According to officials, NASA will complete a first flight risk assessment a few months prior to EM-1, which will include increased first flight risks and will likely indicate a higher probability of vehicle loss.

PROGRAM OFFICE COMMENTS

In commenting on a draft of this assessment, program officials stated that NASA continues to make progress on the Orion spacecraft that will safely take humans past the moon and return them to earth. The Ascent Abort-2 and EM-1 spacecraft are nearly complete; the EM-2 spacecraft assembly is well underway. The program is managing cost and schedule rigorously. While the Orion life cycle development costs have grown since the 2015 Key Decision Point review, the program is planning to a September 2022 EM-2 launch, well within the schedule commitment of April 2023. Program officials also provided technical comments on a draft of this assessment, which were incorporated as appropriate.



Plankton, Aerosol, Cloud, ocean Ecosystem

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-19-262SP

PROJECT INFORMATION

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

International Partner: **Netherlands (Pending agreement)**

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

Launch Vehicle: **TBD**

Mission Duration: **3 years**

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

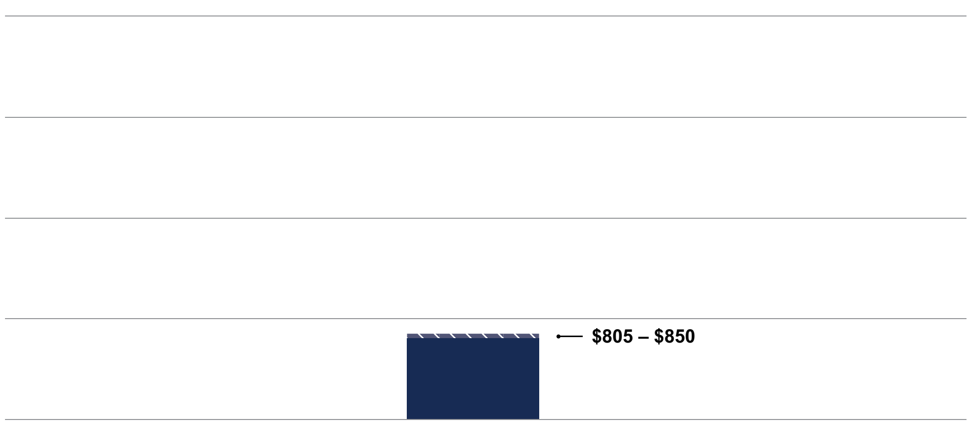
Budget Portfolio: **Science, Earth Science**

PROJECT SUMMARY

The PACE project continues to work towards its preliminary design review with funding uncertainty as the 2020 President's Budget Request did not include a funding request for the project. PACE continues to track risks related to its primary instrument's tilting function. This tilting function is needed to meet a requirement that the instrument tilt to avoid reflection of the sun off the ocean, which would cause data loss. The project also plans to include two small polarimeters to measure how sunlight changes as it passes through clouds, aerosols, and the ocean. According to the project office, PACE has an agreement with the University of Maryland-Baltimore County to provide one polarimeter and is working to finalize an agreement with the Netherlands Institute for Space Research by project confirmation for the second polarimeter. The project is continuing to pursue a shared ride agreement with the Air Force for the launch vehicle. PACE has budgeted $105 million for its launch vehicle, but officials say a rideshare would significantly reduce the project's launch vehicle costs.

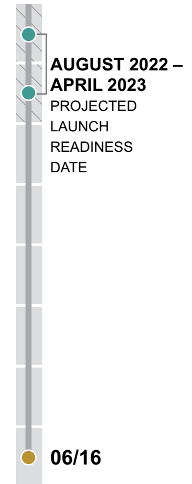
PRELIMINARY COST[a]

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 PACE project is proceeding through the preliminary design and technology completion phase with funding uncertainty. Similar to fiscal years 2018 and 2019, the 2020 President's Budget Request did not include a funding request for the project. The PACE project received funding in fiscal year 2018 and 2019, which has allowed the project to continue work, but it is unknown whether the project will receive any fiscal year 2020 funding. The project continues to use the design-to-cost process that requires it to determine whether its baseline set of capabilities are achievable within the project's $805 million mission cost cap at the 65 percent confidence level. This includes $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 plans to establish its cost and schedule baselines at its confirmation review, currently scheduled for June 2019.

Technology and Design

The PACE project is completing instrument-level design reviews in advance of the project's preliminary design review. The project completed a preliminary design review for its primary instrument, the Ocean Color Instrument (OCI), in May 2018. The project continues to track risks related to the OCI's tilt function, which is necessary to avoid reflection of the sun off the ocean that causes a loss of data. For example, there is a risk that the instrument will exceed its mass allocation, which is constrained by the tilt interface. In an effort to address that risk, the project has eliminated a redundant star tracker, which uses the star field to determine the spacecraft's orientation in space. Officials say this allowed them to increase the instrument's mass allocation from 300kg to 305kg, though they will continue to monitor this risk as they assume there could be mass growth up to critical design review, currently scheduled for January 2020. Officials also say the project maintains the ability to tilt the entire spacecraft instead of the instrument as a backup, though doing so would likely affect coverage.

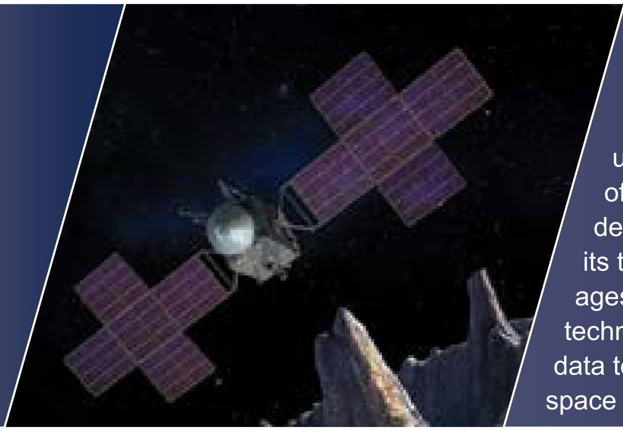
PACE plans to include two small polarimeters—instruments that measure how sunlight changes as it passes through clouds, aerosols, and the ocean—but one of the two agreements with the entities contributing the polarimeters is not complete. Officials say these two polarimeters would provide different science capabilities and would complement each other—the Spectro-Polarimeter for Planetary Exploration (SPEXone) will have a narrow field of view but will offer higher resolution, while the Hyper Angular Rainbow Polarimeter (HARP-2) will have a wider field of view but lower resolution. According to the project office, PACE has an agreement with the University of Maryland-Baltimore County to provide the HARP-2, which passed its preliminary design review in August 2018. A second agreement with the Netherlands Institute for Space Research (SRON) to provide the SPEXone is not yet complete. According to officials, a memorandum of understanding with SRON is needed by project confirmation; however, establishing an agreement at an earlier date would facilitate sharing of technical data.

Launch

The PACE project is continuing to pursue 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 one of the project's top risks, which could cause the project to exceed the $705 million allocated to the project or have to reduce its science capabilities. The project has $105 million budgeted toward the launch vehicle, but officials say a rideshare would significantly reduce costs. NASA and the Air Force have determined there is a path for a shared launch vehicle procurement, but no partner mission has been identified. The project currently plans to begin the procurement process in early 2019 and award the launch vehicle contract in November 2019.

PROJECT OFFICE COMMENTS

The PACE project received a draft copy of this assessment and had no technical corrections or comments.



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 whether it is a planetary core or unmelted material, characterize its topography, assess the elemental composition, and determine the relative ages of its surface regions. The project will also test a new laser communication technology that encodes data in photons rather than radio waves, to enable more data to be communicated in a given amount of time between a probe in deep space and Earth.

Source: NASA/JPL-Caltech/Arizona State Univ./Space Systems Loral/Peter Rubin. | GAO-19-262SP

FORMULATION

- 12/16 Project selection
- 04/18 Project mission system review
- **12/18 GAO 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**

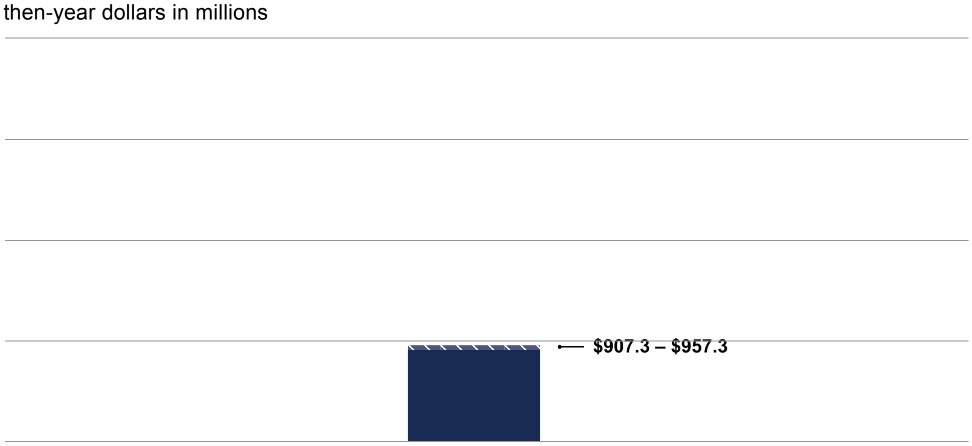
Budget Portfolio: **Science, Planetary Science**

PROJECT SUMMARY

The Psyche project plans to hold its confirmation review in May 2019, at which point it will establish cost and schedule baselines. The project continues to work toward its launch date of August 2022, but the project is experiencing staffing shortfalls at the Jet Propulsion Laboratory that are delaying systems engineering work products and flight software. The Psyche project reported that its design is based heavily on heritage design and that all of its technologies are mature, but the project is carrying risks associated with the heritage designs. For example, a primary risk to mission success is predicted launch environments that exceed some heritage design capabilities. As a result, the project is considering changes to how the instruments are positioned onto the spacecraft and conducting design analysis and additional testing to reduce redesign risks.

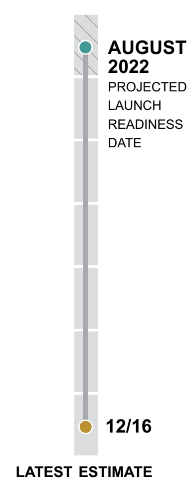
PRELIMINARY COST[a]

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 Psyche project plans to hold its confirmation review in May 2019, at which point it will establish its cost and schedule baselines. The project continues to work toward its accelerated launch date of August 2022, which will allow it to arrive at the target asteroid over 4 years earlier than its original proposed 2023 launch date due to a quicker flight path. The project reported that staffing shortfalls at the Jet Propulsion Laboratory are delaying systems engineering work products and flight software. The project is working to acquire additional systems engineering support and replan the schedule to accommodate software delays. The project is currently holding schedule reserves consistent with Jet Propulsion Laboratory policy, but is slightly below planned cost reserves due to several risks recently being realized.

Technology and Design

The Psyche project reported that its design is based heavily on heritage design and that all of its technologies are mature, but the project is carrying risks that the launch environment will exceed some of the capabilities of the heritage instrument designs. For example, the project is tracking a risk that the predicted shock levels for the imager instrument—a heritage design from the Mars Science Laboratory mission—could be higher than those seen on the earlier mission due to its position on the spacecraft. As a result, qualification testing may be required to resolve the technical issue at increased cost and schedule risk. Additionally, the mechanical and dynamic loads on the Gamma Ray and Neutron Spectrometer instrument—which will be used to determine Psyche's elemental composition—are higher than the previously qualified levels. The project and its contractors are conducting design analysis and investigating alternative mounting options, such as a deployable boom, to reduce vibration levels.

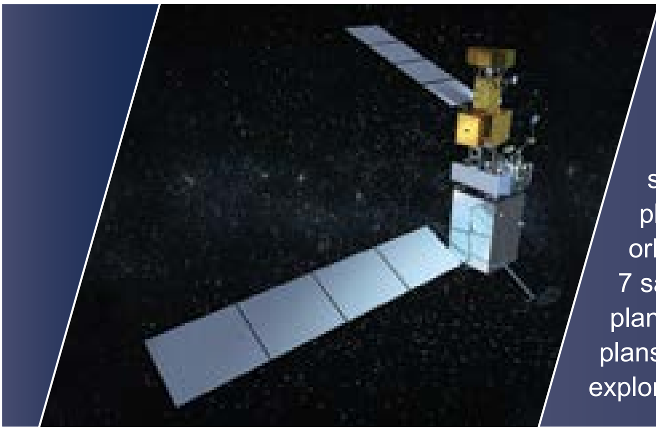
The Psyche project plans to fly with the Deep Space Optical Communications (DSOC) technology demonstration—a laser-based communication device that could be beneficial to future deep space missions requiring high data rates—but considers its potential late delivery as a schedule threat. NASA is developing and funding DSOC as a separate project in the Space Technology Mission Directorate. However, 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

The project continues to assess the risk that it may have to conduct integration and testing off-site because it plans to share a clean room with the Europa Clipper project, which has stricter environmental requirements. The project continues to research potential mitigations, including partitioning the clean room in a cost-effective way that meets both projects' requirements.

PROJECT OFFICE COMMENTS

In commenting on a draft of this assessment, project officials noted that schedule impacts are localized, there has been no impact to the critical path or to integration returns, and that the project still exceeds all project schedule margin requirements. Project officials also provided technical comments on a draft of this assessment, 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. NASA plans to incorporate elements of the core Restore-L technologies into its lunar exploration campaign, such as for refueling the Lunar Gateway.

Source: NASA. | GAO-19-262SP

FORMULATION

- **05/16** Formulation start
- **10/16** System requirements/ mission definition review
- **11/17** Preliminary design review
- **12/18 GAO review**
- **06/19** Critical design review
- **07/19** Project confirmation

IMPLEMENTATION

- **12/20** System integration review
- **12/22** 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**

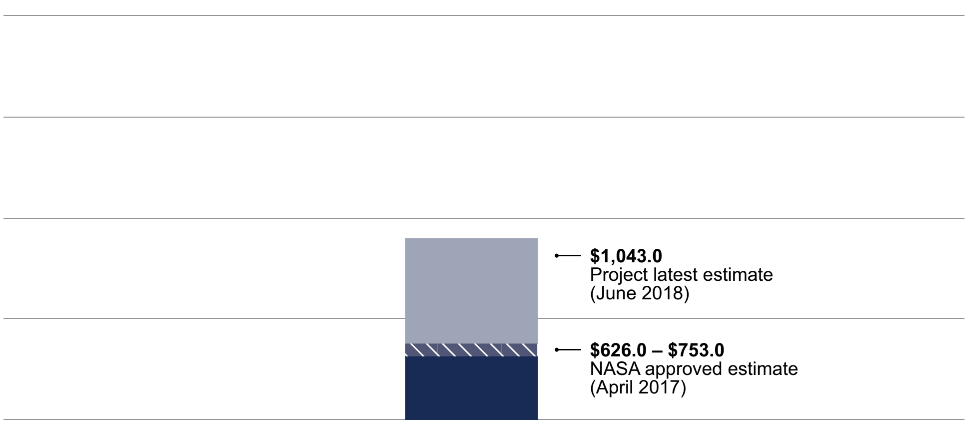
Budget Portfolio: **Space Technology, Research and Development**

PROJECT SUMMARY

The Restore-L project is working to a launch readiness date of December 2022, which is 2 years later than the preliminary launch readiness date that NASA approved when the project entered the preliminary design phase. The project is working to this later date because the Space Technology Mission Directorate's (STMD) proposed funding profile for the project does not allow the project to work to its original schedule. This new funding profile creates several programmatic risks, including having no cost reserves to address risks and unforeseen technical challenges as they occur during development. The project is planning to hold its project confirmation, the point at which the project will formally establish its cost and schedule baselines, in July 2019. If confirmed, the project estimated that its life-cycle costs would be approximately $290 million higher than previously estimated.

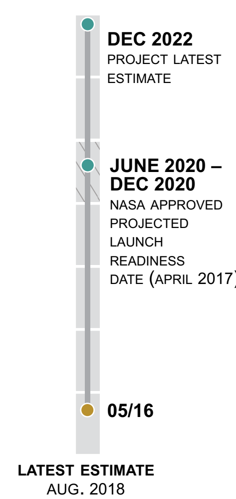
PRELIMINARY COST[a]

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 preliminary cost and schedule estimates that NASA approved when it entered the preliminary design phase because STMD's proposed budget for the project did not allow the project to work to its original funding plan. In April 2017, NASA set a projected launch readiness date between June and December 2020. However, the funding profile STMD proposed for future years would not allow the project to maintain a launch in 2020. After subsequent analysis, STMD authorized the project to proceed to a planned July 2019 project confirmation, the point at which the project will formally establish its cost and schedule baselines, with a flat budget plan of $130 million per fiscal year from 2018 to 2023. STMD also approved a new launch readiness date of December 2022—2 years later than the prior NASA-approved preliminary schedule.

If NASA confirms the project with the proposed flat budget plan, the project's costs will be 39 to 67 percent higher than the prior NASA-approved preliminary cost estimate range. The project estimated that this plan would increase the project's life cycle costs to as much as $1,043 million, approximately $290 million higher than the prior preliminary cost estimate. This estimate includes costs to continue operation of Landsat 7 into fiscal year 2024 because the project's current notional schedule would delay Restore-L's launch outside the servicing window for Landsat 7. The agreed-upon servicing window for Landsat 7 was originally January through September 2021. In addition, the cost estimate includes increased funding for the Robotic Refueling Mission 3, which is a demonstration on the International Space Station that launched in December 2018. The demonstration will test the robotic tools that Restore-L will carry for satellite servicing.

The project's new plan creates several programmatic risks. For example, the project does not have any cost reserves for development. As a result, the project will not have funding set aside to address risks and unforeseen technical challenges as they occur. The project is holding schedule reserves, according to its plan, which project officials said will help offset the negative effects of lacking cost reserves. However, project officials also said that the project may need to use schedule reserves prior to its planned June 2019 critical design review due, in part, to procurement delays and workforce shortages. In addition, the project decided to delay procurement of its launch vehicle to stay within the flat budget each year. The project is working with NASA's Launch Service Program to pursue an 18-month launch vehicle procurement, which is a shorter timeframe than usual. The delayed procurement will result in the project storing Restore-L, when completed, for approximately 6 months prior to launch.

Technology

The Restore-L project has one remaining technology—the vision navigation system—that it needs to mature, and plans to do so by its critical design review. This is later than recommended by best practices, which 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 project did not mature this technology at that review because it was new to the project. Prior to the review, the project found that its prior vision navigation system did not meet requirements and the vendor was unable to resolve the issue. To mature the technology, the project plans to conduct a demonstration of the integrated system using an engineering test unit in May 2019.

PROJECT OFFICE COMMENTS

In commenting on a draft of this assessment, Restore-L officials stated that all estimates of the project launch readiness date and costs are preliminary while the project is in formulation. In addition, officials stated that a comparison of preliminary launch readiness date and cost estimate does not reflect poor project performance. We included a comparison of the previously approved NASA preliminary cost and schedule estimates to the project's current cost estimate and the STMD approved launch readiness date because the project delayed its project confirmation by over a year, from April 2018 to July 2019, and is proceeding with work typically conducted in implementation. Officials also provided technical comments, which were incorporated as appropriate.

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.

Source: NASA. | GAO-19-262SP

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**

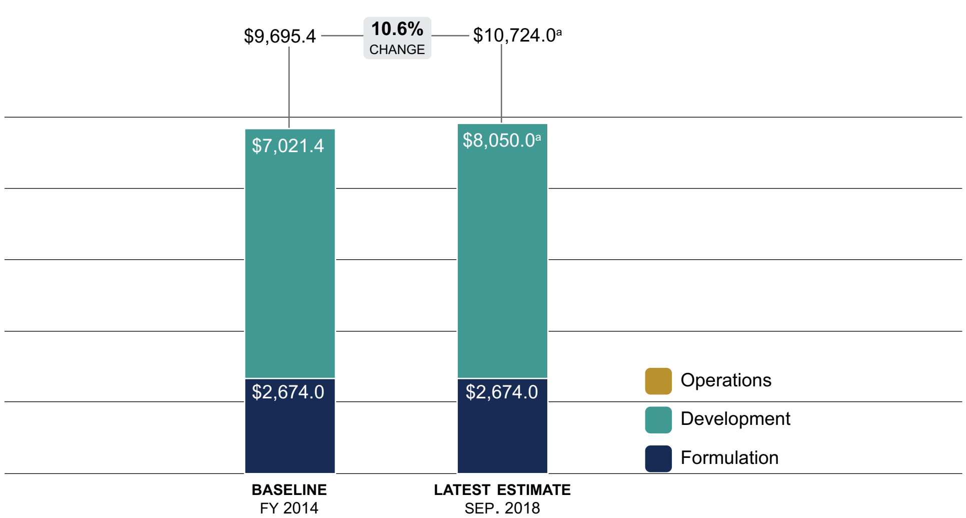
Budget Portfolio: **Exploration, Exploration Systems Development**

PROJECT SUMMARY

The SLS program is unlikely to meet the June 2020 launch date for Exploration Mission 1 (EM-1). As of late 2018, the program reported that the boosters, engines, and upper stage all had schedule reserves—time allocated to specific activities to address delays or unforeseen risks—to support a June 2020 launch. The core stage, however, does not have schedule reserves remaining as the program continues to work through manufacturing issues. According to program officials, Boeing underestimated both the complexity of core stage engine section assembly and the time and manpower that would be needed to complete the core stage effort. As a result, the estimated stages development cost has increased by about $1.4 billion and the stages contract effort now exceeds the contract's negotiated cost ceiling. In September 2018, NASA and Boeing began the process to renegotiate the core stage contract. Further, the program has extensive integration and testing to complete with no schedule reserve before delivery of the core stage to Kennedy Space Center.

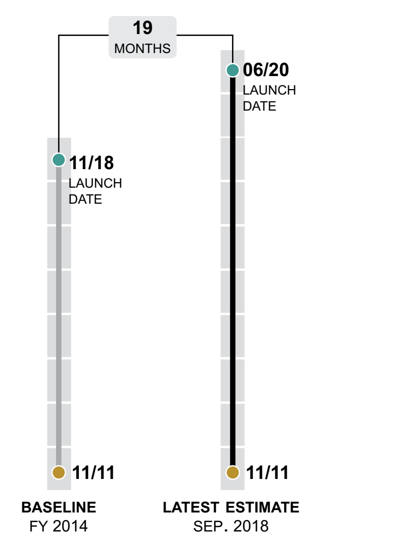
COST PERFORMANCE

then-year dollars in millions



[a]Assumes June 2020 launch date.

SCHEDULE PERFORMANCE



Cost and Schedule Status

Less than one year after announcing a new launch readiness date—December 2019 with 6 months of schedule reserve to June 2020—for EM-1, NASA officials acknowledged the revised December 2019 launch date is unachievable. Further, there are 6 to 12 months of schedule risk associated with the June 2020 date, which means the first launch may occur as late as June 2021 if all risks are realized. Officials attribute the further schedule delay to production challenges with the core stage—which functions as the SLS's fuel tank and structural backbone. According to program officials, Boeing underestimated both the complexity of engine section assembly and the time and manpower that would be needed to complete the effort. For example, in February 2018 the engine section schedule allowed 4 months to complete assembly in June 2018. As of November 2018, the engine section schedule indicated that assembly would be complete in January 2019. In that same timeframe, the delivery schedule to Kennedy Space Center for the program's core stage has slipped 6 months from May 2019 to November 2019.

The total estimated EM-1 stages development cost has increased by about $1.4 billion. NASA officials told us a significant portion of this increase is attributed to the stages contract effort, which now exceeds the contract's negotiated cost ceiling. In September 2018, NASA and Boeing began the process to renegotiate the contract and program costs are expected to increase further based on these negotiations. NASA officials indicated that in the interim, Boeing is working under an undefinitized contract action, which authorizes the contractor to continue work before reaching a final agreement on all contract terms. Further, when updating its cost estimate, the program chose to reallocate some costs for liquid engine development and booster efforts that had been included as part of the SLS EM-1 baseline cost estimate to future missions. These costs remain in the baseline cost estimate but are not included in the updated program cost estimate.

Technology, Design, and Manufacturing

Core stage engine section assembly has been a continuing manufacturing issue for the program. SLS officials indicated the engine section has a very complex design with many parts in a relatively small, cramped area, so any time problems are found with parts that have already been installed, removing, repairing or replacing them often requires that other parts be removed. This became an issue in spring 2018 when NASA discovered that tubing used in the engine section was contaminated with paraffin wax and other debris. As some of the tubing sections had already been installed, resolving this issue affected the program schedule. Further, program officials stated that Boeing initially underestimated the manpower that would be needed to achieve the desired schedule. Program officials indicated that in an effort to recover schedule, Boeing has increased its core stage workforce at the Michoud Assembly Facility from 100 to more than 210 assembly technicians to support three shifts 7 days a week.

Integration and Test

The program has extensive integration and testing to complete, but has no schedule reserve through delivery of the core stage to Kennedy Space Center for the June 2020 launch date. In addition to completing production of flight and test articles, the program has to integrate the engines to the core stage for a green run test. During this test, NASA will fire the four main engines for about 500 seconds. This test will stress the flight components as well as the ground equipment. In addition, Boeing officials indicated the core stage is the largest liquid hydrogen fueled rocket stage ever built and the green run test will be the first time the stage is filled with liquid hydrogen. Contractor officials indicated that one of the top remaining technical risks to the green run test is that the core stage may develop leaks when it is filled. According to these officials, they have conducted extensive scaled testing of the gaskets and seals used in the core stage; however, it is difficult to precisely predict how this large a volume of liquid hydrogen will affect the stage. Should leaks or other issues be discovered, the program will need time to assess and mitigate difficulties or glitches, which could delay the enterprise integration and test schedule.

Other Issues to Be Monitored

The program has completed key safety assessments, and according to program officials the first flight risk assessment will be prepared in 2020. NASA's June 2017 analysis found the probability of loss for the integrated SLS and Orion vehicles to be 1 in 140 for the first mission, which meets its objective for EM-1. Officials stated that, per NASA and industry best practices, this analysis assumed a level of system maturity that an unflown SLS vehicle and an unflown Orion crew module have not yet attained. According to officials, NASA will complete a first flight risk assessment a few months prior to EM-1, which will include increased first flight risks and will likely indicate a higher probability of vehicle loss.

PROJECT OFFICE COMMENTS

In commenting on a draft of this assessment, program officials stated that challenges associated with the first core stage are largely associated with first-time-through complex processes. The government-contractor team is learning from these experiences to refine work instructions that will ensure curtailed processing time on subsequent manufacturing.

Space Network Ground Segment Sustainment

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.

Source: NASA. | GAO-19-262SP

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**

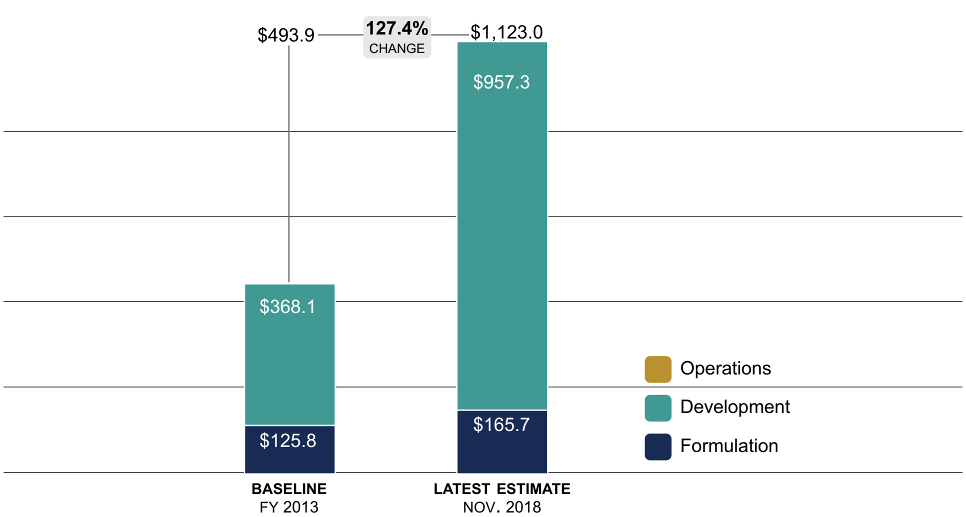
Budget Portfolio: **Space Operations, Space and Flight Support**

PROJECT SUMMARY

The SGSS project is now working toward a final acceptance review date of June 2021—4 years beyond the date agreed to when NASA established the project's baseline in 2013—following a review of the health of the project. The independent review team concluded that no commercial alternatives exist and that terminating the project would provide no residual value to NASA because the agency would still need to complete the upgrades through another effort. Project costs have increased to $1,123.0 million, or 127 percent higher than the costs NASA established in the 2013 baseline. Officials consider the first operational readiness review, scheduled for September 2019, to be the project's most critical remaining milestone because, at this point, 95 percent of the non-recurring engineering work is expected to be complete. Though officials say the project has been meeting most of its milestones recently, the project still has concerns about contractor performance going forward. For example, according to officials, the subcontractor has been unable to provide the necessary staff at the White Sands Complex, leading the contractor to take over the remaining work. This may result in cost increases and inefficiencies.

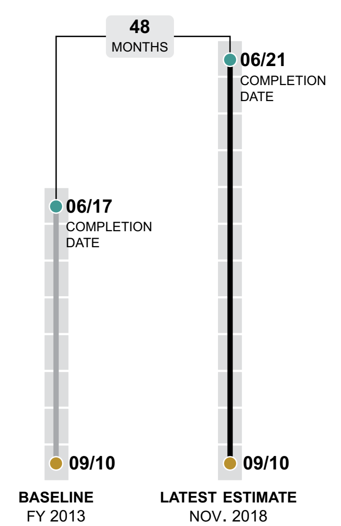
COST PERFORMANCE

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 June 2018, an independent review team recommended continuation of the SGSS project, after having reviewed the project's overall health. The review included whether current cost and schedule estimates were credible, whether there were potential alternatives to the project, and ultimately whether NASA should proceed with or cancel SGSS. The team concluded that there are no commercial alternatives that could meet the project's requirements. Further, the team determined that terminating the project would provide no residual value to NASA because the agency would still need to complete the upgrades through another effort.

Based on these recommendations, the SGSS project will continue to final acceptance review with the stipulation that NASA notify the Office of Management and Budget of any cost or schedule growth, among other things. The project is working toward a final acceptance review date of November 2020, with seven months of schedule reserve available to extend the date to June 2021. The updated project cost is approximately $1.1 billion through the final acceptance review, plus an additional $365.7 million from Space Network users outside of NASA. This represents four years of delays and cost increases of over 127 percent since NASA established a cost and schedule baseline for the project in 2013, while the project's scope has decreased from nine terminals at three sites to six terminals at one site. The project is currently working toward a first operational readiness review date of September 2019, which can be pushed to January 2020 with schedule reserves. Project officials consider the first operational readiness review the most critical milestone for the remainder of the project, as over 95 percent of the non-recurring engineering is expected to be complete by this milestone.

Contractor

Project officials stated the contractor has met about 95 percent of its milestones since replacing the project manager in fiscal year 2017. However, while officials pointed to areas of improvement, there are still some concerns about contractor performance. One concern is that, according to officials, the subcontractor has been unable to provide an adequate number of staff with the appropriate skill level at the White Sands Complex, resulting in the contractor deciding to phase out the subcontractor and take over the remaining work. Officials say this has introduced a new risk that there will be cost increases and inefficiencies as a result, as both the contractor and subcontractor will be working simultaneously for a period of time. Officials say the project will also send its own personnel to the site, such as those with antenna expertise, as they are concerned about the contractor's ability to complete all of the work. Additionally, officials say the contractor needs to improve its systems engineering roles. For example, the project manager is not always kept informed, and in one instance the systems engineering leads were not able to provide a rationale for delaying a test.

Integration and Test

The project continues to track risks related to software defects being higher than baseline model projections. According to officials, integration and test is inherently difficult, and it is not unusual to have to resolve software defects during this time. Officials also stated that these defects to date have not exposed major architectural or design issues. As of November 2018, the project was tracking a risk that verification of these defects, in addition to other integration issues, could exceed the capacity of the integration and test team and affect cost and schedule.

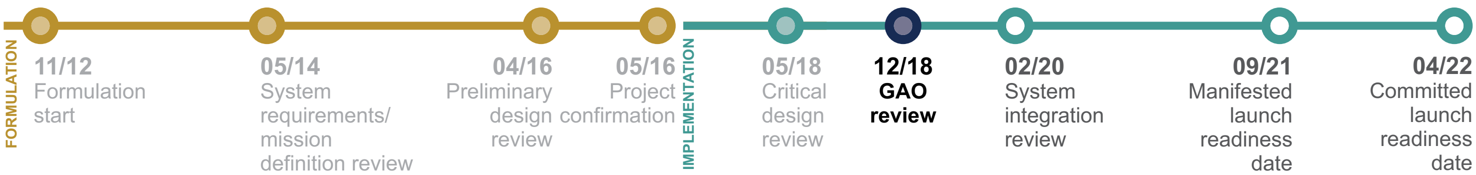
PROJECT OFFICE COMMENTS

SGSS project officials provided technical comments on a draft of this assessment, 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-19-262SP



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**

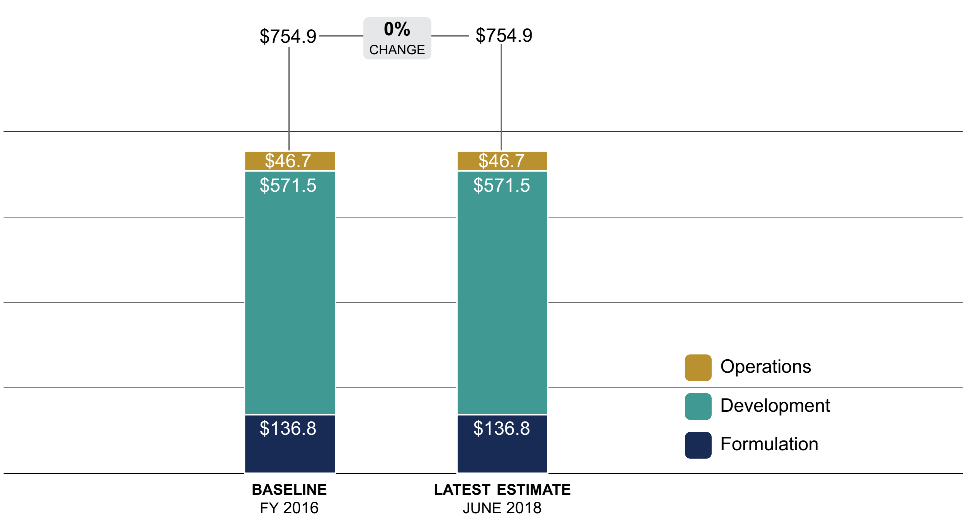
Budget Portfolio: **Science, Earth Science**

PROJECT SUMMARY

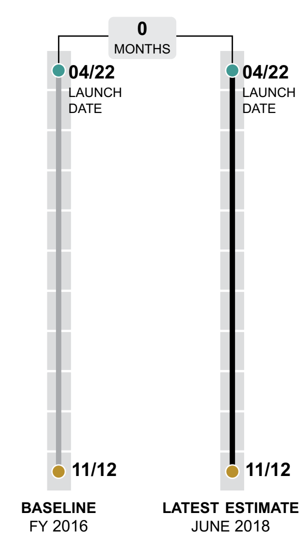
The SWOT project plans to launch before its committed launch date and within its cost baseline despite delays related to its primary instrument, the Ka-Band Radar Interferometer (KaRIn). The current planned launch date is September 2021, which is 7 months prior to the project's committed launch readiness date. SWOT has continued to face issues with KaRIn, the most complicated technology development effort for the project. For example, the project had to redesign, build, and test transformers for the flight-model high-voltage power supply after identifying problems with the quality of transformer parts and to accommodate manufacturing delays with the CNES-supplied Radio Frequency Unit. SWOT completed its critical design review in May 2018 having released about 97 percent of its design drawings, meeting best practices for design maturity. To calibrate and validate the measurements from the KaRIn instrument, the project plans to use an airborne sensor as well as Light Detection and Ranging and a series of underwater gliders.

COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The SWOT project is still operating within its cost and schedule baselines despite delays with its primary instrument, the Ka-Band Radar Interferometer (KaRIn), which is the project's most complicated technology development effort. The project plans to launch in September 2021, which is 7 months prior to its committed launch readiness date. SWOT had planned to launch even earlier, in April 2021, but experienced a 5.5-month delay due to delays related to components of KaRIn such as the radio frequency unit and the high voltage power supply. To cover the cost of this delay, the project received $14 million of the $50 million in NASA headquarters-held reserves—funding that may be used to address issues outside of a project's control—which brought the project's reserves back to planned levels. Due to anomalies identified during testing, project officials anticipate needing about $4 million of reserves while maintaining the remaining $10 million to cover future risks and issues. The project plans to hold its system integration review in February 2020.

Technology and Design

The project completed its critical design review in May 2018 with a stable design. The project conducted the review in two parts, the first in February and the second in May, due to delays with two key components of the KaRIn instrument. These components, the radio frequency unit and the high-voltage power supply, faced manufacturing quality issues and were reviewed after the project's other components. The radio frequency unit will be delivered late from CNES due to manufacturing issues and updates to the firmware of the hyperbox—the digital assembly within the radio frequency unit. In addition, the instrument's high-voltage power supply was delayed due to issues with the quality of transformer parts that required the project to redesign, build, and test the transformers for the flight-model power supply. As of its critical design review, the project released about 97 percent of its design drawings, meeting the best practice of releasing 90 percent of design drawings by critical design review. Our work has shown that meeting this best practice helps to lower the risk of subsequent cost and schedule growth.

In addition, the project experienced several anomalies during testing that affected cost but have not required the use of schedule reserves. In two cases, assumptions in the project's initial analysis of the materials used for the restraint for the KaRIn antenna and for a component of the mechanism that aligns the antenna were incorrect, requiring redesigns. Project officials told us they identified the problems, redid the analyses, and made changes to the materials involved, which they anticipate will resolve the issues. The project also reviewed similar analyses across the system and determined that no additional redesigns were necessary, according to officials.

Other Issues to Be Monitored

The project is tracking a schedule risk involving the availability of testing facilities and services. Although the project has reserved the needed facilities, such as vibration testing facilities, officials noted there is a chance that the availability may change due to large demand from other users, facility breakdown, or changes to the project's own schedule. The project is mitigating this risk by seeking outside facilities as a contingency.

To calibrate and validate the measurements from the KaRIn instrument, the project plans to use an airborne sensor as well as Light Detection and Ranging (LIDAR) and a series of underwater gliders. The airborne sensor will help calibrate and validate measurements for inland waters, whereas the LIDAR and underwater gliders will help the project calibrate and validate measurements for ocean waters as the airborne sensor is not effective for oceans due to heavy wave activity.

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 noted that the project successfully completed its critical design review and that the manufacturing and testing of system components is underway. The project is working with subject matter experts, subcontractors and mission partners to address risks and rectify technical issues while developing workarounds to maintain the project's budget and schedule. SWOT officials also provided technical comments, which were incorporated as appropriate.

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.

Source: NASA. | GAO-19-262SP

FORMULATION
- 02/16 Formulation start
- 03/18 System requirements/ mission definition review
- **12/18 GAO review**
- 11/19 Preliminary design review
- 12/19 Project confirmation

IMPLEMENTATION
- 06/21 Critical design review
- 06/23 System integration review
- 09/25 – 09/26 Projected launch readiness date

PROJECT INFORMATION

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

International Partner: **TBD**

Launch Location: **TBD**

Launch Vehicle: **TBD**

Mission Duration: **5 years (does not include on-orbit commissioning)**

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

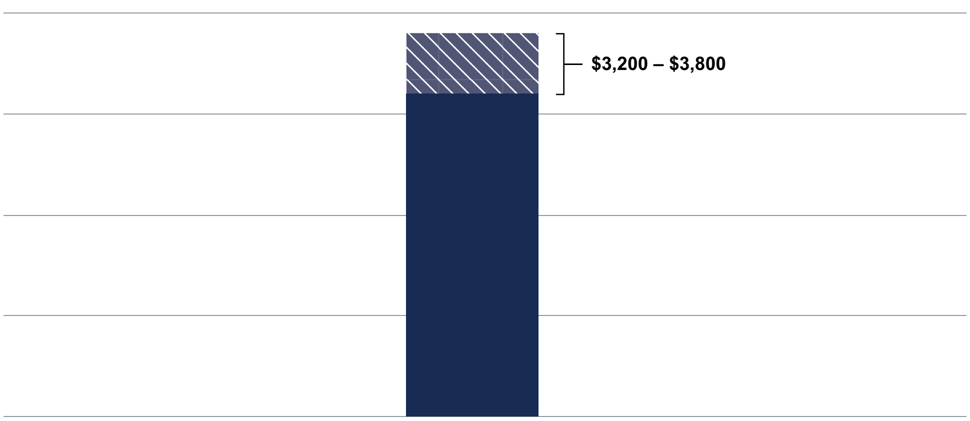
Budget Portfolio: **Science, Astrophysics**

PROJECT SUMMARY

The WFIRST project was approved to proceed with the preliminary design and technology completion phase in May 2018. WFIRST continues to maintain its basic architecture despite having to reduce the cost and complexity of the design in order to stay within the project's $3.2 billion life cycle cost target. This life cycle cost target does not include the costs of the Space Technology Mission Directorate technology contribution. The project reduced costs for the Wide Field Instrument and coronagraph instrument and the coronagraph is being treated as technology demonstration without science requirements, to reduce cost risk. WFIRST has continued to refine its design and make progress, such as the new lighter door design. The President's 2019 Budget Request proposed canceling the WFIRST project. However, the Conference Report accompanying the fiscal year 2019 Consolidated Appropriations Act stated that the Act included no less than $312.2 million for WFIRST for fiscal year 2019. Furthermore, the Conference Report emphasized the need to adhere to the $3.2 billion life cycle cost cap. While NASA again did not request funding in its fiscal year 2020 budget request, the project is working toward its confirmation review, which is planned for December 2019.

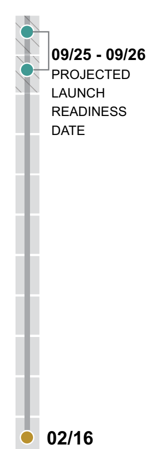
PRELIMINARY COST[a]

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. This range represents the Science Mission Directorate contribution. The Space Technology Mission Directorate will also contribute an additional $134 million to the project.*

PRELIMINARY SCHEDULE



Cost and Schedule Status

The WFIRST project entered the preliminary design and technology completion phase and established preliminary cost and schedule targets in May 2018. The project established a preliminary life cycle cost range of $3.2 to 3.8 billion and set the launch readiness date as September 2025 to September 2026. The preliminary cost range does not include the cost of the Space Technology Mission Directorate technology contribution. The latest cost estimate does include the design changes that resulted from an October 2017 independent review conducted to ensure the mission's scope and required resources are well understood and executable. The independent review found that the project was not executable unless its mission scope was redesigned or its preliminary cost target was increased. Although the project does not commit to a cost baseline until it enters the implementation phase, NASA directed the project to reduce the cost and complexity of the design in order to maintain costs at the bottom of the project's preliminary life cycle cost range—$3.2 billion. NASA concluded that the revised plan for WFIRST was credible, responsive to program requirements, and that the mission was likely to be achieved with the available resources. NASA did not request funding for the WFIRST project in its fiscal year 2019 budget request, but the Conference Report accompanying the fiscal year 2019 Consolidated Appropriations Act stated that the Act included no less than $312.2 million for WFIRST for fiscal year 2019. Furthermore, the Conference Report emphasized the need to adhere to the $3.2 billion life cycle cost cap. While NASA again did not request funding in its fiscal year 2020 budget request, the project is working toward its confirmation review, which is planned for December 2019.

Design and Technology

In response to the independent review findings, NASA directed the project to reduce the project's scope and to decrease its cost. Overall, WFIRST retained its basic architecture, including the 2.4m telescope, Wide Field Instrument, and the Coronagraph Instrument, but some design and requirements changes were necessary to reduce costs. For example, the project reduced some of the capabilities of the Wide Field Instrument—intended to measure light from a billion galaxies and perform a survey of the inner Milky Way. One such capability was the Integral Field Channel, which was eliminated because the international partner was unable to meet schedule requirements. The project saved $50 million in costs associated with accommodating the contribution, and plans to compensate for the loss of the Integral Field Channel by replacing it with a new mode in the Wide Field instrument.

In addition, as part of a review of Wide Field Instrument detector requirements, the project established an overall requirement for all of the detectors combined instead of individual detectors, which the project expects will save time and reduce costs. Further, the Coronagraph Instrument—designed to perform high contrast imaging and spectroscopy of nearby exoplanets—was designated as a technical demonstration without specific science requirements, which further reduces the cost risks to the project. The Coronagraph Instrument will have fewer operational modes while still maintaining essential technology demonstration elements. Project officials stated that the changes the project has made to reduce cost have not reduced the ability of WFIRST to meet science requirements.

NASA continues to make progress in its development of the spacecraft. For example, the project has developed a new lighter door design but it can only be deployed once, which means all necessary course corrections must be completed before the door is deployed according to project officials. In addition, NASA is considering maintaining the capability for WFIRST to use robotic servicing and 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. The costs for the capability to be "starshade ready" and robotic servicing interfaces are included in the $3.2 billion life cycle cost[a]. However, NASA officials stated if NASA later decides to include starshade interfaces, decisions regarding these interfaces that increase scope would also need to be accompanied by a decision to increase cost.

Developmental Partner

NASA is considering several potential contributions from various international partners, including European Space Agency, France, Germany, and Japan, for elements of the Wide Field Instrument, coronagraph, and ground system. For example, NASA is working with the international partners on contribution items such as Star Trackers, a Lithium Ion battery, and ground station for telemetry and tracking. The process for approving these contributions is to be completed prior to project confirmation.

PROJECT OFFICE COMMENTS

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

[a]According to NASA, WFIRST Starshade ready costs include only elements with long lead times that require design or procurements prior to WFIRST critical design review. If a separate starshade project is approved before or at the time of the WFIRST critical design review, the starshade project would cover all subsequent design and accommodation costs.

Agency Comments and Our Evaluation

We provided a draft of this report to NASA for its review and comment. In its written response, reprinted in appendix VI, NASA stated it values GAO's independent perspective on NASA major acquisitions. NASA also noted that it looks forward to continuing to work with GAO to identify and address challenges that may enable cost and schedule improvements.

In commenting on GAO's use of design drawing best practices, NASA stated that it no longer uses the percentage of design drawings released by critical design review as a metric to measure design stability. NASA stated that the design drawing release metric is a legacy standard developed prior to the use of computerized drawings and is no longer an applicable standard for modern NASA projects.

NASA has expressed similar opinions in the past, but our reviews of NASA and DOD projects have found that, generally, programs that complete certain knowledge practices have better cost and schedule outcomes than programs that do not implement those practices. Knowledge that a product's design is stable early in the program facilitates informed decisions about whether to significantly increase investments and reduces the risk of costly design changes that can result from unknowns after initial manufacturing begins. Likewise, later knowledge that the design can be manufactured affordably and with consistent high quality prior to making a production decision ensures that targets for cost and schedule during production will be met.

Further, in light of different opinions about the importance of assessing design stability of a project at the critical design review, GAO convened a panel of experts in the space community in 2013. The experts—both government and industry—identified additional metrics that could buttress the assessment of programs throughout all phases of development, including the program's level of funding reserves and schedule margin. While we incorporated these additional metrics into our assessments of individual projects, they cannot be effectively associated with measurement at any one point in a project's life cycle, which is important to assessing NASA's overall progress in reducing acquisition risk.

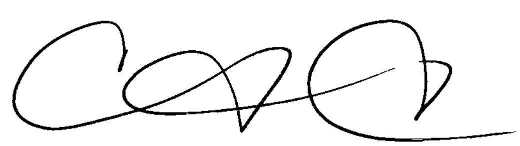
While we continue to believe that having a stable design at a project's critical design review is an important measure and key to successful programmatic outcomes, we understand that technology advancements may have changed the way design drawings are documented and used across NASA. We look forward to continued dialogue with NASA on the best ways to assess design progress in light of these changes.

In commenting on GAO's practice of including projects in formulation, NASA indicated that it would like for GAO to return our focus to projects that have reached confirmation because it can be overly burdensome for projects in formulation to respond to GAO requests for information. GAO has always included projects in formulation since we began this assessment of NASA's major projects in 2009. It is important to include projects that are early in the acquisition lifecycle in order to provide Congress with a complete understanding of the cost, schedule, and technical performance of NASA's portfolio of major projects. Further, project confirmation reviews might be delayed creating a situation where significant risk is behind the project before the project was included in our assessment. For example, this year, NASA delayed the Restore-L project's confirmation review by over a year due to funding issues even though the project is proceeding with activities normally completed after project confirmation. If we focused only on projects that have held a confirmation review, we would not provide Congress with a full understanding of the risks and challenges projects are facing when NASA delays confirmation reviews.

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 Kyrsten Sinema
Ranking Member
Subcommittee on Aviation and Space
Committee on Commerce, Science, and Transportation
United States Senate

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

The Honorable Kendra Horn
Chairwoman
The Honorable Brian Babin
Ranking Member
Subcommittee on Space and Aeronautics
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 critical technologies and (3) the stability of project designs at key points in the development process. We also described the status and assessed the risks and challenges faced by NASA's 24 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 complete individual assessments for three projects that launched during our review, but included data from these projects in other analyses, as appropriate.

This is our 11th annual report assessing selected large-scale NASA program, projects, and activities. To complete our annual assessments, we typically compare cost and schedule performance of NASA's portfolio across each of our reporting periods. The reporting period is the year we issue our report, and we have typically used cost and schedule data that NASA provided to us early in that calendar year. For example, for our last assessment, we based the 2018 reporting period on data NASA provided to us in January and February 2018.[1] Due to the partial government shutdown, which occurred between December 2018 and January 2019 due to a lapse in appropriations for fiscal year 2019, data included in this report is current as of December 2018, unless otherwise noted. This report does not assess the effects, if any, of the partial government shutdown on the cost or schedule of the projects in the portfolio.

To respond to the objectives of this review, we developed several standard data questionnaires. We developed multiple questionnaires, which were completed by NASA's Office of the Chief Financial Officer, to gather data on each project's cost and schedule. We used another questionnaire, which was completed by each project office, to gather data on projects' 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 questionnaire data from our prior reviews.

[1] GAO-18-280SP.

To assess the cost and schedule performance of NASA's major projects, we compared cost and schedule data as of June 2018 provided on questionnaires by NASA for the 17 projects in the implementation phase during our review to previously established cost and schedule baselines.[2] The Commercial Crew Program has a tailored project life cycle and project management requirements, so it was excluded from some analyses. In addition, we assessed development cost and schedule performance for NASA's portfolios of major projects for 2009 to June 2018 to examine longer-term trends. To determine cost performance, we compared the projects' baseline development costs and development costs as of June 2018. For projects that had launched, we used the final development cost data from the project's Key Decision Point E memorandum.

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 current launch readiness or completion date as of June 2018. To understand how NASA is managing large and complex missions within the current budget environment, we examined NASA's budget documentation. We also spoke to officials about NASA's plans for upcoming lunar efforts and to what extent these efforts may become major projects in the future. If a project had a major decision event, such as establishing a cost and schedule baseline, before the end of December 2018, we included that data in our analysis. In addition, NASA provided an updated cost estimate for the Space Launch System as of September 2018 that we included in our analysis.

To assess technology maturity, we asked project officials to complete a questionnaire 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.

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

For the 16 projects that had held a preliminary design review and identified critical or heritage technologies, we compared those levels against our technology maturity best practice 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.

Further, we examined a subset of six projects—those that had not yet passed preliminary design review as of the beginning of our review—to provide observations on the extent to which technology risk across NASA's major projects is reported. Specifically, we collected and analyzed specific information from each project that had not passed preliminary design review as of the beginning of our review on the definitions, processes, and documentation used for identifying critical and heritage technologies. We compared these findings to GAO best practices related to identifying and evaluating technologies as noted in the Technology Readiness Assessment Guide to determine the extent to which technologies and technology maturity levels are identified consistently across NASA's projects and to determine the extent to which technology maturity is underreported. As a case study example, we completed a record of analysis on technology readiness on one project that had not yet reached preliminary design review to determine to what extent the project complied with best practices for technology readiness. We selected the case study project, Europa Clipper, for several reasons including its high life-cycle cost estimate and because the project was approaching its preliminary design review, which is the point in time when projects are expected to have matured their critical technologies. While the case study provides us with a more in-depth understanding of NASA's process for selecting and evaluating critical technologies, we cannot generalize findings from this case study to all of the major projects in NASA's portfolio.

To assess design stability, we asked project officials to complete a questionnaire 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.[3] 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 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 completion of project validation and verification plans, we asked project officials to complete a questionnaire that provided data on whether a plan was completed by the critical design review.

Our work was performed primarily at NASA headquarters in Washington, D.C. In addition, we and other GAO teams working on related reviews

[3]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.

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 individual project assessments for 21 projects in the portfolio with an estimated life-cycle cost greater than $250 million. We did not complete individual assessments for projects that launched during our review. 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 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 questionnaire. For the Commercial Crew program, we obtained cost and schedule data directly from the program. When applicable, we compared the level of cost and schedule reserves held by the project to the level required by center policy.

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 it 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 questionnaire to each project office. In the questionnaire, 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 questionnaire. We then reviewed project documentation—including monthly status reports, 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 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 cost, schedule, launch, contractor, development partner, design, technology, 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 six 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

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

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 2018 to May 2019 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 2019 Report

In 2019, we assessed 24 major NASA projects. Figure 10 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 10: Cost and Schedule of Major NASA Projects Assessed in GAO's 2019 Report by Phase

Phase	Acronym	Project name	Preliminary launch readiness date	Preliminary cost estimate (in millions)
Formulation	Clipper	Europa Clipper	July 2023	$3,100 – $4,000
Formulation	IMAP	Interstellar Mapping and Acceleration Probe	October 2024	$565
Formulation	PACE	Plankton, Aerosol, Cloud, ocean Ecosystem	Aug. 2022 – Apr. 2023	$805 – $850
Formulation	Psyche	Psyche	August 2022	$907.3 – $957.3
Formulation	Restore-L	Restore-L	June – Dec. 2020	$626 – $753
Formulation	WFIRST	Wide-Field Infrared Survey Telescope[a]	Sep. 2025 – Sep. 2026	$3,200 – $3,800

Phase	Acronym	Project name	Current launch readiness date	Current cost estimate (in millions)
Implementation	CCP	Commercial Crew Program—Boeing[b]	January 2020	$7,122.9
Implementation	CCP	Commercial Crew Program—SpaceX[b]	September 2019 (under review)	
Implementation	DART	Double Asteroid Redirection Test	February 2022	$313.9
Implementation	EGS	Exploration Ground Systems	June 2020	$3,230.7
Implementation	ICESat-2	Ice, Cloud, and Land Elevation Satellite-2[c]	September 2018	$1,056.1
Implementation	ICON	Ionospheric Connection Explorer	TBD	$252.7
Implementation	InSight	Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport[c]	May 2018	$813.8
Implementation	JWST	James Webb Space Telescope	March 2021	$9,662.7
Implementation	L9	Landsat 9	November 2021	$885.0
Implementation	LBFD	Low Boom Flight Demonstrator	January 2022	$582.4
Implementation	LCRD	Laser Communications Relay Demonstration	Under revision	Under revision
Implementation	Lucy	Lucy	November 2021	$981.1
Implementation	Mars 2020	Mars 2020	July 2020	$2,460.4
Implementation	NISAR	NASA Indian Space Research Organisation Synthetic Aperture Radar	September 2022	$896.9
Implementation	Orion	Orion Multi-Purpose Crew Vehicle	April 2023	$11,658.1
Implementation	PSP	Parker Solar Probe[c d]	August 2018	$1,548.2
Implementation	SGSS	Space Network Ground Segment Sustainment[e]	June 2021	$1,123.0
Implementation	SLS	Space Launch System	June 2020	$10,724
Implementation	SWOT	Surface Water and Ocean Topography	April 2022	$754.9

Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-19-262SP

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]The cost range for the WFIRST project represents the Science Mission Directorate contribution. The Space Technology Mission Directorate will also contribute an additional $134 million to the project.

[b]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.

[c]The IceSat-2, InSight, and Parker Solar Probe projects launched in 2018.

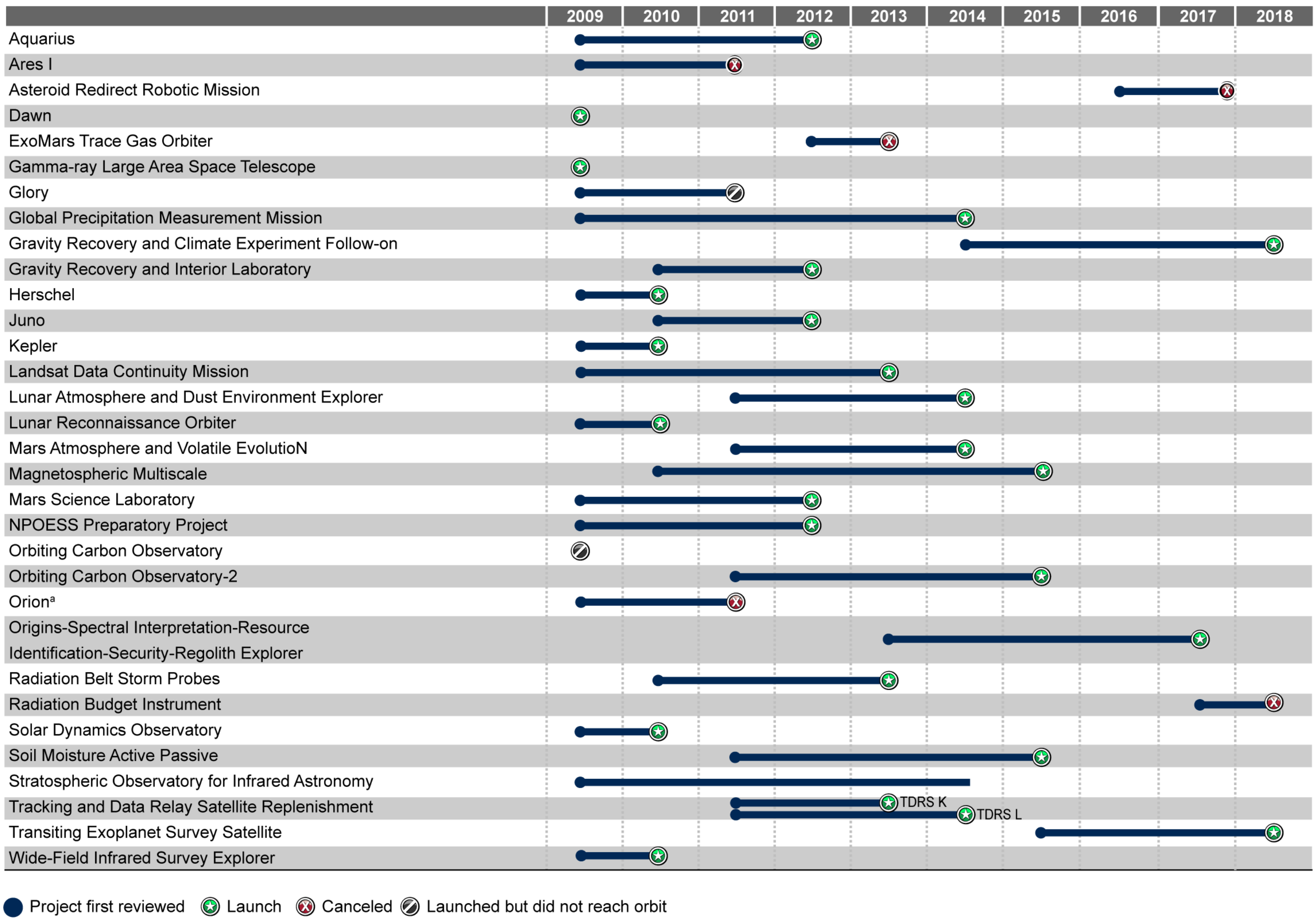
[d]In May 2017, NASA renamed the Solar Probe Plus project as the Parker Solar Probe project.

[e]In 2016, NASA reclassified 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.

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

We have reviewed 56 major National Aeronautics and Space Administration (NASA) projects or programs since our initial review in 2009. Figure 11 provides a list of projects included in our assessments from 2009 to 2018. These projects were not included in the 2019 review because they launched, were canceled, or launched but failed to reach orbit.

Figure 11: Major NASA Projects Reviewed in GAO's Annual Assessments from 2009-2018



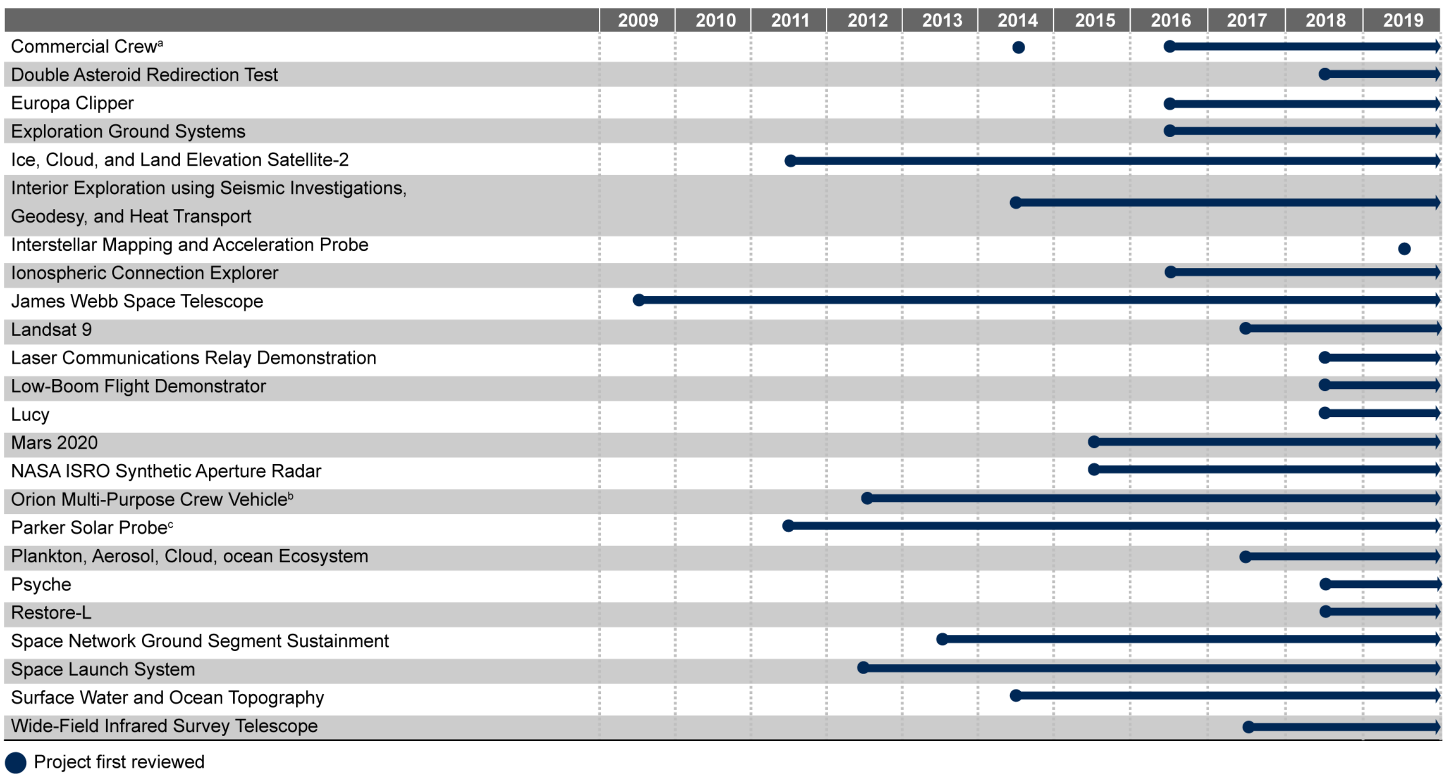
Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-19-262SP

[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.

Figure 12 provides a list of projects included in our 2019 assessment, including when the projects were first included in the review.

Figure 12: Major NASA Projects Reviewed in GAO's 2019 Assessment



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-19-262SP

[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 3: 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 (demonstrates function without considering form or fit). 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.

Technology readiness level	Description	Hardware	Demonstration environment
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.
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 and representation of National Aeronautics and Space Administration data from NPR 7123.1B Appendix E | GAO-19-262SP

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

[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).

that point in time because it generally signifies when the program is 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

May 14, 2019

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-19-262SP). 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.

NASA has long recognized the inherent challenges in managing large, complex space flight programs and has accordingly worked over many years to improve policies and procedures that control cost and schedule while ensuring mission success. In light of recent challenges in cost and schedule growth experienced by several of the Agency's highest profile missions, as well as the ongoing GAO designation of NASA's acquisition management as a high-risk area, NASA established a new Corrective Action Plan (CAP) in December 2018. The CAP contains nine key initiatives designed to strengthen the Agency's cutting-edge program and project management efforts and to improve transparency for NASA's stakeholders. NASA appreciates the GAO's recognition of these initiatives in the assessment and will continue to provide the GAO with updates on our progress against the CAP as successful implementation will contribute to improved programmatic performance across the Agency in the years ahead.

While the GAO continues to apply its design stability best practice metric of 90 percent of design drawings completed by the Critical Design Review, NASA no longer uses this metric internally to measure design stability. In NASA's 2011 response to this audit series, the Agency stated that the design drawing release metric is a legacy standard developed prior to the use of computerized drawings and is no longer an applicable standard for modern NASA projects. Beginning in 2016, NASA's system engineering handbook no longer recommended the 90 percent design drawing metric. While only 40 percent of NASA's major projects had 90 percent or more of their design drawings releasable at Critical Design Reviews held between 2000 and 2018, projects that met the design drawing best practice experienced 18 percent greater cost growth and 16 percent greater schedule growth than those that did not, reinforcing that the current metric may no longer be applicable to measuring NASA project design stability. NASA looks forward to working with the GAO to explore alternative methodologies to measuring project design stability as an indicator for potential cost and schedule issues. Alternative methodologies may include, but are not limited to, metrics identified through the CAP Research Initiative that is currently exploring enhanced implementation indicators and/or those identified through discussions with GAO regarding industry best practices.

NASA agrees with the GAO's finding that there are some instances of inconsistency across the Agency in the definitions and interpretations of technology readiness levels. In light of this recognition, one of the initiatives included in the CAP established in December 2018 is to pursue the creation of a technology readiness assessment best practices document. This effort will capture the technology readiness assessment information across the Agency, identify best practices, and serve as a reference to relevant Agency guidance documents. The intent is to provide best practice information on how to conduct technology readiness assessments as a single resource for projects to access in the formulation phase of their life cycles.

NASA appreciates the GAO's recognition of the complex portfolio budgeting that NASA exercises annually during its budget formulation period. Each year, NASA conducts a sophisticated multi-stage Agency-wide programming phase that considers the multitude of NASA stakeholder priorities and requirements against directed and projected funding availability. Given constrained resources, it is common for difficult decisions to be made in proposed budget content. Any annual appropriations that deviate from the proposed budgets are handled through the established procedures that comply with Congressional transfer limits and all other applicable laws and are executed with the intent to maximize the efficient use of appropriated funds. While appreciating the GAO's finding, NASA recognizes that the prioritization of proposed funding allocations will always represent a challenge. Complicating matters further, the frequent recurrence of Continuing Resolutions leads to uncertainty and inefficiency that can adversely impact our programs' and projects' planning and execution. As always, the Agency remains committed to ensuring good stewardship of the taxpayers' investment in its efforts on behalf of the Nation.

This year's report represents the eleventh annual iteration of the GAO's legislatively mandated assessment of NASA's major acquisitions. Since the inaugural report's issuance in 2009, the GAO has provided NASA with several highly valued insights into various aspects of our acquisition approaches, many of which have resulted in programmatic improvements and enhancements. However, in recent years, NASA perceives a concerning growth in the number of audit inquiries impacting projects and programs early in their life cycles (e.g., Gateway, IMAP, and Clipper). Information requests received during the pre-Phase A and Phase A formulation portions of the life cycle typically target these efforts when project long-term plans and commitments lack the level of detail that the GAO is accustomed to receiving from projects later in their life cycles. During the early life-cycle formulation phases, the projects are in an initial creation state and newly formed project management teams focusing on standing up their organizations often find external inquiry to be premature and overly burdensome. 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 during formulation. NASA would appreciate a return to the original mandate for this important assessment, which focused on major acquisitions that have attained confirmation.

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

Appendix VII: GAO Contact and Staff Acknowledgments

GAO Contact

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

Staff Acknowledgments

In addition to the contact named above, Molly Traci, Assistant Director; Andrea Bivens; Brian Bothwell; Tina CotaRobles; Lorraine Ettaro; Kelly Friedman; Laura Greifner; Kurt Gurka; Erin Kennedy; Meredith Kimmett; Christopher Lee; Jonathan Munetz; Jose A. Ramos; Carrie Rogers; Daniel R. Singleton; Ryan Stott; Roxanna T. Sun; John Warren; Alyssa Weir; Robin Wilson; and Kristin Van Wychen made significant contributions to this report.

Related GAO Products

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