United States Government Accountability Office

Report to Congressional Committees

April 2020

NASA

Assessments of Major Projects

GAO-20-405

GAO

Highlights

Highlights of GAO-20-405, 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. In May 2019, GAO found that the cost of NASA's major projects had grown by almost 28 percent since they were baselined with an average launch delay of 13 months.

Congressional conferees included a provision for GAO to prepare status reports on selected large-scale NASA programs, projects, and activities. This is GAO's 12th annual assessment. This report assesses (1) the cost and schedule performance of NASA's portfolio of major projects and (2) progress NASA has made identifying and addressing challenges that contribute to acquisition risk, among other objectives. This report also includes assessments of 24 major projects, each with a life-cycle cost of over $250 million using 2020 data. To conduct its review, GAO analyzed cost, schedule, technology maturity, and other data; reviewed project status reports; and interviewed NASA officials.

What GAO Recommends

GAO has made a number of recommendations over the last 5 years to improve NASA's acquisition of major projects. NASA has implemented changes in response to many of these recommendations, although 17 recommendations have not yet been fully addressed. NASA generally agreed with the findings in this report.

View GAO-20-405. For more information, contact Cristina T. Chaplain at (202) 512-4841 or chaplainc@gao.gov.

April 2020

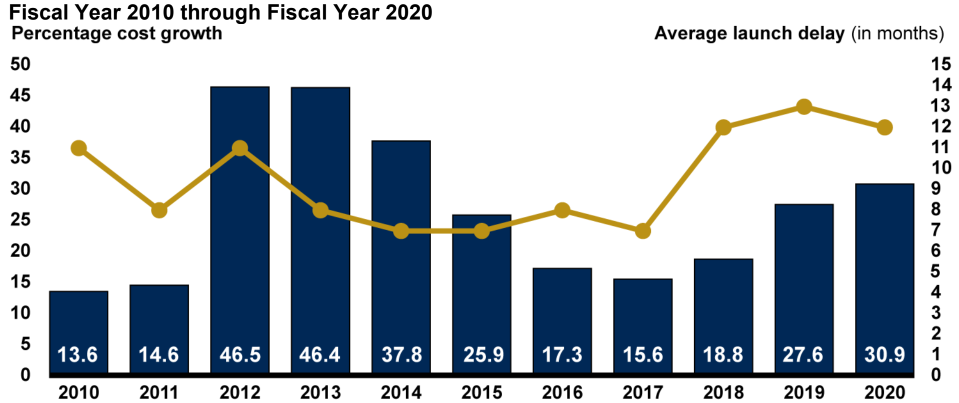
NASA

Assessments of Major Projects

What GAO Found

The National Aeronautics and Space Administration's (NASA) portfolio of major projects continued to experience significant cost and schedule growth this year and the performance is expected to worsen. Since GAO last reported on the portfolio in May 2019, cost growth was approximately 31 percent over project baselines—the third consecutive year that cost growth has worsened after a period of decline. The average launch delay was 12 months, compared to 13 months last year. See figure.

Development Cost Performance and Average Launch Delay for Major NASA Projects from Fiscal Year 2010 through Fiscal Year 2020



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-20-405

Additional cost growth and schedule delays are likely after NASA establishes a new launch date for Artemis I—an uncrewed test flight of the Space Launch System, Orion crew capsule, and associated ground systems. Further, in 2019, GAO found that the Space Launch System (SLS) and Orion programs have underreported cost growth. GAO recommended that SLS calculate cost growth based on costs that are currently included in the first mission and that the Orion program update its cost estimate to reflect the schedule agreed to in its baseline. Both recommendations still require action to address. Looking ahead, NASA will continue to face significant cost and schedule risks as it undertakes complex efforts to return to the moon under an aggressive time frame.

NASA has taken actions to identify and address challenges contributing to its chronic difficulty meeting cost and schedule goals. For example, in response to a GAO recommendation, NASA plans to broaden its use of a project management process known as earned value management. In addition, NASA plans to assess and update its cost and schedule estimates at more points in the acquisition process and bolster its training for analysts who oversee projects. Such actions will help to provide a better foundation for decision-making, but it will take time to assess the extent to which these efforts are having an effect. Further, GAO's work has found that success also hinges on leadership commitment, accountability, and demonstrated progress.

Contents

Tables

Figures

Abbreviations

AEPS	Advanced Electric Propulsion System
AMU	Antenna Management Unit
ASI	Italian Space Agency
CCP	Commercial Crew Program
CDR	Critical Design Review
CGI	Coronagraph Instrument
CNES	Centre National d'Etudes Spatiales
DART	Double Asteroid Redirection Test
EGS	Exploration Ground Systems
ESA	European Space Agency
EVM	Earned Value Management
FTIS	Flight Test Instrumentation System
GFAS	Ground Flight Application Software
GN&C	Guidance, Navigation, and Control System
GRNS	Gamma Ray and Neutron Spectrometer
GSLV	Geosynchronous Satellite Launch Vehicle
HEO	Human Exploration and Operations
ICON	Ionospheric Connection Explorer
ICPS	Interim Cryogenic Propulsion Stage
IFS	Integral Field Spectrograph
IMAP	Interstellar Mapping and Acceleration Probe
IPAO	Independent Program Assessment Office
ISRO	Indian Space Research Organisation
ISS	International Space Station
JCL	joint cost and schedule confidence level
JPL	Jet Propulsion Laboratory
JWST	James Webb Space Telescope
KaRIn	Ka-Band Radar Interferometer
KASI	Korea Astronomy and Space Science Institute
KDP	key decision point
LBFD	Low Boom Flight Demonstrator
LCRD	Laser Communications Relay Demonstration
LICIACube	Light Italian CubeSat for Imaging of Asteroids
LIDAR	Light Detection and Ranging
MDR	Mission Definition Review
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
OLI-2	Operational Land Imager 2

Orion	Orion Multi-Purpose Crew Vehicle
PACE	Plankton, Aerosol, Cloud ocean Ecosystem
PDP	Plasma Diagnostics Package
PDR	preliminary design review
PIXL	Planetary Instrument for X-ray Lithochemistry
PPE	Power and Propulsion Element
PSP	Parker Solar Probe
SCaN	Space Communication and Navigation
SCCS	Spaceport Command and Control System
SCS	Sampling and Caching Subsystem
SDO	Solar Dynamics Observatory
SDR	System Definition Review
SEP	Solar Electric Propulsion
SLS	Space Launch System
SGSS	Space Network Ground Segment Sustainment
SHERLOC	Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals
SIR	System Integration Review
SLS	Space Launch System
SPHEREx	Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ices Explorer
SPIDER	SPace Infrastructure DExterous Robot
SRB	Standing Review Board
STMD	Space Technology Mission Directorate
SWOT	Surface Water and Ocean Topography
SwRI	Southwest Research Institute
TIRS-2	Thermal Infrared Sensor 2
TRA	Technology Readiness Assessment
TRL	Technology Readiness Level
USRA	Universities Space Research Association
WFI	Wide Field Instrument
WFIRST	Wide-Field Infrared Survey Telescope

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

April 29, 2020

Congressional Committees

The National Aeronautics and Space Administration (NASA) is planning to invest at least $65 billion over the life cycle of its current portfolio of 25 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.[1] It 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, Plankton, Aerosol, Cloud ocean Ecosystem (PACE) for Earth science, and the Wide Field Infrared Survey Telescope (WFIRST) for astrophysics.

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 12th annual report responding to that mandate. This report assesses (1) the cost and schedule performance of NASA's portfolio of major projects; (2) NASA's progress developing and maturing technologies and achieving design stability; and (3) NASA's progress identifying and addressing challenges that contribute to acquisition risk. This report also includes individual assessments of 24 major NASA projects. When NASA determines that a project has an estimated life cycle cost of over $250 million, we include that project in our annual review up through launch or completion. We did not complete an individual project assessment for the 25th project, Ionospheric Connection Explorer (ICON), which launched in October 2019, during our review.

[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 projects as major projects rather than large-scale projects as this is the term used by NASA.

To assess the cost and schedule performance, technology maturity, and design stability of NASA's major projects, we collected information on these areas from projects using a questionnaire, analyzed projects' monthly status reports, interviewed NASA project and headquarters officials, and reviewed project documentation. Information available for each project depends on where a project is in its life cycle.[3] For the 18 projects in the implementation phase we compared current cost and schedule estimates as of January 2020 to their original cost and schedule baselines, identified the number of technologies being developed, and compared technology maturity levels at the program's preliminary design review to those levels identified in GAO acquisition best practices and NASA policy.[4] We also compared each project's progress with design drawings at the critical design review against GAO-identified acquisition best practices and analyzed subsequent design drawings changes. We reviewed historical data on cost and schedule performance, technology maturity, and design stability for major projects from our prior reports and compared these data to the performance of NASA's current portfolio of major projects. To assess progress NASA made identifying and addressing challenges that contribute to acquisition risk, we identified and assessed NASA's progress in addressing challenges affecting the portfolio raised in prior GAO work, NASA's Corrective Action Plan to address GAO's high-risk designation, and interviews with senior NASA officials.

To complete our project assessments, we analyzed monthly status reports, analyzed data questionnaires, 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 May 2019 to April 2020 in accordance with generally accepted government auditing standards.

[3]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. 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.

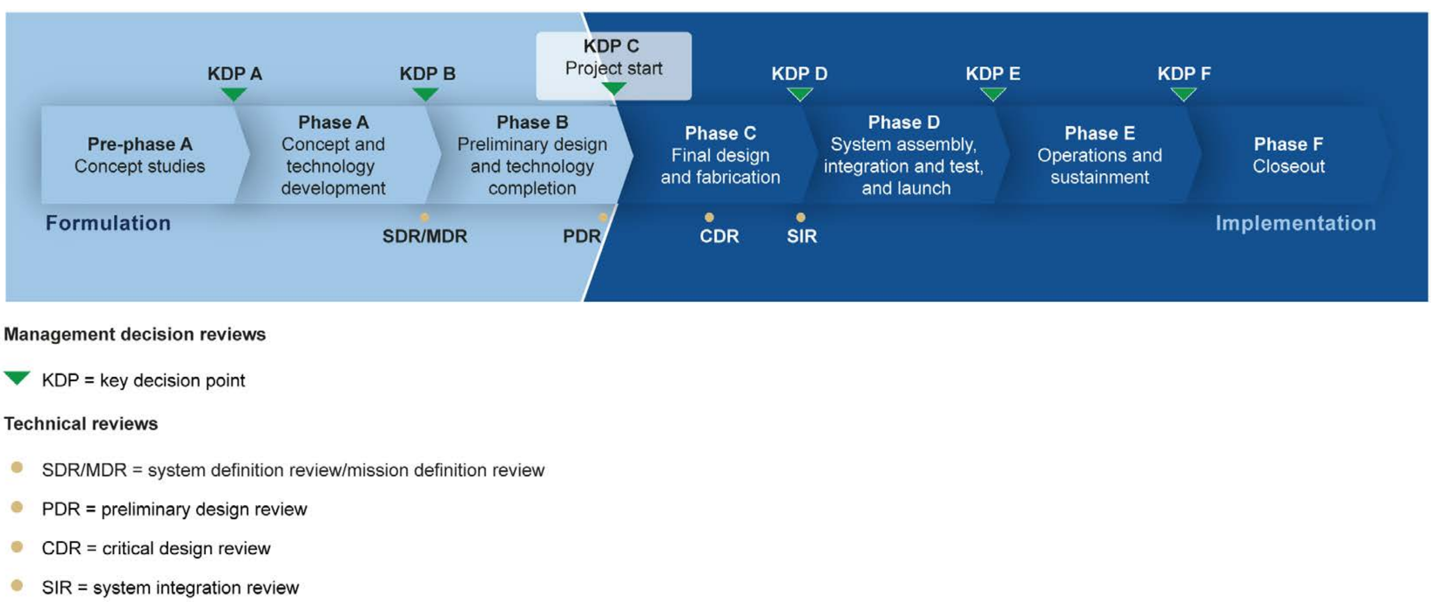
[4]GAO, *Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects [Reissued with revisions on Feb. 11, 2020.],* GAO-20-48G (Washington, D.C.: Jan. 7, 2020). National Aeronautics and Space Administration, *NASA Systems Engineering Processes and Requirements,* NASA Procedural Requirement (NPR) 7123.1C (Feb. 14, 2020).

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 can enter each new phase. Figure 1 depicts NASA's life cycle for space flight projects.

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



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-20-405

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.[5] Prior to entering phase B, projects develop a range of the projects' expected cost and schedule which are used to inform the budget planning for that project. During phase B, the project also develops programmatic measures and technical leading indicators, which track various project metrics such as requirement changes, staffing demands, and mass and power utilization. Near the end of formulation, leading up to the preliminary design review, the project team completes technology development and its preliminary design.

Formulation culminates in a review at key decision point C, where cost and schedule baselines are established, documented, and confirmed 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, and addresses available annual resources. NASA policy requires that projects

[5]Heritage technologies are technologies that have been used successfully in operation. Such technologies may be used in new ways where the form, fit, or function is changed; the environment to which it will be exposed in its new application is different than those for which it was originally qualified, or process changes have been made in its manufacture.

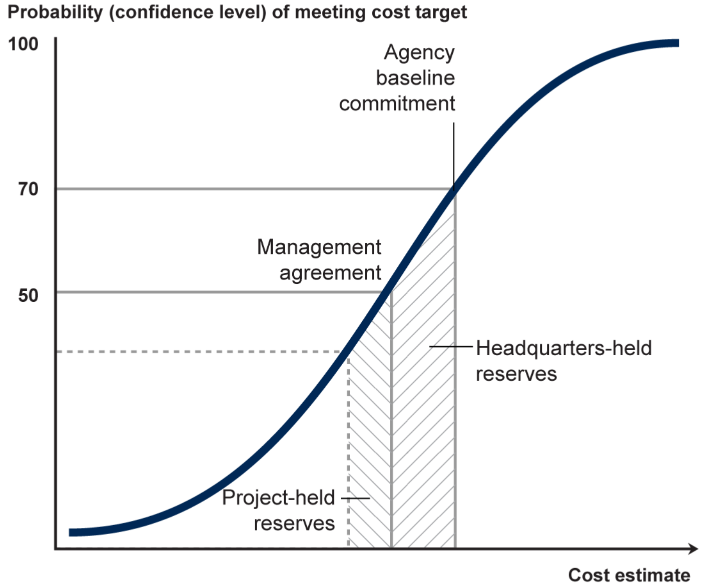
be baselined and budgeted at the 70 percent confidence level and funded at a level equivalent to at least the 50 percent confidence level.[6]

The management agreement and agency baseline commitment include cost and schedule reserves held at the project and NASA headquarters levels, 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 management agreement—for example, if a project needs additional funds for an issue outside of the project's control—NASA headquarters may allocate headquarters-held reserves. Figure 2 notionally depicts how NASA would distribute cost reserves for a project that was baselined in accordance with its JCL policy.

[6]National Aeronautics and Space Administration, *NASA Space Flight Program and Project Management Requirements* paras 2.4.4 and 2.4.4.2, NASA Procedural Requirements (NPR) 7120.5E (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.

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-20-405

The total amount of cost and schedule reserves held at the project level varies based on where the project is in its life cycle. Seven centers or laboratories are responsible for managing 24 NASA major projects. Of these, two centers or laboratories manage 16 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, mission flight 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

[8]National Aeronautics and Space Administration, *Schedule and Budget Margins for Flight Projects,* Goddard Procedural Requirements 7120.7B (Sep. 17, 2018); *Marshall Space Flight Center Engineering and Program/Project Management Requirements,* Marshall Procedural Requirements 7120.1 (Aug. 26, 2014); Langley Research Center, *Space Flight Project Practices Handbook*, LPR 7120.5 B-2 (Mar. 17, 2014); and Jet Propulsion Laboratory, *Flight Project Practices*, *Rev. 8* (Oct. 6, 2010). The Kennedy Space Center and Johnson Space Center do not have center-specific guidance for reserves. The Johns Hopkins University Applied Physics Laboratory manages the Double Asteroid Redirect Test (DART) and Dragonfly projects and has guidelines for schedule reserves, but not for cost reserves. The Johns Hopkins University Applied Physics Laboratory SD-QP-012, Rev. b, *Space Exploration Sector (SES) Quality Procedure: Earned Value Management System (EVMS) Project Management Control System (PMCS)* (Apr. 4, 2017).

site. Projects track their reserves between phases to help ensure they hold reserves consistent with these requirements. The final major project, the Low Boom Flight Demonstrator (LBFD), does not have a lead center because it is using a virtual project office with project members located in different NASA centers. The project office uses 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 in order to determine if the design is mature enough to support proceeding with the final design and fabrication. After the critical design review and just prior to beginning phase D, the project completes a system integration review to evaluate the readiness of the project and associated supporting infrastructure to begin system assembly, integration, and test. In phase D, the project performs system assembly, integration, test, and launch activities. Phases E and F consist of operations and sustainment and project closeout.

NASA Projects Reviewed in GAO's Annual Assessment

NASA's portfolio of major projects includes satellites equipped with advanced sensors to study the Earth, a rover that plans to collect soil and rock samples on Mars, telescopes intended to explore the universe, and spacecraft to transport humans and cargo beyond low-Earth orbit. When NASA determines that a project will have an estimated life cycle cost of more than $250 million, we include that project in our annual review. After a project launches or reaches full operational capability and holds its key decision point E, we no longer include an assessment of it in our annual report.

Table 1 includes a list of all projects included in this report. Four projects are being assessed for the first time this year: 1) Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ices Explorer (SPHEREx), 2) Dragonfly, 3) Power and Propulsion Element (PPE), and 4) Solar Electric Propulsion (SEP). For a list of all the projects and their current cost and schedule estimates, see appendix II. Appendix III includes a list of all the projects that we have reviewed from 2009 to 2020.

Table 1: Major NASA Projects Reviewed in GAO's 2020 Assessment

Projects in formulation	Dragonfly
	Interstellar Mapping and Acceleration Probe (IMAP)
	Power and Propulsion Element (PPE)
	Restore-L
	Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ices Explorer (SPHEREx)
	Wide Field Infrared Survey Telescope (WFIRST)
Projects in implementation	Commercial Crew Program (CCP)
	Double Asteroid Redirection Test (DART)
	Europa Clipper
	Exploration Ground Systems (EGS)
	Ionospheric Connection Explorer (ICON)[a]
	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)
	Plankton, Aerosol, Cloud, ocean Ecosystem (PACE)
	Psyche
	Solar Electric Propulsion (SEP)
	Space Launch System (SLS)
	Space Network Ground Segment Sustainment (SGSS)
	Surface Water and Ocean Topography (SWOT)

Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-20-405

[a]The ICON project launched in 2019.

Over the past 8 years, we have issued several reports assessing NASA's progress in acquiring its largest projects and programs in more depth.[9] For example, in December 2019, we found that NASA had quickly refocused its acquisition plans to support accelerated plans to land astronauts on the moon by 2024. We reported, however, that some decisions related to requirements, cost, and schedule for the lunar mission were lagging.[10] We recommended that NASA define and

[9]See related GAO products at the end of this report.

[10]GAO, *NASA Lunar Programs: Opportunities Exist to Strengthen Analyses and Plans for Moon Landing,* GAO-20-68 (Washington, D.C.: Dec. 19, 2019).

schedule reviews that align requirements across lunar programs and create a cost estimate for the first lunar mission. NASA agreed with these and other recommendations and outlined steps to implement them with expected completion dates ranging from April 2020 to September 2021.

Further, key to NASA's plans to return to the moon are three programs—Space Launch System (SLS), Orion crew capsule, and the associated ground systems at Kennedy Space Center—that have been under development for several years. After a series of delays, NASA is reevaluating the planned June 2020 launch date for the first integrated test flight of these systems, an uncrewed mission known as Artemis I. We have made 20 recommendations in prior reports to strengthen NASA's acquisition management of these three programs. NASA generally agreed with our recommendations and has implemented eight of the recommendations. Further action is needed to fully implement the remaining recommendations. For example, in 2019, we recommended that NASA direct the SLS and Orion programs to reevaluate their strategies for incentivizing contractors and determine whether they could more effectively incentivize contractors to achieve the outcomes intended as part of ongoing and planned contract negotiations.[11] NASA agreed with the intent of this recommendation and stated that the SLS and Orion program offices will reevaluate their strategies for incentivizing contract performance as part of contracting activities, including contract restructures, contract baseline adjustments, and new contract actions. We will continue to follow up on the actions the agency is taking to address this recommendation.

We have also reported for several years on the James Webb Space Telescope (JWST) project, which has experienced significant cost increases and schedule delays. Prior to being approved for development, cost estimates for JWST ranged from $1 billion to $3.5 billion, with expected launch dates ranging from 2007 to 2011. Before 2011, early technical and management challenges, contractor performance issues, low levels of cost reserves, and poorly phased funding levels caused JWST to delay work after confirmation, which contributed to significant cost and schedule overruns, including launch delays. Following an independent review that found JWST was executing well from a technical standpoint, but that the baseline cost estimate did not reflect the most

[11]GAO, *NASA Human Space Exploration: Persistent Delays and Cost Growth Reinforce Concerns over Management of Programs,* GAO-19-377 (Washington, D.C.: June 19, 2019).

probable cost with adequate reserves in each year of project execution, Congress placed an $8 billion cap on the formulation and development costs for the project in November 2011. NASA rebaselined JWST with a life cycle cost estimate of $8.835 billion that included additional funding for operations and a planned launch in October 2018.[12]

Subsequently, problems discovered during testing caused multiple delays that led NASA to replan the project in June 2018. Now estimated at $9.7 billion, the project's costs have increased by 95 percent and its launch date has been delayed by over 6.5 years since its cost and schedule baselines were established in 2009. In January 2020, we found that the JWST project had made significant progress, including completing testing of the observatory's individual elements and integrating them together, but the project estimates only a 12 percent likelihood of meeting its most recent planned March 2021 launch date.[13]

NASA's Major Project Portfolio's Cost and Schedule Performance Expected to Worsen and Challenging Lunar Programs Beginning

The cost performance of NASA's portfolio of major projects has worsened for the third consecutive year, while the average schedule delay has decreased. Since we last reported in May 2019, cost growth has increased from 27.6 percent to approximately 31 percent. The average launch delay decreased from 13 months to approximately 12 months.[14] Our analysis shows that NASA's cost and schedule performance is expected to deteriorate as a result of several factors, including likely Artemis I delays and understated cost growth for the Orion and SLS programs. According to NASA officials, the partial government shutdown that occurred between December 2018 and January 2019 did not affect projects' cost and schedule baselines, but these officials identified varying other effects including the use of cost and schedule reserves. Looking forward, programs that will be part of NASA's plans to conduct a lunar

[12]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).

[13]GAO, *James Webb Space Telescope: Technical Challenges Have Caused Schedule Strain and May Increase Costs,* GAO-20-224 (Washington, D.C.: Jan. 28, 2020).

[14]GAO, *NASA: Assessments of Major Projects,* GAO-19-262SP (Washington, D.C.: May 30, 2019).

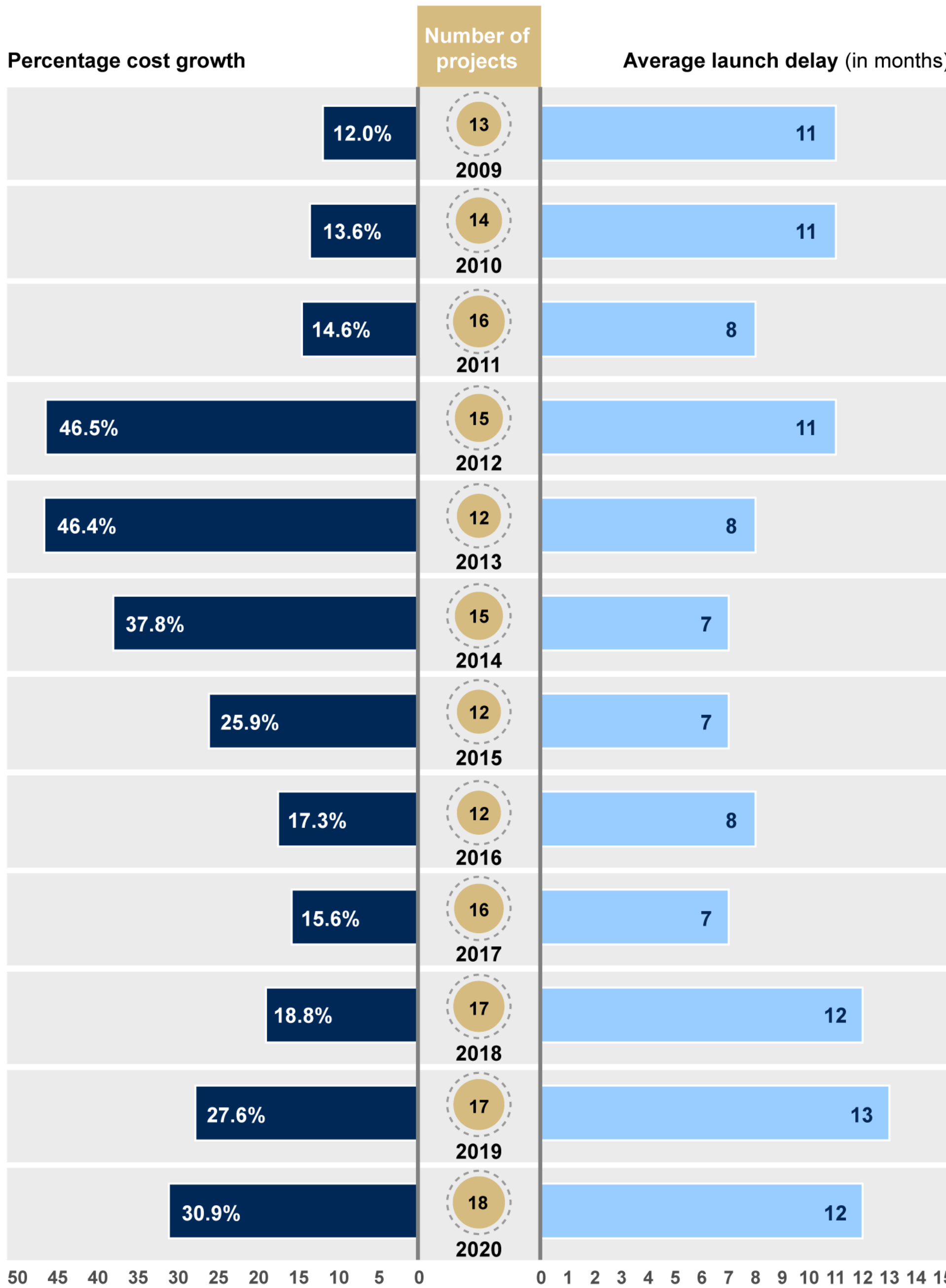
landing in 2024 will begin to enter the portfolio and present additional cost and schedule risks as NASA works toward this aggressive target date.

Negative Cost and Schedule Performance Will Be Further Exacerbated by Pending Artemis I Delay

The cost performance of NASA's portfolio of major projects continues to deteriorate for the third consecutive year and both cost and schedule performance are expected to worsen when NASA announces a new schedule for the Artemis I mission.[15] Overall development cost growth was approximately 31 percent, compared with 27.6 percent cost growth reported last year, and the average launch delay was approximately 12 months, compared with the 13 month delay that we reported last year (see fig. 3).

[15]GAO-19-377.The Artemis I mission is the first planned uncrewed demonstration mission of the Space Launch System, Orion Multi-Purpose Crew Vehicle, and Exploration Ground Systems programs. The Artemis II mission is the first planned crewed demonstration mission of these programs.

Figure 3: Development Cost Growth Performance and Average Launch Delay for Major NASA Projects from 2009 to 2020



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-20-405

Note: The years in the figure are the year we issued the report. Cost and schedule performance is compared across each report period (i.e., from one year to the next). In 2018, we were not able to determine the full extent of portfolio cost growth as NASA did not have an updated cost estimate for the Orion program at that time.

Since we last reported, our analysis found that six projects reported development cost growth, with four of these projects also reporting schedule delays. Two projects reported a development cost decrease. The remaining projects stayed within cost and schedule estimates since we last reported. Table 2 provides data on the cost and schedule performance of the 18 major projects in development that have cost and schedules baselines since our last assessment.[16]

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

			Cumulative performance from original baseline through current assessment		Changes between last GAO assessment and current assessment	
Overall performance	**Project**	**Year confirmed**	**Cost (millions of dollars)**	**Schedule (months)**	**Cost (millions of dollars)**	**Schedule (months)**
Lower than expected cost	NISAR	2016	-20.6	0	-42.6	0
	Lucy	2018	-8.0	0	-8.0	0
Within baseline	DART	2018	0.0	0	0.0	0
	Europa Clipper	2019	0.0	0	N/A	N/A[f]
	Landsat 9	2017	0.0	0	0.0	0
	LBFD	2018	0.0	0	0.0	0
	PACE	2019	0.0	0	N/A	N/A[f]
	Psyche	2019	0.0	0	N/A	N/A[f]
	SEP	2020	0.0	0	N/A	N/A[f]
	SWOT	2016	0.0	0	0.0	0
Higher than expected cost	ICON[a]	2014	9.4	24	7.2	10
	Orion[b]	2015	918.2	0	539.2	0
Replan[c]	EGS[d]	2014	485.5	28	64.1	9
	Mars 2020	2016	359.3	0	310.9	0
	SLS[d]	2014	1,728.8	28	700.2	9
Rebaseline[e]	LCRD	2017	36.8	14	36.8	14
	SGSS	2013	589.2	48	0.0	0
	JWST	2008	4,421.5	81	0.0	0
	Total		**$8,520.1**	**223**	**$1,607.8**	**42**

Legend: DART Double Asteroid Redirection Test;: NISAR: NASA Indian Space Research Organisation – Synthetic Aperture Radar; LBFD: Low Boom Flight Demonstrator; PACE: Plankton, Aerosol, Cloud, ocean Ecosystem; SEP Solar Electric Propulsion; SWOT: Surface Water and Ocean Topography;

[16]GAO-19-262SP.

ICON: Ionospheric Connection Explorer; Orion: Orion Multi-Purpose Crew Vehicle; EGS: Exploration Ground Systems; SLS: Space Launch System; LCRD: Laser Communications Relay Demonstration; SGSS: Space Network Ground Segment Sustainment; JWST: James Webb Space Telescope.

Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-20-405

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

[a]ICON launched in 2019.

[b]The Orion program's cost and schedule baseline is tied to the crewed Artemis II mission.

[c]A replan is a process generally initiated if development costs increase by 15 percent or more. NASA replanned the SLS program even though development costs did not increase by 15 percent or more. A replan does not require a new project baseline to be established.

[d]The SLS and EGS programs' cost and schedule baselines are tied to the uncrewed Artemis I mission.

[e]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).

[f]Project crossed from formulation to implementation during our review period.

Cost growth and schedule delays since our last assessment occurred for the following reasons:

- The Orion program reported $539.2 million in development cost growth since our last assessment due to effects from the Artemis I uncrewed test flight's schedule slipping and poor contractor performance. The program reported no schedule delays because it has not delayed its launch readiness date of April 2023 for the crewed Artemis II test flight. This test flight is the milestone against which NASA assesses the Orion program's schedule performance.
- The SLS and EGS programs reported a combined $764.3 million in development cost growth since our last assessment due to poor SLS program performance and schedule delays. Both programs are now estimating costs to achieve a launch readiness date of March 2021. This represents an additional 9 months of delay since our last assessment, but, as of January 2020, this date was still under review by NASA leadership.
- The Mars 2020 program reported development cost growth of $310.9 million due to multiple development difficulties, delayed deliveries, and higher than anticipated procurement costs. The program reported no schedule delays as it continues to work towards its July 2020 launch readiness date.
- The Laser Communications Relay Demonstration (LCRD) program reported development cost growth of $36.8 million due to a slip in the

launch readiness date of its host spacecraft from November 2019 to January 2021 and unexpected work on a key component.

- The Ionospheric Connection Explorer's (ICON) program reported $7.2 million cost growth and experienced an additional 10-month delay due to delays related to its launch vehicle. The project successfully launched in October 2019.

Two projects reported a cost decrease since the last update:

- Lucy reported $8 million less in development costs due the launch vehicle procurement cost being less than originally estimated when NASA approved the project's cost and schedule baseline.
- The NASA Indian Space Research Organisation Synthetic Aperture Radar (NISAR) reported a development cost decrease. NASA reduced NISAR's reserves by $20.6 million because it had assessed that the project's risk posture had improved and these reserves were no longer necessary. We previously reported that NISAR was not meeting its cost baseline because of $30 million in cost growth associated with plans to collect additional soil moisture and natural hazard data of value to other federal agencies and the science community.[17] While NISAR is continuing to develop the capabilities to collect these additional data, NASA has subsequently made a decision to no longer include these costs as part of NISAR's cost estimate because they were not part of the baseline plan.

While our analysis reflects the status of cost and schedule for these major programs as of January 2020, it does not account for expected changes to the portfolio's cost and schedule performance due to pending schedule revisions and underreported costs for human exploration programs. Specifically, the portfolio analysis does not reflect an agency-approved schedule for the Artemis I mission because it had not been finalized at the time of our review. In July 2019—following the reassignment of key leadership that oversees the programs—the NASA Administrator stated that one of the first tasks once new leadership is in place would be to reexamine the Artemis I schedule. According to officials, the new Associate Administrator for Human Exploration and Operations joined NASA on December 2, 2019. As of January 2020, this schedule revision was still pending and both programs were estimating costs to a March 2021 launch date. In June 2019, we found the date could be as late as

[17]GAO, *NASA: Assessments of Major Projects,* GAO-18-280SP (Washington, D.C.: May 1, 2018).

June 2021 when all risks at that time were taken into account.[18] Further delays beyond March 2021 would lead to further cost growth.

In addition, the SLS and Orion programs are underreporting their cost growth. Specifically, in 2019, we found that the Orion program was not estimating costs to its committed Artemis II baseline launch date of April 2023.[19] Rather, at that time, the program was estimating costs to an October 2022 launch date. We recommended that NASA direct the Orion program to update its cost estimate to reflect the later schedule. NASA partially concurred with this recommendation stating that the program followed standard estimation processes. Further action is needed to implement this recommendation. Similarly, while NASA acknowledges cost growth for the SLS program, the amount is understated. In 2019, we found this gap resulted because NASA shifted some planned SLS scope to future missions but did not reduce the program's cost baseline accordingly. At that time, when we reduced the baseline to account for the reduced scope, the cost growth was about $1.8 billion or approximately 29 percent. We recommended that SLS update its development cost to be consistent with costs and scope, including costs NASA determined are not in the scope of the first flight. NASA agreed with this recommendation and said it would update the SLS development cost estimate as it proceeds with lunar planning efforts, but this effort is not yet complete.

Government Shutdown Had Various Effects on Projects but Did Not Affect Cost and Schedule Baselines

For 35 days between December 2018 and January 2019, NASA was subject to a partial government shutdown due to a lapse in fiscal year 2019 appropriations. The shutdown resulted in varying effects on NASA's major projects. Effects included delaying key milestone reviews and procurements, but, according to a senior NASA project official, it did not result in breaches of cost and schedule baselines for any projects in the major project portfolio.[20]

Fourteen of 23 projects continued work during the shutdown. Of these 14 projects, seven projects are managed at the Applied Physics Laboratory—a University Affiliated Research Center—and the Jet

[18] GAO-19-377.

[19] GAO-19-377.

[20] This discussion includes 23 of the 25 projects in the major-project portfolio. SPHEREx and Dragonfly are not included because they entered the portfolio after the government shutdown.

Propulsion Laboratory (JPL)—a Federally Funded Research and Development Center—both of which continued operations throughout the shutdown.[21] NASA granted exceptions to the remaining seven projects to continue work, but not all projects received immediate exceptions and officials stated that there were still effects from the shutdown. For example, Landsat 9 was granted an exception approximately 2 weeks into the shutdown. Project officials stated that they accommodated schedule delays by adjusting projected delivery dates for two instruments and using project cost reserves to address cost impacts. The project still plans to launch by its committed launch readiness date. Additionally, officials from various projects that continued to operate noted that NASA was closed, which delayed key meetings and normal coordination with civil-service personnel.

The remaining nine projects in the portfolio that did not operate during the shutdown experienced varying effects from the shutdown, including delaying key milestone reviews, procurements, and hiring, as well as the inability to process invoices and loss of critical skills. Specific examples reported to us from projects in the implementation phase at the time of the shutdown include:

- LBFD delayed several of the project's key milestone dates, including the project's critical design review and flight readiness review, by approximately 5 weeks. Project officials stated they used $5.4 million in cost reserves to absorb the effects of the shutdown. However, officials noted that the decrease of the project's reserves increases risk going forward. The project requested the restoration of the $5.4 million in funds expended as a result of the shutdown through NASA's annual budget process. NASA officials told us a decision will not be made before spring 2020.
- EGS, according to project officials, experienced a schedule delay of around 27 days to Multi-element Verification and Validation. This is 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. NASA officials estimated a $2 million cost associated with this delay. In addition, officials noted that, while construction activities were allowed to proceed, some critical skills such as iron and tubing workers were lost due to uncertainty

[21]The projects that had funding ahead of the shutdown to continue working included DART, Europa Clipper, IMAP, Mars 2020, NISAR, Psyche, and SWOT.

regarding the duration of the government shutdown and the inability to process contractor invoices.

- SGSS—a project that has reported long-standing issues with contractor performance—reported cost and schedule impacts caused by the project not having access to NASA's White Sands Complex, the government shutdown, and a decline in contractor performance. As a result, the project was unable to perform integration and testing activities that were on the project's critical path, affecting the date for the project's first operational readiness review.
- Orion and SLS received partial exceptions to continue critical path work on Artemis I. However, both projects reported effects from the shutdown beyond Artemis I work including delays to procurement activities.

Specific examples reported to us among projects in the formulation phase at the time of the shutdown include:

- PACE established its cost and schedule baselines in August 2019, at which time it included approximately $34 million in costs above its preliminary cost estimate due to delays resulting from the government shutdown.
- WFIRST had to revise its schedule to accommodate 5 weeks of schedule impacts, but the project has not yet established a cost or schedule baseline so the government shutdown did not affect a launch readiness date. Project officials stated they used cost reserves to address $25 million of cost impacts.
- Restore-L incurred a 1-month delay to the project's overall schedule, the consumption of 1-month of schedule margin, and the use of $14 million of the project's cost reserves. The shutdown also resulted in delayed hiring of key positions.
- PPE delayed its planned contract start date from March 2019 to the end of May 2019, which also resulted in a delay to the project's preliminary launch readiness date.

Portfolio Analysis Does Not Yet Reflect New, Large Lunar Projects

Because our cost and schedule analysis in this report is as of January 2020, it does not include new, large lunar projects that will support NASA's efforts to return to the moon. The initial effect will be a reduction in cost and schedule growth because new projects are less likely to have experienced cost and schedule growth, but there is a longer-term risk because the programs themselves are risky. Six new lunar projects are likely to enter the implementation phase soon to meet a human lunar landing by 2024, which we have previously identified as an aggressive schedule.[22] NASA expects four lunar projects to exceed the $250 million major project threshold. However, not all cost estimates are finalized, and none of these projects have established cost and schedule baselines. These efforts include three projects that compose a small platform in lunar orbit called Gateway— PPE, Habitation and Logistics Outpost, and Logistics—and the Human Landing System. NASA has not yet determined whether two other lunar projects—Volatiles Investigating Polar Exploration Rover and Space Suits—will exceed the $250 million threshold.

NASA originally planned a lunar landing for 2028. However, as we have reported, in March 2019, the White House directed NASA to accelerate its plans and return astronauts to the lunar surface by 2024. This timeline was established, in part, to create a sense of urgency regarding returning American astronauts to the Moon. NASA senior officials have acknowledged the aggressiveness of this accelerated schedule. In December 2019, we found that effectively executing the Artemis III mission will require extensive coordination within NASA and its commercial partners, and for each individual program to meet aggressive development time frames. We recommended using program management tools and practices to set these new programs up for success.

Further, the complexity of these efforts present additional cost and schedule risks for NASA's major project portfolio over the next couple of years. An example of one high-risk project is the PPE project, which is being designed to provide Gateway with power, communications, attitude control, orbit maintenance, and the ability to change orbits. The PPE contractor must deliver a solar electric propulsion system as part of PPE's space flight demonstration. NASA maintains a separate project, SEP, which is developing and qualifying the solar electric propulsion system. According to NASA, the contractor completing the development and qualification work has struggled with its performance, which led NASA to modify the development contract and reduce technical requirements for the Solar Electric Propulsion project. For PPE, NASA will be faced with either schedule delays or the need to reduce technical requirements if development challenges continue with solar electric propulsion. Given that NASA plans to launch PPE in less than 3 years—December 2022—this is an area that we will continue to monitor as changes could have

[22]GAO-20-68.

implications for both cost and schedule, and the extent of risk NASA will face in executing the mission.

NASA Has Generally Maintained Portfolio Progress in Demonstrating Technology Maturity and Design Stability

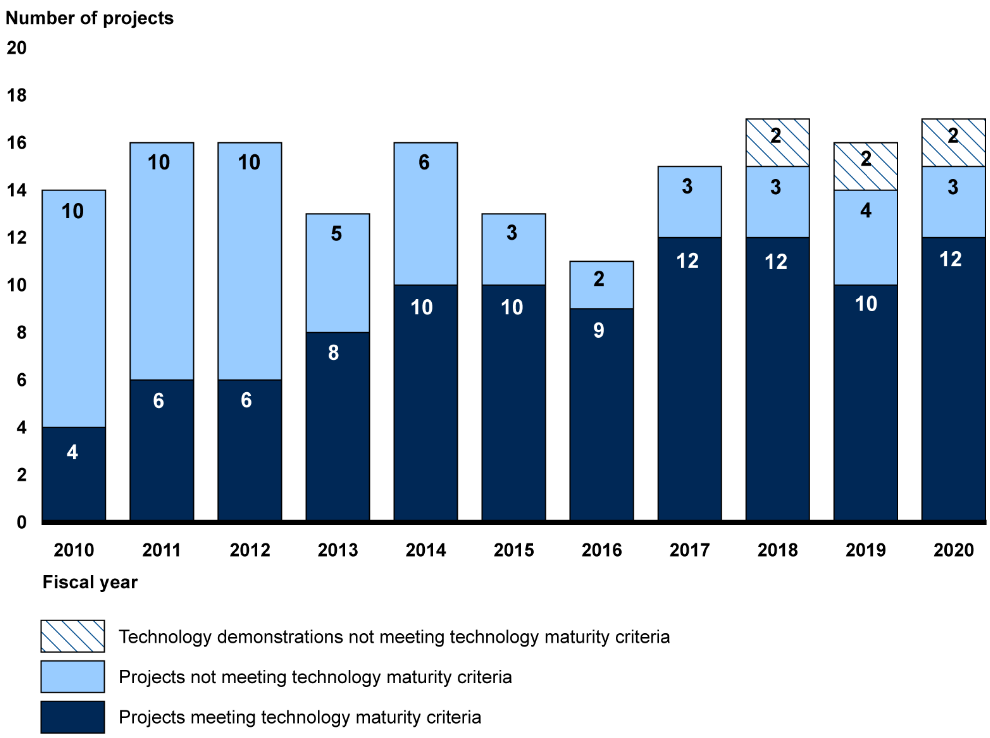
NASA has generally maintained its progress over the years demonstrating the technology and design maturity of its major projects. For example, most NASA major projects have met the best practice of maturing technologies by a preliminary design review and NASA has maintained the number of projects with stable designs at critical design review. With respect to technologies, NASA continues to report low number of critical technologies on its projects compared to several years ago, which may be an indication that projects are taking on less technical risk. But we have also found that there is subjectivity in the process NASA uses to identify critical technologies that could also be a factor in this change. NASA has started to take steps to address concerns regarding subjectivity in the critical technology identification process, and this will be an area we continue to monitor.

NASA Projects Generally Maintain Technology Maturity Levels

We found that most of NASA's major projects in development—12 of 17—met the best practice of maturing all technologies to technology readiness level (TRL) 6 by preliminary design review. This review demonstrates that the preliminary design meets all system requirements with acceptable risk and within the cost and schedule constraints and establishes the basis for proceeding with detailed design. (App. IV provides a description of technology readiness levels, which are the metrics used to assess technology maturity). NASA's technology maturity levels in 2020 were generally consistent with recent years (see fig. 4). We did not include the LBFD and SEP projects, which are technology demonstrations, because the projects do not intend to mature their technologies until operations or qualification testing before hand-off to the PPE project, respectively. Two other technology demonstrations—LCRD and Restore-L—are included in the analysis because both projects intended to mature the technologies before launch. Our best practices work has shown that reaching a TRL 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.[23]

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

Figure 4: Number of NASA's Major Projects Attaining Technology Maturity by Preliminary Design Review from 2010 to 2020



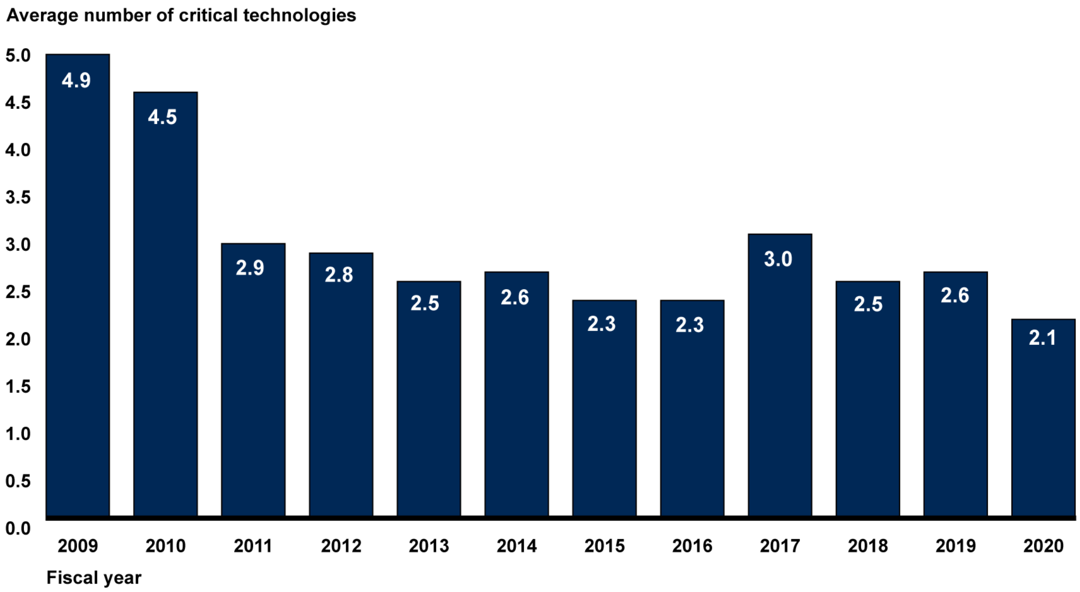
Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-20-405

Note: Includes projects that completed preliminary design review and identified critical or heritage technologies. We included two technology demonstration missions in our analysis—LCRD and Restore-L—because officials had told us that, while these technology demonstration missions are not required to mature technologies before launch, both of these projects intended to do so. The years in the figure are the years we issued the report.

Of the four projects we added to our technology maturity analysis this year, three—Europa Clipper, PACE, and Psyche—matured all of their technologies to a TRL 6. The WFIRST project assessed the maturity of 23 technologies at its preliminary design review (PDR) and determined three were not yet mature. Two heritage technologies were not assessed because changes to their design required further development. The third technology did not need to be matured by PDR because it is a technology demonstration.

The 18 projects in the current portfolio that were in development as of January 2020—meaning the project held both a PDR and a confirmation review—reported an average of 2.1 critical technologies, which is generally consistent with the number projects have self-reported over the past 9 years (see fig. 5). Of the four projects added to the analysis this year—Europa Clipper, PACE, Psyche, and SEP—only PACE and SEP reported having critical technologies. PACE and SEP reported two critical technologies each. One project that left the portfolio this year, Parker Solar Probe, had 10 critical technologies, which contributed to a decrease from 2019 to 2020.

Figure 5: Average Number of Critical Technologies Reported by NASA's Major Projects in Development from 2009 to 2020



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-20-405

Note: Includes all projects that held a preliminary design review (PDR) and key decision point C as of January 2020, except for the Restore-L project. Restore-L held a PDR by this time frame, but has continued to delay its key decision point C review. The years in the figure are the years we issued the report.

As seen in figure 5, an average of 2.1 critical technologies is a marked decrease from the 4.9 and 4.5 average numbers of critical technologies reported in 2009 and 2010, respectively. We have previously observed that the decline in the average number of critical technologies 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.[24] Last year, however, we reported that subjectivity exists in the

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

processes NASA uses to identify and assess critical technologies, which could also be a factor in the changes in the average number of critical technologies and has the potential to affect a comparison of the average number of technologies from year to year.[25]

NASA has continued to take steps to address some of these concerns and is currently drafting a Technology Readiness Assessment (TRA) Best Practices document as part of the agency's High-Risk Corrective Action Plan. An initial draft was prepared at the end of 2019 and is continuing through agency review and revision. NASA intends this document to be a best practices guide that will gather high-level information regarding TRA best practices into a single source with citations to governing documents from across the agency providing information on how to conduct an assessment. We will continue to monitor NASA's efforts in this area.[26]

NASA Has Generally Maintained the Number of Projects Meeting the Design Stability Best Practice, but Most Projects Have Late Design Drawing Growth

NASA has maintained the number of projects with stable designs at critical design review, but most projects still do not meet this best practice. The critical design review is the time in a project's life cycle when the integrity of the project design and its ability to meet mission requirements are assessed. Our work on product development best practices has shown 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. 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."

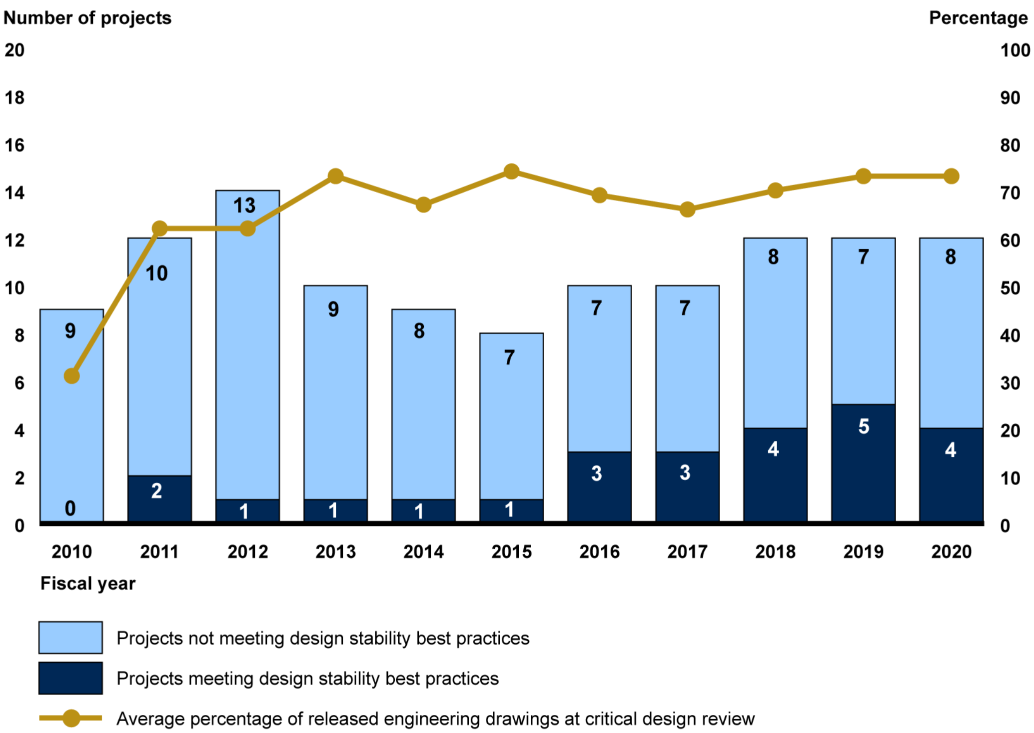
Of the 12 projects that held a critical design review as of January 2020, four projects met the best practice of releasing 90 percent of design drawings by critical design review, which is similar to recent years. The average percentage of drawings releasable at critical design review is 73 percent, the same percentage as last year. While most projects are not

[25]GAO-19-262SP.

[26]For more information on technology readiness assessments, see GAO-20-48G.

meeting the best practice, this still represents an improvement since 2010 (see fig. 6).

Figure 6: NASA Major Projects Releasing at Least 90 Percent of Engineering Drawings and Average Percentage of Released Drawings by Critical Design Review from 2010 to 2020



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-20-405

Note: The years in the figure are the years we issued the report.

This year, we removed three projects from our analysis—Interior Exploration using Seismic Investigations, Geodesy and Heat Transport; Ice, Cloud and land Elevation Satellite-2; and Parker Solar Probe. None of these projects met the best practices as of our analysis in 2019. This year, we added three new projects—DART, LBFD, and Lucy—none of which met the best practice. In addition, the Landsat 9 project experienced drawing growth such that it no longer met the best practice as it did in 2019.

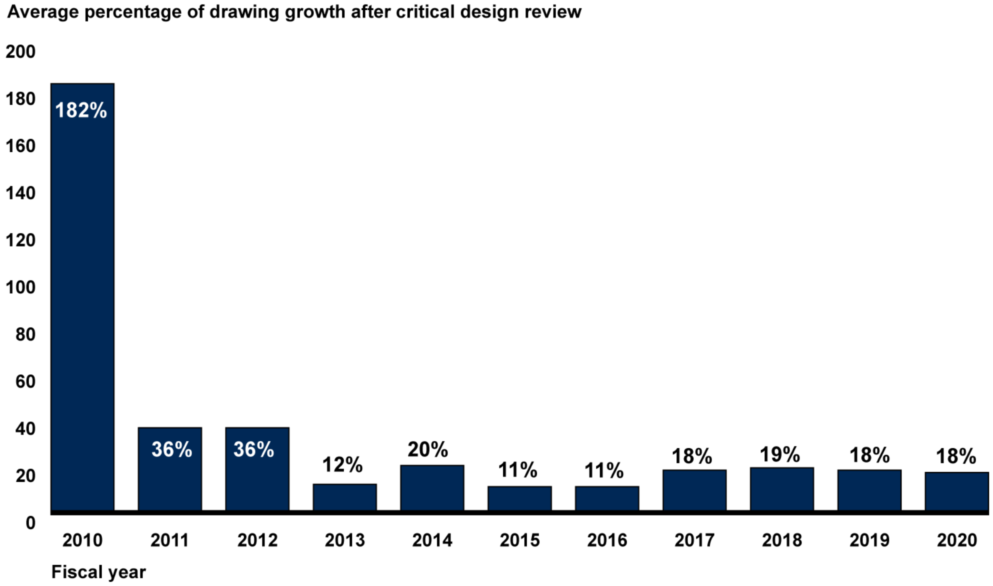
Of the three new projects, the LBFD project released the fewest engineering drawings—37 percent—at its critical design review. Project officials explained that they never anticipated meeting the 90 percent best practice because the contractor is using a rapid prototyping process, which enables the contractor to initiate early fabrication of the vehicle as key design drawings are completed. As a result, the project had been targeting a release of 60 to 70 percent of drawings by critical design review, but the project also did not meet that target. LBFD project officials stated that drawing releases were delayed due to a lack of experienced stress analysts dedicated to the project at the contractor, which was exacerbated by delays from vendors whose parts and specifications are required to complete certain drawings. Officials reported that the contractor's management has taken steps to address these issues. Furthermore, they noted that the project has released drawings for the aircraft's primary structures to allow manufacturing to begin, with the remaining drawings mostly representing the secondary structures and subsystems. For these reasons, despite not meeting the best practice of releasing 90 percent of design drawings by critical design review, project officials expressed confidence in their approach.

Design drawing growth has remained relatively steady, however, certain projects continue to experience such growth.[27] Experiencing a large amount of design drawing growth after critical design review may be an indicator of instability in a project's design late in the development cycle. Design changes at this point can be costly to the project in terms of time and funding because hardware may need to be reengineered or reworked as a result.

This year, nine out of 12 projects experienced design drawing growth after critical design review, compared to nine of 12 projects last year. The average percentage of design drawing growth after critical design review remained the same as last year at 18 percent (see fig. 7).

[27]Design drawing growth is measured as 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.

Figure 7: Average Percentage of Engineering Drawing Growth after Critical Design Review among NASA Major Projects from 2010 to 2020



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-20-405

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

Of the projects experiencing design drawing growth after critical design review this year, growth ranged from 2 percent to 70 percent. Of the projects experiencing the highest growth in design drawings—JWST, LCRD, Mars 2020, and Orion—none had met the best practice of releasing 90 percent of design drawings by critical design review.

As we have previously reported, NASA has raised concerns about our use of the design drawing best practice to assess design stability because, among other reasons, they view it as a legacy standard developed prior to the use of computerized drawings and NASA officials no longer think it is applicable for modern NASA projects.[28] In discussing this concern with project managers, we found that there are a variety of potential tools to measure design stability and no clear consensus on the topic. Some projects still used design drawings, even if they also used computerized drawings and modelling, while others cited mass and power

[28]GAO-19-262SP.

margins, growth in requirements, and projects' schedule performance as other metrics they use to assess stability. In other GAO work in this area, we have seen use of engineering models and prototyping to test design stability.[29]

Traditionally, we have used engineering design drawings released by critical design review because this metric can be applied commonly across most of NASA's portfolio of major projects and because it was among several metrics identified by a panel of experts convened by the National Academy of Sciences for GAO in 2013, which included former NASA officials. However, we understand that several years have passed since the completion of this work and plan to look more broadly at the metric as a part of our ongoing work with both NASA, the Department of Defense, and the Department of Homeland Security. As part of that work, we will continue to follow up with NASA on ongoing efforts it has in this area.

NASA Has Actions Underway to Identify and Address Challenges Contributing to Acquisition Risk

NASA has acknowledged recent challenges in cost and schedule growth and is taking steps to identify and address areas contributing to acquisition risk. GAO has designated NASA's management of acquisitions as a high-risk area for almost 3 decades. In our 2019 High-Risk Assessment, we found that NASA had taken steps to build capacity to reduce acquisition risk, including updating tools aimed at improving cost and schedule estimates but continued to experience challenges.[30] For example, NASA has not always followed best practices in areas such as estimating costs and schedules and earned value management, and projects are reluctant to update their cost and schedule estimates as new risks emerge. Further, in our May 2018 assessment of major projects, we found that several NASA major projects experienced workforce challenges, including not having enough staff or staff with the right skills.[31] NASA has also identified capability gaps in areas such as scheduling, earned value management, and cost estimating.

In December 2018, NASA completed a Corrective Action Plan to address NASA's inclusion in GAO's biennial High-Risk Report and after several of

[29] GAO, *Weapon Systems: Prototyping Has Benefited Acquisition Programs, but More Can Be Done to Support Innovation Initiatives,* GAO-17-309 (Washington, D.C.: June 27, 2017)

[30] GAO-19-157SP.

[31] GAO-18-280SP.

its highest-profile missions experienced cost and schedule growth. This plan identifies a range of initiatives that will help to provide a foundation for making better management decisions, but it will take time to assess the extent to which these efforts are having an effect. Further, our high-risk work has also found that success hinges on leadership commitment, accountability, and demonstrated progress.[32]

The Corrective Action Plan covers a number of initiatives and we identified three that relate to GAO's capacity criteria for high-risk, which is the extent to which the agency has the people and resources to resolve the risk.[33] An update on the status of NASA's progress implementing each initiative follows.

- **Enhance Earned Value Management (EVM) Implementation.** EVM is a key project management tool that integrates information on a project's cost, schedule, and technical efforts for management and decision makers. It measures the value of work accomplished in a given period and compares it with the planned value of work scheduled for that period and the actual cost of work accomplished. EVM is part of the agency's efforts to understand project development needs and to reduce cost and schedule growth. NASA requires EVM for major space flight projects unless waived. This initiative also addresses EVM surveillance, which is a review of a contractor's EVM system with the intention of understanding how well the contractor uses EVM data to manage cost, schedule, and performance.

  The goal of the EVM implementation initiative is to roll out EVM capability to all relevant centers, include EVM data in status meetings, increase surveillance, and reduce errors in EVM data. NASA reported that its four centers with the most EVM projects—Kennedy Space Center, Johnson Space Center, Marshall Space Flight Center, and Goddard Space Flight Center—have EVM capability, and that it plans to expand in-house EVM surveillance capability in 2020. While the centers with the most EVM projects have EVM capability, NASA officials explained there is some cultural resistance to the EVM process due to its perception as expensive, which leads projects and

[32]GAO, *High-Risk Series: Progress on Many High-Risk Areas, While Substantial Efforts Needed on Others*, GAO-17-317 (Washington, D.C.: Feb. 15, 2017); and GAO-19-157SP.

[33]Other initiatives to implement in the Corrective Action Plan include: Improve Human Exploration and Operations Mission Directorate Portfolio Insight and Status, Include Original Agency Baseline Commitments for Performance-Driven Re-baselined Projects, Enhance Annual Strategic Review Process, and Create Technology Readiness Assessment Best Practices Document.

programs to request waivers and deviations from EVM requirements. To address the culture around EVM and promote its use, officials said senior NASA leaders have increased emphasis on EVM at agency-level project reviews from senior leadership, which emphasizes the importance of EVM to projects.

Since at least 2012, NASA struggled with resource constraints regarding EVM surveillance capability. But, according to officials, the agency is now targeting the beginning of 2020 to implement its in-house surveillance plans. Officials explained conducting EVM surveillance is the main approach for NASA's plans to enhance EVM implementation. In November 2012, GAO recommended that NASA update its procedural requirements to implement a formal EVM surveillance program in order to improve the reliability of EVM data collected by NASA programs. NASA agreed with the recommendation but cited concerns about affordability for implementation. NASA currently uses Defense Contract Management Agency (DCMA) to conduct EVM surveillance on some large contracts. However, for contractors without a DCMA presence—such as Applied Physics Laboratory and Southwest Research Institute—NASA validated the EVM system, but has not performed EVM surveillance. Officials expect in-house surveillance to improve the quality of compliance monitoring, and NASA has added three contracted work year equivalents to complete in-house EVM surveillance. NASA plans to add one additional full-time employee or work year equivalent to focus on the initiative to enhance EVM implementation in 2020.

- **Joint Cost and Schedule Confidence Level (JCL) Policy.** A JCL produces a point-in-time estimate that includes all cost and schedule elements in phases A through D, incorporates and quantifies known risks, assesses the impacts of cost and schedule to date, and addresses available annual resources, among other things. NASA originally implemented a JCL policy to help reduce the cost and schedule growth in its portfolio and improve transparency, and increase the probabilities of meeting those expectations.

  NASA has completed this initiative through an update to its JCL policy that now requires projects with life cycle costs over $1 billion to conduct JCLs at key decision points (KDP) B and C, critical design review, and potentially at KDP-D if development costs are 5 percent or more over the agency baseline commitment. Additionally, NASA will require any project with a life cycle cost of $250 million or more that rebaselines its cost and schedule to recalculate its JCL. Previously, a JCL was only required at KDP-C for all projects with a life cycle cost estimate over $250 million, and NASA policy did not require projects to update their JCL as they progressed through development. Figure 8 provides an overview of how JCL requirements have evolved at NASA from 2009 to 2019.

Figure 8: Joint Cost and Schedule Confidence Level (JCL) Policy 2009-2019

2009 JCL Policy

- JCLs required for projects exceeding $250 million at KDP-C
- Requires projects to be baselined at the 70 percent confidence level
- Requires funding the project at least to the 50 percent confidence level

→

2012 NASA JCL Policy

- JCLs required for all projects exceeding $250 million at KDP-C
- JCL suggested for projects over $250 million that rebaseline
- Requires projects to be baselined at the 70 percent confidence level
- Requires funding the project at least to the 50 percent confidence level

→

2019 NASA JCL Policy Update

- JCLs required for all projects exceeding $250 million at KDP-C
- JCL required for projects over $250 million that rebaseline
- If the project costs over $1 billion, JCL also required at KDP-B
- If the project costs over $1 billion, the JCL from KDP-C is required to be updated at critical design review
- If the project costs over $1 billion and costs are 5 percent or more over the development agency's baseline commitment, a JCL is also required at KDP-D
- Requires projects to be baselined at the 70 percent confidence level
- Requires funding the project at least to the 50 percent confidence level

JCL = Joint Cost and Schedule Confidence Level

KDP = Key Decision Point

Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-20-405

Although the JCL policy has been updated, no projects have gone through the new process yet. NASA is waiting for a project that meets the updated policy's criteria—a life cycle cost estimate over $1 billion and passing one of the KDPs—to implement the new aspects of the policy. Based on the schedules of NASA major projects, officials anticipate either a Gateway project, Human Landing System, or the Mars Sample Return will be the first to implement the new policy of conducting a JCL at KDP-B. NASA officials explained that they expect the JCL data collected at KDP-B will be lower quality compared to JCLs completed later in development due to the availability of data at that stage in the project's life cycle. According to officials, Europa Clipper will likely be the first project with a life cycle cost over $1 billion to pass the critical design review milestone, which now requires an update to the KDP-C JCL. Officials reported the Orion program will be doing a JCL at KDP-D because they are more than 5 percent over the agency baseline commitment. Orion's new JCL analysis is in response to the updated JCL policy.

- **Curriculum Development for Programmatic Analysts.** NASA is establishing an updated training curriculum for its analysts to strengthen the agency's programmatic capabilities and promote consistency of the agency's best practices and processes. NASA has started drafting course content for 10 of 28 new courses, and one existing course has been significantly updated. Some of these courses will be piloted by programmatic analysts in fiscal year 2020. Courses cover NASA programmatic policy, JCL implementation, independent assessments, scheduling, cost estimating, and project integration and communication. NASA initiated these new training courses in response to a NASA-conducted study of its programmatic workforce, which found an inadequate number of analysts with proficient skills and limited resources. The training courses aim to strengthen NASA's programmatic capability by emphasizing agency best practices and methods. While new courses are being developed, officials explained NASA has not yet determined expectations for class participation requirements but plan to consider employee experience, demand, and potential classes to serve as "refreshers."

In addition to the Corrective Action Plan, an effort to restructure NASA's Independent Program Assessment Office (IPAO) also aimed to strengthen the programmatic analyst workforce. Restructuring started in October 2015 and was completed in December 2017. Under the restructuring, NASA devolved the responsibility for conducting independent assessments to mission directorates. NASA completed its decentralization of the independent assessment function in an effort to better use its programmatic analyst workforce by deploying staff to the agency's centers to meet program needs in areas such as program management, cost estimating, and resource analysis, and to fill gaps in program analysis skills at the center level. Table 3 shows some of the changes in selected topic areas.

Table 3: Selected Changes from NASA's Independent Program Assessment Office (IPAO) Decentralization, as of June 2016

Topic	From:	To:
Responsibility	• Independent Assessment organized and performed by a central organization (IPAO) • IPAO Reports to Associate Administrator for Independent Assessment	• Independent Assessments continue under the responsibility of the Mission Directorate with support from the Centers • Mission Directorates report to Associate Administrator for Independent Assessment
Review Teams	• Independent assessments performed by Standing Review Boards (SRBs).	No change

Topic	From:	To:
SRB Member Independence	• Come from separate chain of command • Funded from source other than project under review • No conflict of interest	No change
SRB Selection	• SRB chair selection and technical membership facilitated by IPAO working with Convening Authorities. • Cost and schedule analysts and Review Manager assigned by IPAO. • Decision Authority approves SRB.	• SRB chair selected by Mission Directorate and Centers with assistance from Office of the Chief Engineer for technical members and the Office of the Chief Financial Officer for cost and schedule analytical expertise. • Review management facilitation provided by Mission Directorate or Center. • Decision Authority approves membership (no change).

Source: GAO analysis of NASA documentation. | GAO-20-405

With respect to the programmatic workforce assigned to independent assessment teams, the Office of the Chief Financial Officer has a key role in identifying resources across the agency to help mission directorates fulfill this need. Officials within this office told us that one area they have to actively manage is ensuring there are sufficient schedule analysts and civil servants to serve on Standing Review Boards (SRB). According to these officials, the skill set required by schedule analysts is in high demand across the government and is a difficult area to recruit and retain talent, especially when competing with the private sector. Officials explained that they have the option to hire contracted support to serve on SRBs when needed.

NASA also identified SRB civil servant staffing as an area to monitor. In an effort to increase the number of programmatic analysts, NASA staffed SRBs with more junior staff and paired them with more experienced analysts. NASA officials noted this provides a learning experience for junior analysts and has potential to create a pipeline of qualified analysts to serve on SRBs. Mission Directorate officials responsible for assembling the independent assessment teams stated that the Office of the Chief Financial Officer and the Office of the Chief Engineer have provided assistance in this area and there has been no difficulty meeting these staffing needs.

In March 2016, we highlighted three areas that could be negatively affected by the reorganization of the independent assessment function—independence, the robustness of reviews, and information sharing.[34] As

[34]GAO, *NASA: Assessments of Major Projects,* GAO-16-309SP (Washington, D.C.: Mar. 30, 2016).

of January 2020, at least 10 of the projects in our portfolio have set up a SRB through their respective Mission Directorates. In speaking with Mission Directorates, selected projects, and select Standing Review Board chairs, multiple officials told us that the transition was transparent and that the process is now more efficient. For example, one official stated the new process requires less time for tasks like giving presentations, completing paperwork, and attending meetings. One Mission Directorate new to the SRB process reported the reviews are working well and SRBs provided additional insights to the independent reviews the Mission Directorate was already conducting.

However, officials from another Mission Directorate noted there is an ongoing challenge in the consistency of interpreting SRB conflict of interest rules across the centers. Previously, one center was responsible for vetting all conflicts of interest and now the process is decentralized. According to officials, the decentralization may be contributing to varying strictness of the rules, which can cause efficiency problems because of inconsistent rejections of potential SRB members. For example, very strict vetting can make SRB staffing difficult in specialized areas, where there are only a handful of experts to choose from. According to officials, NASA headquarters and General Counsel are aware of this challenge.

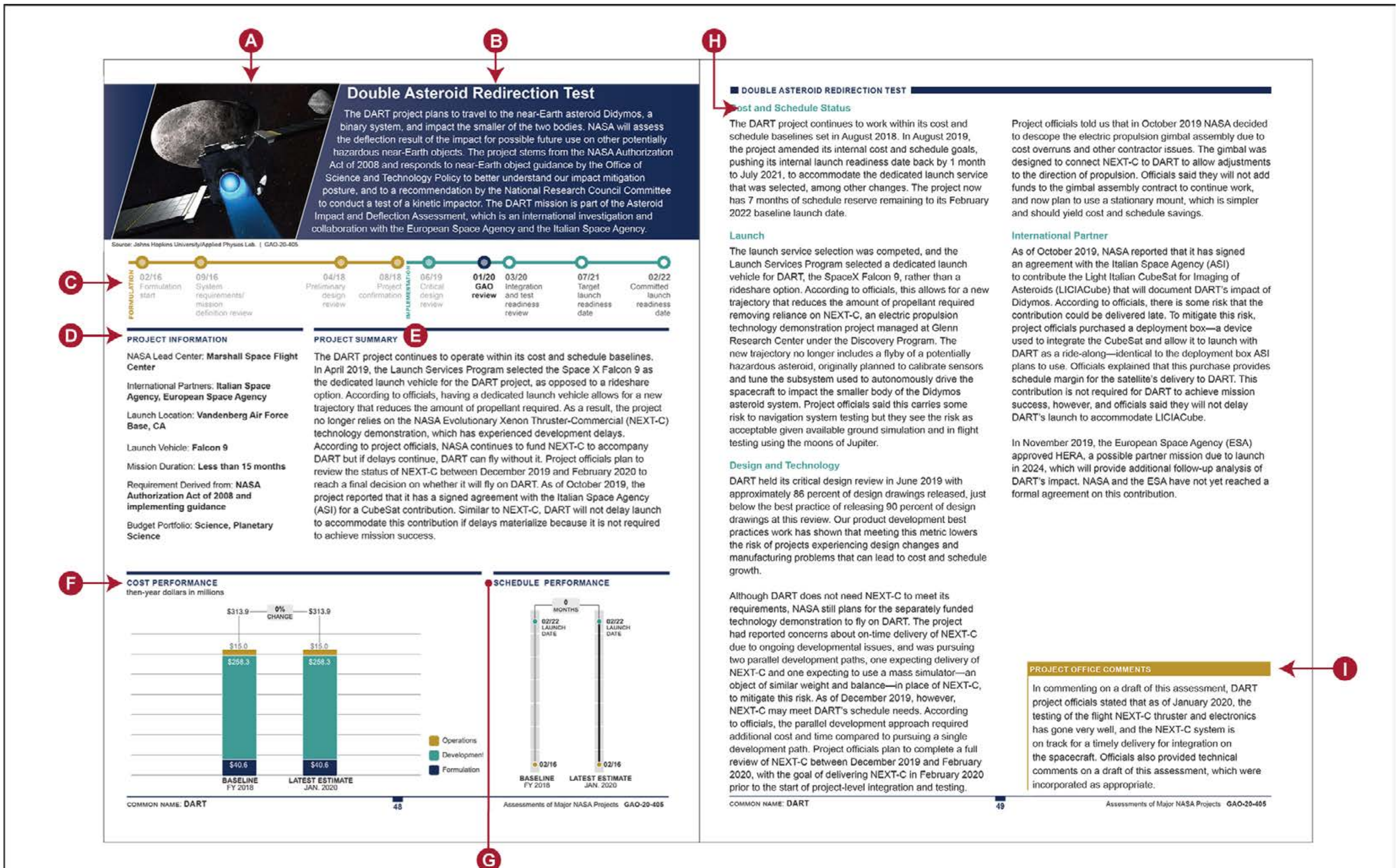
It is too early to tell if the decentralization of IPAO will improve the quality of reviews or address skill gaps in the workforce. This is in part due to the frequency with which SRBs are held. According to NASA policy, SRBs must be conducted at various points in a project's life cycle. However, with some projects taking years to complete, it is possible a project has had limited exposure to the new independent assessment function since it has not passed many, if any, of these key points since the dissolution of IPAO in 2015. As time passes, more projects will conduct more SRBs under the new model, and its effectiveness could be better evaluated at that time. We will continue to monitor the transition through future reviews, including of NASA's lunar programs.

Project Assessments

In the following section, we summarize the individual assessments of the 24 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. Twenty-one 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. Three 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.

Figure 9: Illustration of a Sample Project Assessment



A
B
H

■ DOUBLE ASTEROID REDIRECTION TEST

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-20-405

C

FORMULATION
02/16 Formulation start
09/16 System requirements/ mission definition review
04/18 Preliminary design review
08/18 Project confirmation
IMPLEMENTATION
06/19 Critical design review
01/20 GAO review
03/20 Integration and test readiness review
07/21 Target launch readiness date
02/22 Committed launch readiness date

D

PROJECT INFORMATION

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

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

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

Launch Vehicle: **Falcon 9**

Mission Duration: **Less than 15 months**

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

Budget Portfolio: **Science, Planetary Science**

PROJECT SUMMARY
E

The DART project continues to operate within its cost and schedule baselines. In April 2019, the Launch Services Program selected the Space X Falcon 9 as the dedicated launch vehicle for the DART project, as opposed to a rideshare option. According to officials, having a dedicated launch vehicle allows for a new trajectory that reduces the amount of propellant required. As a result, the project no longer relies on the NASA Evolutionary Xenon Thruster-Commercial (NEXT-C) technology demonstration, which has experienced development delays. According to project officials, NASA continues to fund NEXT-C to accompany DART but if delays continue, DART can fly without it. Project officials plan to review the status of NEXT-C between December 2019 and February 2020 to reach a final decision on whether it will fly on DART. As of October 2019, the project reported that it has a signed agreement with the Italian Space Agency (ASI) for a CubeSat contribution. Similar to NEXT-C, DART will not delay launch to accommodate this contribution if delays materialize because it is not required to achieve mission success.

F

COST PERFORMANCE
then-year dollars in millions

$313.9
0% CHANGE
$313.9
$15.0
$258.3
$40.6
$15.0
$258.3
$40.6
BASELINE FY 2018
LATEST ESTIMATE JAN. 2020
Operations
Development
Formulation

SCHEDULE PERFORMANCE

0 MONTHS
02/22 LAUNCH DATE
02/22 LAUNCH DATE
02/16
02/16
BASELINE FY 2018
LATEST ESTIMATE JAN. 2020

COMMON NAME: DART
48
Assessments of Major NASA Projects GAO-20-405

G

Cost and Schedule Status

The DART project continues to work within its cost and schedule baselines set in August 2018. In August 2019, the project amended its internal cost and schedule goals, pushing its internal launch readiness date back by 1 month to July 2021, to accommodate the dedicated launch service that was selected, among other changes. The project now has 7 months of schedule reserve remaining to its February 2022 baseline launch date.

Launch

The launch service selection was competed, and the Launch Services Program selected a dedicated launch vehicle for DART, the SpaceX Falcon 9, rather than a rideshare option. According to officials, this allows for a new trajectory that reduces the amount of propellant required removing reliance on NEXT-C, an electric propulsion technology demonstration project managed at Glenn Research Center under the Discovery Program. The new trajectory no longer includes a flyby of a potentially hazardous asteroid, originally planned to calibrate sensors and tune the subsystem used to autonomously drive the spacecraft to impact the smaller body of the Didymos asteroid system. Project officials said this carries some risk to navigation system testing but they see the risk as acceptable given available ground simulation and in flight testing using the moons of Jupiter.

Design and Technology

DART held its critical design review in June 2019 with approximately 86 percent of design drawings released, just below the best practice of releasing 90 percent of design drawings at this review. Our product development best practices work has shown that meeting this metric lowers the risk of projects experiencing design changes and manufacturing problems that can lead to cost and schedule growth.

Although DART does not need NEXT-C to meet its requirements, NASA still plans for the separately funded technology demonstration to fly on DART. The project had reported concerns about on-time delivery of NEXT-C due to ongoing developmental issues, and was pursuing two parallel development paths, one expecting delivery of NEXT-C and one expecting to use a mass simulator—an object of similar weight and balance—in place of NEXT-C, to mitigate this risk. As of December 2019, however, NEXT-C may meet DART's schedule needs. According to officials, the parallel development approach required additional cost and time compared to pursuing a single development path. Project officials plan to complete a full review of NEXT-C between December 2019 and February 2020, with the goal of delivering NEXT-C in February 2020 prior to the start of project-level integration and testing.

Project officials told us that in October 2019 NASA decided to descope the electric propulsion gimbal assembly due to cost overruns and other contractor issues. The gimbal was designed to connect NEXT-C to DART to allow adjustments to the direction of propulsion. Officials said they will not add funds to the gimbal assembly contract to continue work, and now plan to use a stationary mount, which is simpler and should yield cost and schedule savings.

International Partner

As of October 2019, NASA reported that it has signed an agreement with the Italian Space Agency (ASI) to contribute the Light Italian CubeSat for Imaging of Asteroids (LICIACube) that will document DART's impact of Didymos. According to officials, there is some risk that the contribution could be delivered late. To mitigate this risk, project officials purchased a deployment box—a device used to integrate the CubeSat and allow it to launch with DART as a ride-along—identical to the deployment box ASI plans to use. Officials explained that this purchase provides schedule margin for the satellite's delivery to DART. This contribution is not required for DART to achieve mission success, however, and officials said they will not delay DART's launch to accommodate LICIACube.

In November 2019, the European Space Agency (ESA) approved HERA, a possible partner mission due to launch in 2024, which will provide additional follow-up analysis of DART's impact. NASA and the ESA have not yet reached a formal agreement on this contribution.

PROJECT OFFICE COMMENTS
I

In commenting on a draft of this assessment, DART project officials stated that as of January 2020, the testing of the flight NEXT-C thruster and electronics has gone very well, and the NEXT-C system is on track for a timely delivery for integration on the spacecraft. Officials also provided technical comments on a draft of this assessment, which were incorporated as appropriate.

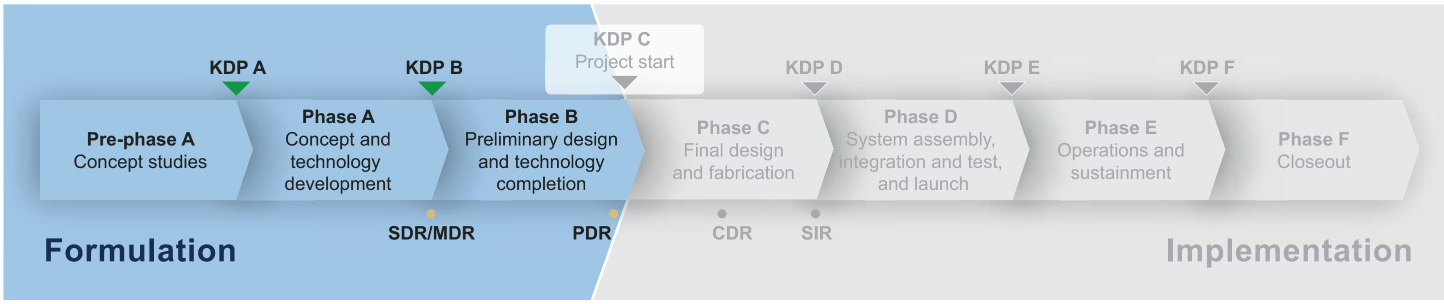
COMMON NAME: DART
49
Assessments of Major NASA Projects GAO-20-405

- **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-20-405

Assessments of Projects in the Formulation Phase

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.



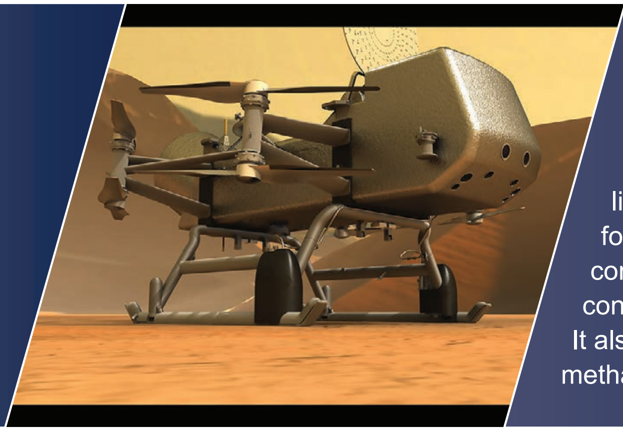
Management decision reviews

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 analysis of National Aeronautics and Space Administration data. | GAO-20-405



Dragonfly

Dragonfly will explore diverse environments of Titan—Saturn's largest moon—from organic dunes to the deposits of an impact crater where liquid water and complex organic materials key to life once existed together for possibly tens of thousands of years. Its instruments will study chemical components and prebiotic processes needed for the development of life; what conditions can make a planet or moon habitable; and search for evidence of life. It also will investigate the moon's atmospheric and surface properties, such as methane levels, as well as its subsurface ocean and liquid reservoirs.

Source: Johns Hopkins Applied Physics Laboratory. | GAO-20-405

PROJECT INFORMATION

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

Mission Duration: **2.7 years**

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

Budget Portfolio: **Planetary Science**

Next Major Project Event: **Preliminary Design Review (TBD)**

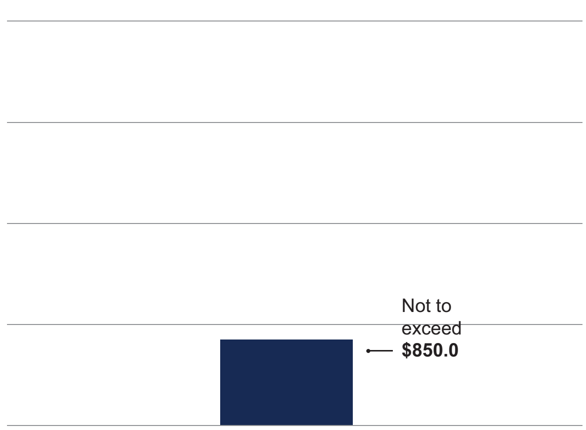
CURRENT STATUS

In June 2019, NASA selected the Dragonfly project as part of the agency's New Frontiers program from a 2016 competitive announcement of opportunity. Dragonfly will employ four instruments to study the chemical complexity and diversity of Titan's environment. Three of its four instruments are based on instruments that have flown on previous planetary missions. This is the first time that NASA will fly a multi-rotor vehicle for science on another planet; Dragonfly is expected to have eight rotors and fly like a large drone. It will take advantage of Titan's dense atmosphere to fly its entire science payload to new places for repeatable and targeted access to surface materials. Dragonfly will use a Multi-Mission Radioisotope Thermoelectric Generator to provide constant power, including charging its battery between flights.

The project proposed an April 2025 launch date, in accordance with the announcement of opportunity, but NASA selected its back-up launch date of April 2026. NASA stated that it directed the project to target this later launch date because the earlier launch date carried considerable schedule risk. Both launch dates allow Dragonfly to arrive at Titan in December 2034.

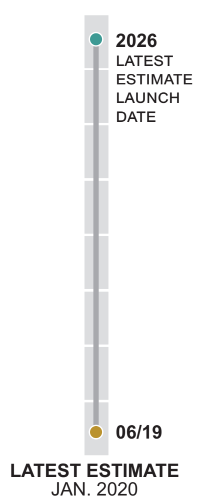
PRELIMINARY COST[a]

Fiscal year 2015 dollars in millions



[a] *The announcement of opportunity established a cost cap of $850 million for the mission based on a 2025 launch date, which does not include international contributions or the launch vehicle. The revised cost for the 2026 launch date has not yet been formalized.*

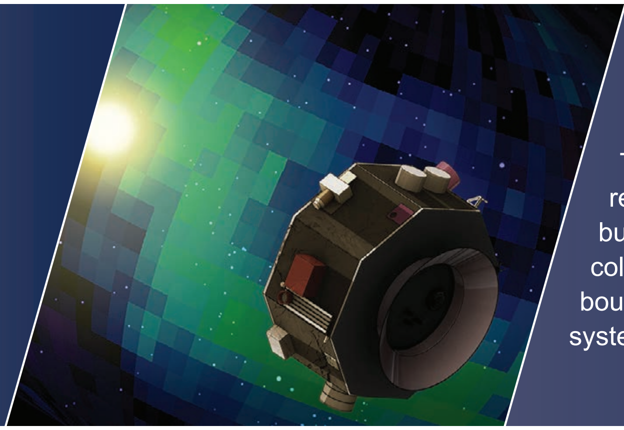
PRELIMINARY SCHEDULE



PROJECT OFFICE COMMENTS

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

PAGE INTENTIONALLY LEFT BLANK



Source: NASA. | GAO-20-405

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 the solar wind (a constant flow of particles from our Sun)—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.

PROJECT INFORMATION

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

Mission Duration: **3 years**

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

Budget Portfolio: **Science, Heliophysics**

Next Major Project Event: **Preliminary Design Review (planned February 2021)**

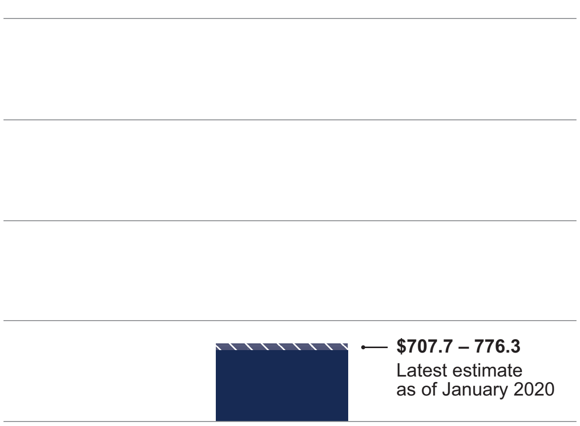
CURRENT STATUS

IMAP entered the preliminary design and technology completion phase in January 2020. At this decision point, NASA established a preliminary lifecycle cost estimate range of $707.7 million to $776.3 million for the project. This includes launch services and reserves and a launch readiness date range of October 1 to December 21, 2024. Following the January 2020 review, the project continues to finalize the science requirements with headquarters—the minimum level of science that needs to be achieved by the project to consider the mission a success. The project plans to hold its confirmation review in March 2021, at which point it will establish its cost and schedule baselines.

The IMAP project plans to include 10 instruments, which are intended to measure atoms, ions, magnetic fields, and solar wind particles. Project officials told us that the project was designed to use existing technologies to collect the first set of comprehensive observations and is not intended to demonstrate any new technologies. All of IMAP's instruments include technologies from other NASA projects. In addition, officials stated that two of the instruments can be de-scoped in the future, as they are not needed to meet the project's proposed science requirements.

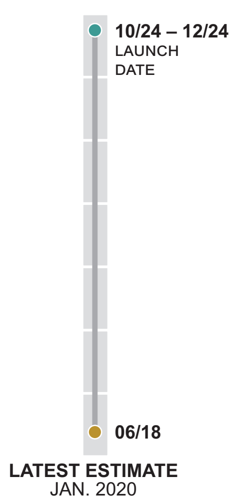
PRELIMINARY COST[a]

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.

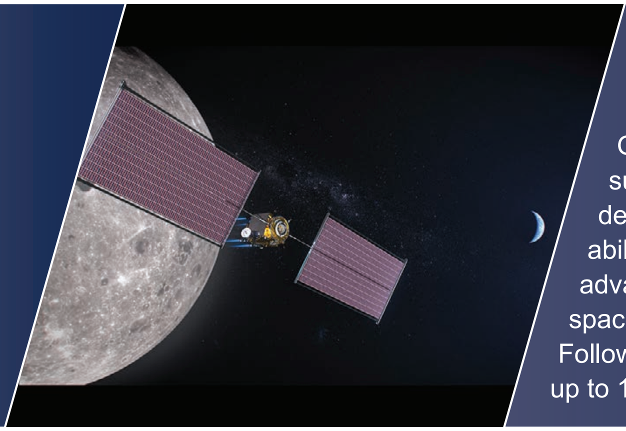
PRELIMINARY SCHEDULE



PROJECT OFFICE COMMENTS

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

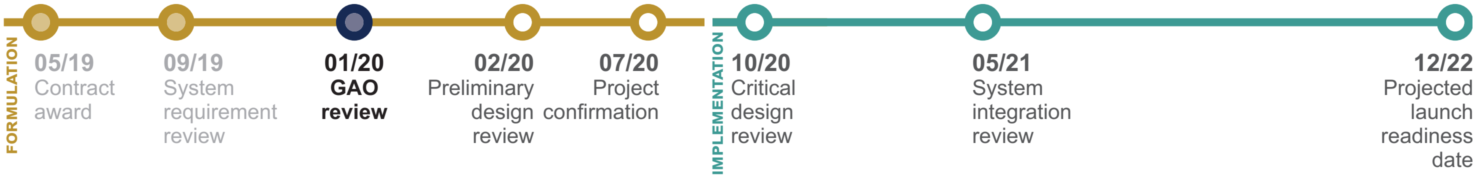
PAGE INTENTIONALLY LEFT BLANK



Power and Propulsion Element

The Power and Propulsion Element (PPE) will be the first module of the Gateway, a small platform in lunar orbit. NASA plans for PPE to dock with subsequent Gateway modules to support human lunar landings. PPE is designed to provide the Gateway with power, communications, and the ability to change orbits, among other things. PPE also aims to demonstrate advanced Solar Electric Propulsion (SEP) technology to support future human space exploration. NASA is managing SEP development as a separate project. Following launch, the contractor will operate PPE for an on-orbit demonstration of up to 1 year, after which NASA will have the option to acquire PPE.

Source: NASA. | GAO-20-405



PROJECT INFORMATION

NASA Lead Center: **Glenn Research Center**

International Partner: **None**

Launch Location: **Kennedy Space Center**

Launch Vehicle: **Falcon Heavy**

Mission Duration: **15 years**

Requirement Derived from: **Space Policy Directive-1 and 2018 NASA Strategic Plan**

Budget Portfolio: **Exploration Research and Development**

PROJECT SUMMARY

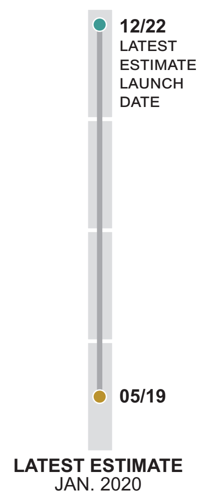
The PPE project is using the contract's value at award of $375 million as its preliminary cost estimate, but the project's costs will be higher when the project establishes cost and schedule baselines at its planned July 2020 confirmation review. After assessing risks related to requirements alignment with the Gateway program, NASA is considering a modification to PPE's firm-fixed-price contract to address two requirements gaps between PPE and Gateway. The gaps are related to power and controllability. In addition, the SEP project's planned contributions to PPE, including providing data verifying that its Advanced Electric Propulsion System (AEPS) meets requirements, are facing development delays. Project officials said that the SEP contributions may not be required to complete Gateway mission objectives if delays continue, but the project would have to request relief from its technology demonstration requirements. Project officials stated it was too early in the design process to make that determination.

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. NASA uses these estimates for planning purposes. NASA is using the contract's value at award as its preliminary estimate and a full lifecycle cost estimate that includes costs above the contract will be higher.*

PRELIMINARY SCHEDULE



Cost and Schedule Status

In May 2019, NASA awarded a firm-fixed price contract to build and perform a spaceflight demonstration of the PPE hardware, which also provided for distinct projects such as trade studies and requirement analyses under indefinite delivery/indefinite quantity terms. The contract's value at award of $375 million serves as the project's preliminary cost estimate. Once established, the project's cost baseline will be higher than this value because it will include additional costs, such as for NASA project management activities and cost reserves. The PPE project is targeting a preliminary launch readiness date of December 2022, which includes 3 months of schedule reserve. NASA plans to review and approve the PPE project's cost and schedule baseline at a Gateway program-level review scheduled for July 2020, which will also serve as the project's confirmation review.

Technology and Design

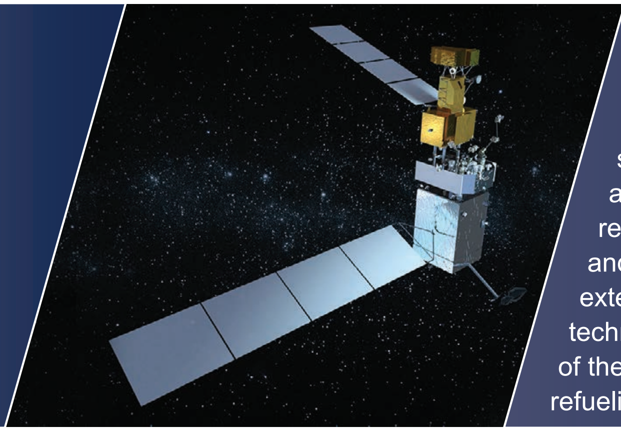
The PPE project finalized its requirements before the Gateway program finalized corresponding requirements at the program level, leading to requirements gaps between PPE and Gateway that may result in a modification to the firm-fixed price contract. The two gaps relate to the amount of power PPE is expected to provide Gateway and controllability. Misalignment between PPE and Gateway requirements could result in mission-limiting compatibility issues. NASA told us that it awarded the contractor two task orders under the indefinite delivery/indefinite quantity portion of the contract to study the possible gaps. The contractor recommended that NASA modify its spacecraft to address the requirements gaps, which NASA stated will require a contract modification. As of January 2020, NASA is assessing the contractor's recommendations to address the requirements gaps before issuing a contract modification.

The PPE contractor must deliver a solar electric propulsion system as part of PPE's spaceflight demonstration. NASA maintains a separate project, SEP, that is developing and qualifying the electric propulsion system. According to NASA, the contractor completing the development and qualification work has struggled with its performance, which led NASA to modify the development contract and reduce technical requirements. According to PPE officials, if the development continues to lag, they may be able to accomplish their Gateway requirements with an already developed lower-kilowatt system, but would have to request relief from their technical demonstration requirements. Project officials stated that it was too early in the design process to determine if they could use only the lower-kilowatt system. In addition, the SEP project also plans to provide PPE with a Plasma Diagnostics Package (PDP) —a piece of flight hardware that will collect data about the physical environment surrounding PPE to inform future designs and validate models—but is currently projecting that it will miss the PPE need date by 4 months.

The PPE project will assess the maturity of its ten technologies at its planned February 2020 preliminary design review, at which point best practices recommend maturing technologies to a technology readiness level 6 to minimize risk. The technologies associated with the electric propulsion system have not yet been tested in a relevant environment to achieve a technology readiness level 6.

PROJECT OFFICE COMMENTS

PPE project officials 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 and on-orbit assembly and installation of an antenna. 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-20-405

PROJECT INFORMATION

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

International Partner: **None**

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

Launch Vehicle: **TBD**

Mission Duration: **12 months**

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

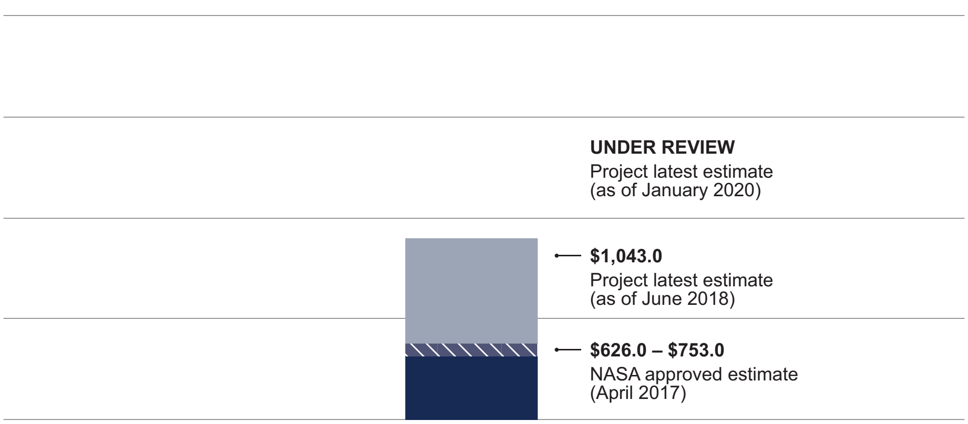
Budget Portfolio: **Space Technology, Research and Development**

PROJECT SUMMARY

The Restore-L project is no longer working to preliminary cost and schedule estimates that NASA approved when the project entered the preliminary design phase, largely due to issues related to funding and the late addition of a new payload. NASA has not yet approved a cost and schedule baseline for the program, but the program is now working to a launch readiness date of December 2023. This is almost 3 years after the launch readiness date estimate at KDP-B. The project expects its preliminary cost estimate of $1,043 million to increase once it establishes a cost baseline in order to reflect the extension in schedule. In addition, the project has experienced programmatic challenges, including not having sufficient cost reserves to address risks and workforce shortages that have led to delays in some of Restore-L's subsystems.

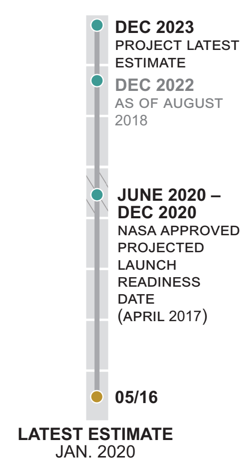
PRELIMINARY COST[a]

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 the project entered the preliminary design phase. The reasons are twofold. First, the Space Technology Mission Directorate's (STMD) proposed budget for the past 2 years has not allowed 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 has proposed for the project does not allow the project to maintain this launch date. Second, STMD directed the project to add a new payload—known as the SPace Infrastructure DExterous Robot (SPIDER)—in April 2019. The new payload intends to demonstrate on-orbit assembly and installation of an antenna.

As a result of the direction to add SPIDER and delays on Restore-L's key subsystems, the project has replanned its launch readiness date to December 2023. This is about 3 years later than the project's estimate at key decision point-B. As of January 2020, the project reports that it is maintaining schedule reserves above guidelines based on this new launch readiness date. However, the project also reports that its current level of funding does not include sufficient cost reserves for fiscal year 2020. As a result, project officials do not anticipate having sufficient cost reserves to address risks and unforeseen technical challenges as they occur. In addition, project officials stated that they anticipate that life-cycle costs will increase above the project's prior estimate in order to support a later launch date. NASA has not yet approved a cost and schedule baseline for this project.

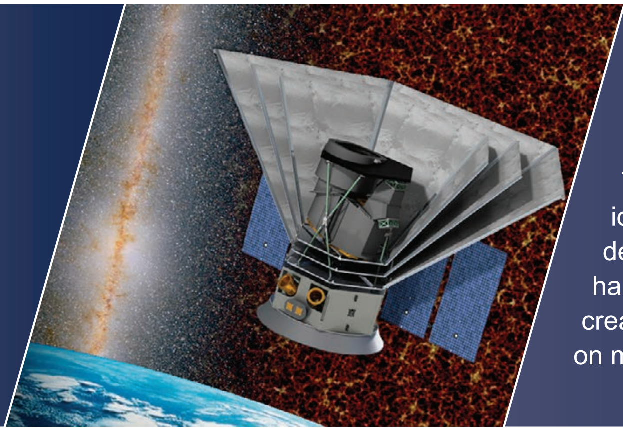
In addition, the project experienced workforce challenges in June 2019 that led to delays on its key subsystems and the use of about 4 months of schedule reserves. The project has had a shortage of both government and contractor staff, and as a result has not had staff with the unique skills required to develop its robotics system, as well as in other key areas. Project officials said that reasons for the workforce challenges include a loss of engineering support contactors after the Goddard Space Flight Center awarded a new support contract, uncertainty in funding, and the long timeline for hiring civil servants. The project plans to mitigate these challenges by working with the center to obtain more skilled contractor support and hiring more civil servants.

Technology

The Restore-L project has six remaining technologies that it needs to mature. Prior to adding the SPIDER payload in 2019, the project had one remaining technology—the vision navigation system—that it needed to mature. The project did not mature this technology to a technology readiness level 6 by the project's preliminary design review in November 2017 as recommended by best practices because the system was newly added by the project. The project has since reported that the vision navigation system has achieved a technology readiness level 6. After adding the SPIDER payload in 2019, the project added six new critical technologies that are not yet mature. Project officials said that they aim to mature these technologies to technology readiness level 6 or above before Restore-L launches.

PROJECT OFFICE COMMENTS

In commenting on a draft of this assessment, Restore-L project officials said that technology demonstration missions are not expected to achieve a technology readiness level 6 by preliminary design review, but will be mature later in the project's lifecycle. Officials expected this progression of technology maturity based on the nature of the mission. Officials also provided technical comments on a draft of this assessment, which were incorporated as appropriate.



Source: NASA/ Jet Propulsion Laboratory. | GAO-20-405

Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ices Explorer

The Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ices Explorer (SPHEREx) mission will probe the origin and destiny of the universe, explore whether planets around other stars could harbor life, and explore the origin and evolution of galaxies. The mission will create a map of the entire sky and survey the sky every 6 months to gather data on more than 300 million galaxies and 100 million stars in the Milky Way.

PROJECT INFORMATION

NASA Lead Center: **Jet Propulsion Laboratory**

International Partners: **Korea Astronomy and Space Science Institute (KASI)**

Mission Duration: **2 years**

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

Budget Portfolio: **Science, Astrophysics**

Next Major Project Event: **Preliminary Design Review (June 2020)**

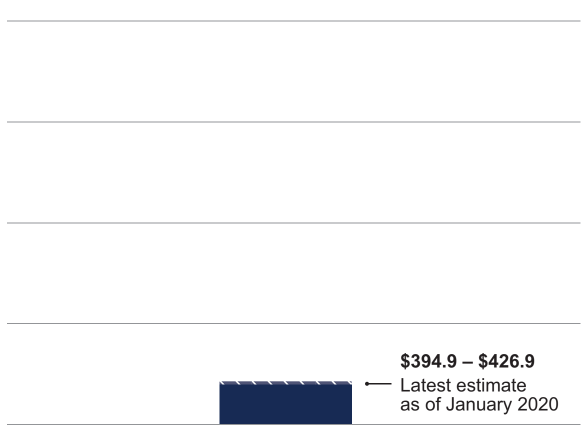
CURRENT STATUS

In February 2019, the SPHEREx project was selected from a competitive announcement of opportunity to be a new mission for NASA's Astrophysics Explorers Program. SPHEREx will include a telescope to map and survey the sky in optical and near-infrared light and a passive cooling system to keep the telescope cool enough to detect infrared light without interference from the sun, moon, or spacecraft. The project reports that it completed all the technology development work needed for the telescope and other technologies before entering the preliminary design and technology completion phase.

The project is currently working towards an internal launch date during the second quarter of fiscal year 2024 and expects the mission to operate for two years. The preliminary lifecycle cost estimate range is $395 million to $427 million, which includes a cost cap amount of $275 million that is managed by the project and $120 million for the launch vehicle and related costs. The project reported that the January 2019 government shutdown delayed NASA's selection from the competitive announcement, increasing its cost estimate by approximately $1 million because of changes in inflation over a 5-month delay. The SPHEREx project plans to hold its confirmation review in August 2020, at which point it will establish cost and schedule baselines.

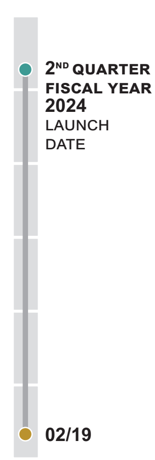
PRELIMINARY COST[a]

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

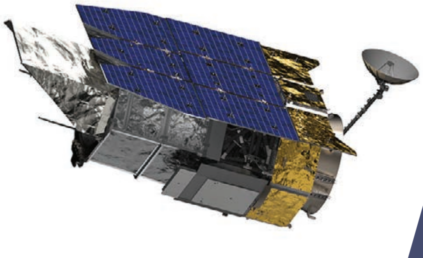


PROJECT OFFICE COMMENTS

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

PAGE INTENTIONALLY LEFT BLANK

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/Goddard Space Flight Center. | GAO-20-405

FORMULATION
- 02/16 Formulation start
- 03/18 System requirements/ mission definition review
- 10/19 Preliminary design review
- **01/20 GAO review**
- 02/20 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: **European Space Agency, Centre National d'Etudes Spatiales, Japan Aerospace Exploration Agency, Max Planck Institute**

Launch Location: **Kennedy Space Center/ Eastern Test Range**

Launch Vehicle: **TBD (Heavy Class)**

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

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

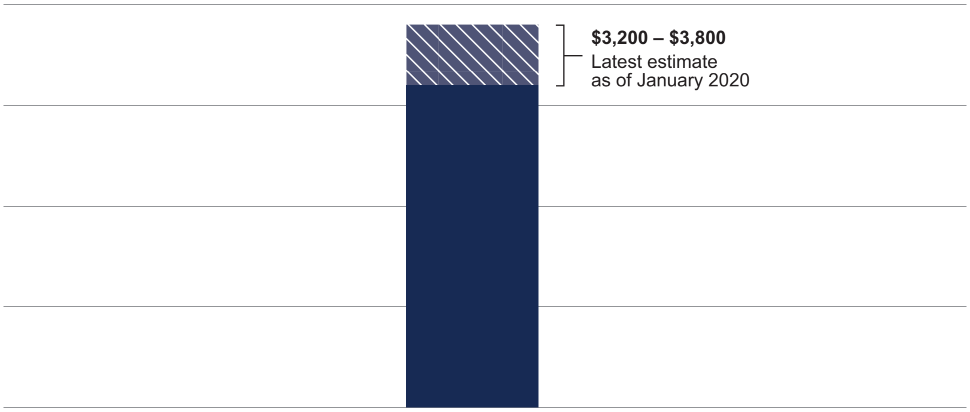
Budget Portfolio: **Science, Astrophysics**

PROJECT SUMMARY

In October 2019, the WFIRST project passed its preliminary design review and is working toward its confirmation review, which was rescheduled for February 2020. WFIRST has continued to refine its design and make progress, but had to remove the planned spectrograph in the Coronagraph Instrument and make other changes in order to reduce cost and improve the coronagraph's mass and power margins. WFIRST added a prism to the Wide Field Instrument element wheel to make up for some of the science capabilities that had been planned for the eliminated Integral Field Channel. The Wide Field Instrument changes will not reduce the ability of WFIRST to meet science requirements. In fiscal year 2019, WFIRST received $59 million less funding than it planned and had to use project reserves to cover the difference. The explanatory statement accompanying the fiscal year 2020 Consolidated Appropriations Act stated that the Act provided $510.7 million for WFIRST, while NASA did not request any funding for it. Further, the President's 2021 Budget Request proposed canceling the WFIRST project.

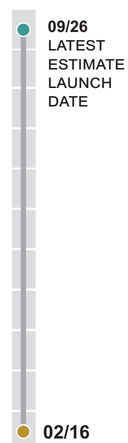
PRELIMINARY COST[a]

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

While the President's fiscal year 2021 budget again proposed canceling WFIRST, as of January 2020, the project was working toward its rescheduled confirmation review, the point at which the project will formally establish its cost and schedule baselines. In fiscal year 2019, WFIRST received $59 million less than the amount identified in the funding plan that it had been operating under from the beginning of the fiscal year. The project primarily used reserves to cover the difference, and the Science Mission Directorate intends to replenish the difference in a future fiscal year. Additionally, NASA estimates that the government shutdown had a schedule impact of 5 weeks at a cost of about $25 million, which was also absorbed with project reserves.

Further, as in the previous fiscal year, NASA did not request funding for WFIRST in its fiscal year 2020 budget request, but the explanatory statement accompanying the fiscal year 2020 Consolidated Appropriations Act stated that the Act included $510 million for the project.

Design and Technology

The WFIRST project passed its preliminary design review (PDR) with 20 of its 23 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. NASA assessed the remaining three technologies at a technology readiness level 5 at PDR. The project requested a waiver for two heritage technologies because changes to their design required further development. The third technology did not need to be matured by PDR because it is a technology demonstration.

The design of the Wide Field Instrument (WFI)—intended to measure light from a billion galaxies and perform a survey of the inner Milky Way—has undergone extensive optimization, according to project officials. For example, to make up for some of the science capabilities planned for the eliminated Integral Field Channel, it added a prism to the WFI element wheel, which will provide optical filters and be used for supernova observations. Project officials said the addition of the prism will increase costs by $7 million, and will not reduce the ability of WFIRST to meet science requirements. Also, WFIRST is tracking a schedule risk regarding the WFI flight detectors production yields. To date only 4 of the 18 detectors needed have qualified as a flight unit. The detectors are challenging to produce, and the project continues to assess the WFI schedule to find efficiencies and other mitigation activities.

To address cost growth and mass and power issues with the Coronagraph Instrument (CGI) —a technology demonstration designed to perform high contrast imaging and spectroscopy of nearby exoplanets—the project eliminated the Integral Field Spectrograph (IFS). Among other changes, the project replaced the IFS with a prism that allowed it to regain adequate budget, mass, and power margins. The CGI still meets its spectrographic requirements with this change.

Launch Vehicle

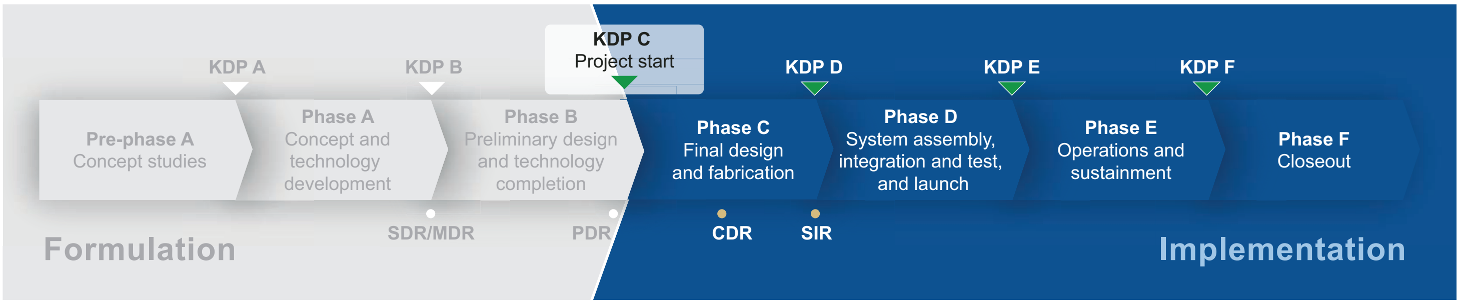
No current launch vehicles are certified to launch missions with WFIRST's level of investment and risks and have the capacity necessary to launch WFIRST's mass. The project has initiated discussions with NASA's Launch Services Program to start procuring the launch vehicle in 2020. The project had considered using the Space Launch System (SLS) as a launch vehicle, but it is no longer a viable option due to schedule constraints and analysis showing that SLS's predicted performance will exceed WFIRST acoustic requirements. There are three remaining launch vehicle options—Falcon Heavy, New Glenn, and Vulcan—that could be available for WFIRST's scheduled 2026 launch, but these vehicles are in varying stages of development or certification. The WFIRST project is trying to minimize the risks to its designs associated with not having identified a launch vehicle. For example, the WFIRST project is creating mechanical loading requirements that envelope potential launch vehicles to the extent possible.

PROJECT OFFICE COMMENTS

In commenting on a draft of this assessment, project officials noted that the project completed its confirmation review on February 28, 2020, and established a lifecycle cost baseline of $3,934 million which includes a $3,591.3 million baseline for WFIRST and a $342.7 million baseline for the CGI. The project set a launch readiness date of October 2026. Project officials provided other technical comments on this assessment, which were incorporated as appropriate.

Assessments of Projects in the Implementation Phase

Project implementation consists of phases C through F during which the project holds critical design and system integration reviews before preparing for system assembly, integration and test, and launch.



Management decision reviews

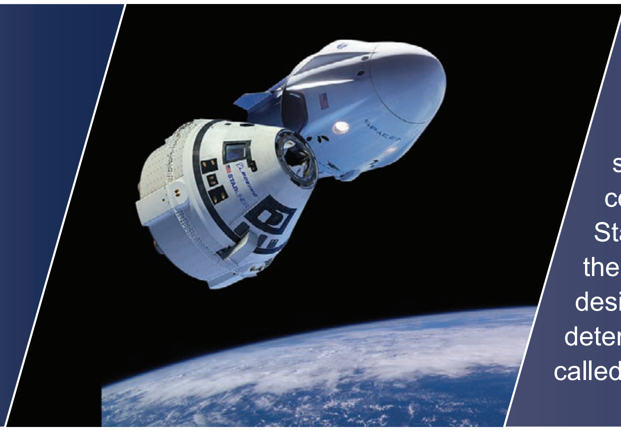
KDP = key decision point

Technical reviews

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

Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-20-405

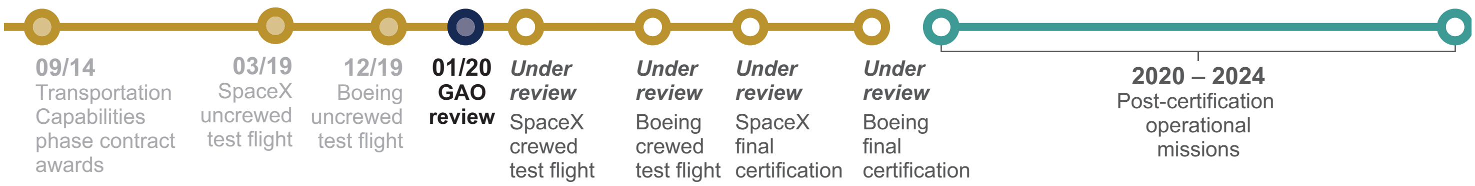
PAGE INTENTIONALLY LEFT BLANK



Source: NASA. | GAO-20-405

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. 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.



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**

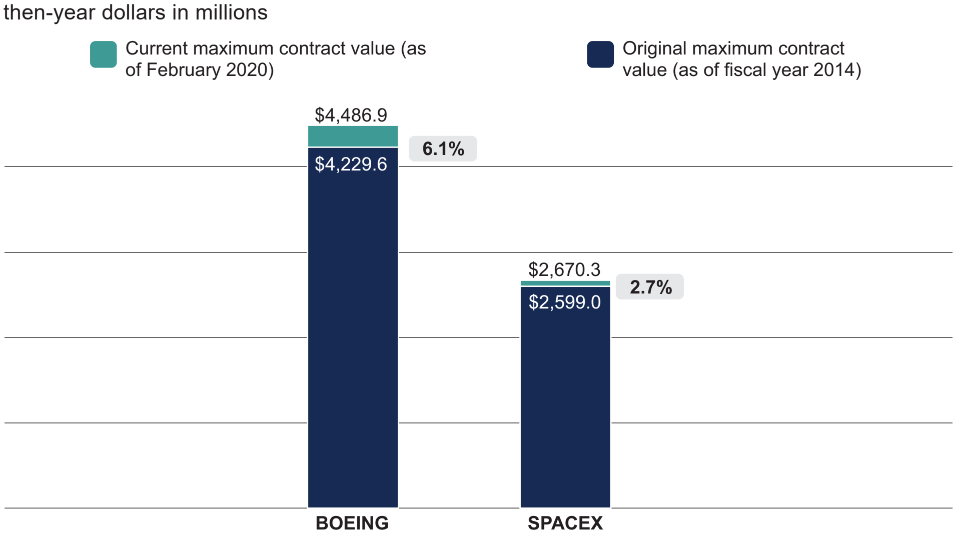
[a]Blue Origin and Sierra Nevada Corporation do not have contracts for the current phase and therefore were not included in this assessment.

PROJECT SUMMARY

As of February 2020, the Commercial Crew Program does not have a publicly available schedule for completing certification and flying the first operational mission. Both contractors have completed two key test events. SpaceX conducted an uncrewed test flight in March 2019 and in-flight abort test in January 2020. Boeing conducted a pad abort test in November 2019 and an abbreviated uncrewed test flight in December 2019. During the uncrewed test flight, Boeing successfully launched and landed its spacecraft, but the spacecraft did not reach the planned orbit and did not dock with the ISS. As a result, NASA is currently assessing whether a second uncrewed test flight is needed. Both contractors continue to address risks identified by the program related to their parachute systems. Additionally, external schedule pressure to conduct an operational mission is increasing as NASA's presence on the ISS is set to decrease to one astronaut in April 2020 and none in October 2020. As a result, the Commercial Crew and ISS Programs are assessing two schedule options for SpaceX's crewed test flight.

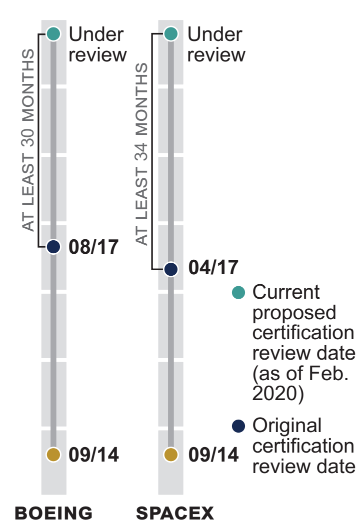
COST PERFORMANCE[b]

then-year dollars in millions



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

SCHEDULE PERFORMANCE



Schedule Status

As of February 2020, the Commercial Crew Program did not have a publicly available schedule for completing certification and conducting the first operational mission. In July 2019—following the reassignment of key leadership that oversees the program—the NASA Administrator stated that one of the first tasks once new leadership is in place would be to reexamine the cost and schedule for the Commercial Crew Program, among other key programs. The new Associate Administrator for Human Exploration and Operations Directorate joined NASA in December 2019, but a schedule for when either contractor would be ready to fly an operational mission was still pending at the time of our review.

Integration and Test

SpaceX has completed two key test events—an uncrewed test flight in March 2019 and an in-flight abort test in January 2020—in advance of its crewed test flight. The in-flight abort test demonstrated the spacecraft's ability to safely carry crew away from the launch vehicle in the event of an emergency. In February 2020, SpaceX shipped the crewed test flight spacecraft to Florida for final testing and prelaunch processing. At that time, SpaceX still needed to complete two parachute tests that program officials told us they requested to gain additional information to help validate the system for crewed flight. Program officials told us, however, that SpaceX had made significant progress since fall 2019 to address risks related to its parachute system including finalizing the design and conducting several tests.

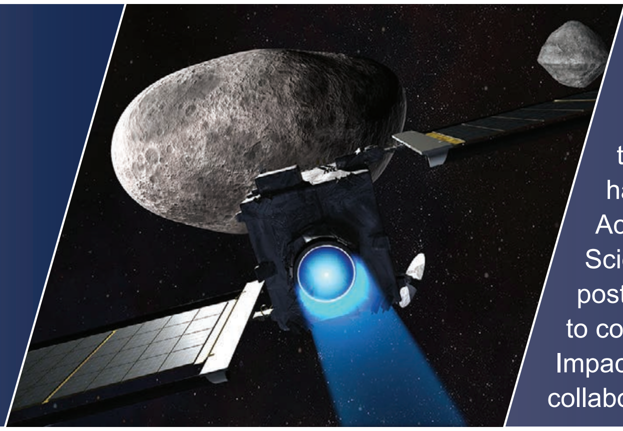
Boeing has also completed two key test events—a pad abort test in November 2019 and an uncrewed test flight in December 2019—but the uncrewed test flight was abbreviated due to an anomaly. During the uncrewed test flight, Boeing successfully launched and landed its spacecraft, but the spacecraft did not reach the planned orbit and did not dock with the ISS. NASA and Boeing launched a joint investigation team to examine the issues revealed by the flight. In February 2020, the joint team had identified three issues: (1) a software issue, which resulted in an anomalous mission elapsed timer; (2) a separate software issue, which was addressed during the mission, but could have affected the disposal of the spacecraft's service module, which provides propulsion on-orbit; and (3) a communication issue, which impeded Boeing's ability to command and control the spacecraft. NASA reports that the joint team has identified the technical root cause for the first two anomalies, but the intermittent communication issues are still being investigated. The Commercial Crew Program continues to assess whether Boeing will need to conduct an additional uncrewed test flight or whether it can proceed to the crewed test flight. Further, the program continues to work with Boeing to conduct additional testing to gain a better understanding about the parachute system.

Other Issues to Be Monitored

External schedule pressure to conduct an operational mission soon is increasing. The NASA presence on the ISS is set to drop to one astronaut in April 2020 and none by October 2020 if a Commercial Crew Program contractor is not able to begin flying operational missions, unless NASA purchases a seat on the Russian Soyuz spacecraft. The Commercial Crew and ISS programs are assessing two schedule options related to SpaceX's crewed test flight: (1) launch the crewed test flight as soon as possible as a short duration mission, or (2) launch the crewed test flight after April 2020, when the U.S. presence on the ISS drops to one crewmember, as a long duration mission to provide additional crew capability

PROJECT OFFICE COMMENTS

CCP project officials did not provide comments on a draft of this assessment.



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-20-405

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

IMPLEMENTATION
- 06/19 Critical design review
- **01/20 GAO review**
- 03/20 Integration and test readiness review
- 07/21 Target launch readiness date
- 02/22 Committed launch readiness date

PROJECT INFORMATION

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

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

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

Launch Vehicle: **Falcon 9**

Mission Duration: **Less than 15 months**

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

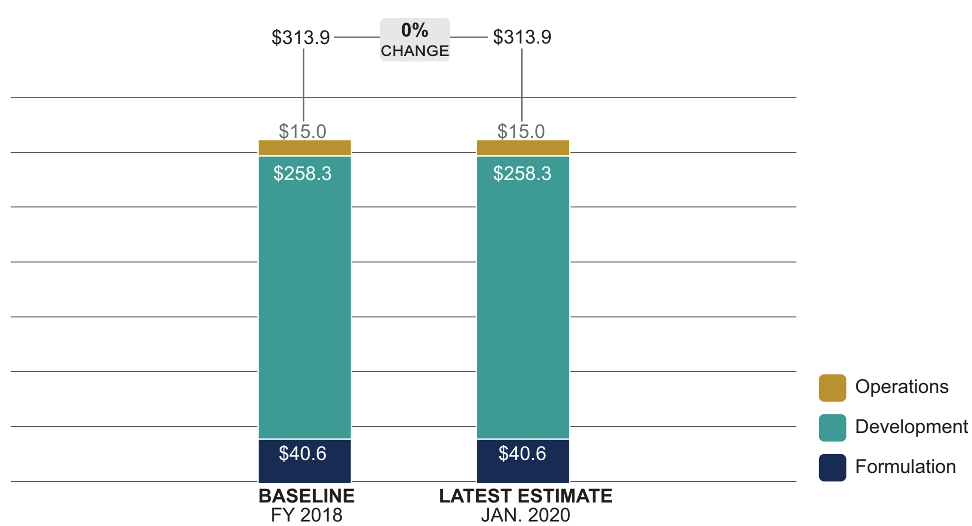
Budget Portfolio: **Science, Planetary Science**

PROJECT SUMMARY

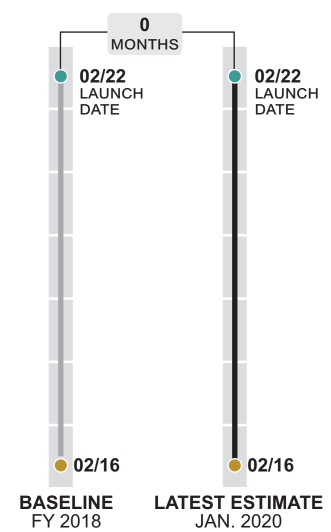
The DART project continues to operate within its cost and schedule baselines. In April 2019, the Launch Services Program selected the SpaceX Falcon 9 as the dedicated launch vehicle for the DART project, as opposed to a rideshare option. According to officials, having a dedicated launch vehicle allows for a new trajectory that reduces the amount of propellant required. As a result, the project no longer relies on the NASA Evolutionary Xenon Thruster-Commercial (NEXT-C) technology demonstration, which has experienced development delays. According to project officials, NASA continues to fund NEXT-C to accompany DART but if delays continue, DART can fly without it. Project officials plan to review the status of NEXT-C between December 2019 and February 2020 to reach a final decision on whether it will fly on DART. As of October 2019, the project reported that it has a signed agreement with the Italian Space Agency (ASI) for a CubeSat contribution. Similar to NEXT-C, DART will not delay launch to accommodate this contribution if delays materialize because it is not required to achieve mission success.

COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The DART project continues to work within its cost and schedule baselines set in August 2018. In August 2019, the project amended its internal cost and schedule goals, pushing its internal launch readiness date back by 1 month to July 2021, to accommodate the dedicated launch service that was selected, among other changes. The project now has 7 months of schedule reserve remaining to its February 2022 baseline launch date.

Launch

The launch service selection was competed, and the Launch Services Program selected a dedicated launch vehicle for DART, the SpaceX Falcon 9, rather than a rideshare option. According to officials, this allows for a new trajectory that reduces the amount of propellant required removing reliance on NEXT-C, an electric propulsion technology demonstration project managed at Glenn Research Center under the Discovery Program. The new trajectory no longer includes a flyby of a potentially hazardous asteroid, originally planned to calibrate sensors and tune the subsystem used to autonomously drive the spacecraft to impact the smaller body of the Didymos asteroid system. Project officials said this carries some risk to navigation system testing but they see the risk as acceptable given available ground simulation and in flight testing using the moons of Jupiter.

Design and Technology

DART held its critical design review in June 2019 with approximately 86 percent of design drawings released, just below the best practice of releasing 90 percent of design drawings at this review. Our product development best practices work has shown that meeting this metric lowers the risk of projects experiencing design changes and manufacturing problems that can lead to cost and schedule growth.

Although DART does not need NEXT-C to meet its requirements, NASA still plans for the separately funded technology demonstration to fly on DART. The project had reported concerns about on-time delivery of NEXT-C due to ongoing developmental issues, and was pursuing two parallel development paths, one expecting delivery of NEXT-C and one expecting to use a mass simulator—an object of similar weight and balance—in place of NEXT-C, to mitigate this risk. As of December 2019, however, NEXT-C may meet DART's schedule needs. According to officials, the parallel development approach required additional cost and time compared to pursuing a single development path. Project officials plan to complete a full review of NEXT-C between December 2019 and February 2020, with the goal of delivering NEXT-C in February 2020 prior to the start of project-level integration and testing.

Project officials told us that in October 2019 NASA decided to descope the electric propulsion gimbal assembly due to cost overruns and other contractor issues. The gimbal was designed to connect NEXT-C to DART to allow adjustments to the direction of propulsion. Officials said they will not add funds to the gimbal assembly contract to continue work, and now plan to use a stationary mount, which is simpler and should yield cost and schedule savings.

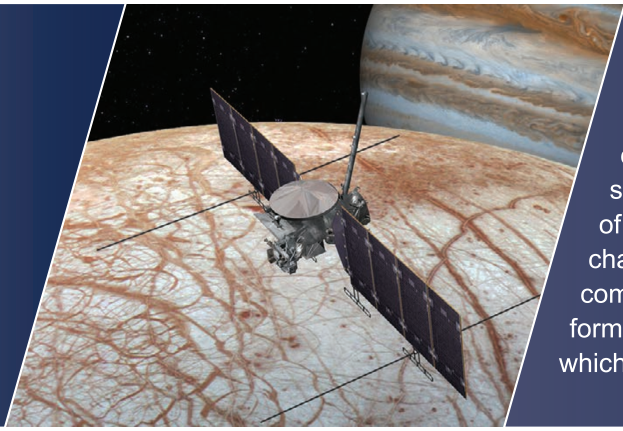
International Partner

As of October 2019, NASA reported that it has signed an agreement with the Italian Space Agency (ASI) to contribute the Light Italian CubeSat for Imaging of Asteroids (LICIACube) that will document DART's impact of Didymos. According to officials, there is some risk that the contribution could be delivered late. To mitigate this risk, project officials purchased a deployment box—a device used to integrate the CubeSat and allow it to launch with DART as a ride-along—identical to the deployment box ASI plans to use. Officials explained that this purchase provides schedule margin for the satellite's delivery to DART. This contribution is not required for DART to achieve mission success, however, and officials said they will not delay DART's launch to accommodate LICIACube.

In November 2019, the European Space Agency (ESA) approved HERA, a possible partner mission due to launch in 2024, which will provide additional follow-up analysis of DART's impact. NASA and the ESA have not yet reached a formal agreement on this contribution.

PROJECT OFFICE COMMENTS

In commenting on a draft of this assessment, DART project officials stated that as of January 2020, the testing of the flight NEXT-C thruster and electronics has gone very well, and the NEXT-C system is on track for a timely delivery for integration on the spacecraft. Officials also 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-20-405

FORMULATION

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

IMPLEMENTATION

- **01/20 GAO review**
- 08/20 Critical design review
- 03/21 System integration review
- 09/25 Committed 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**

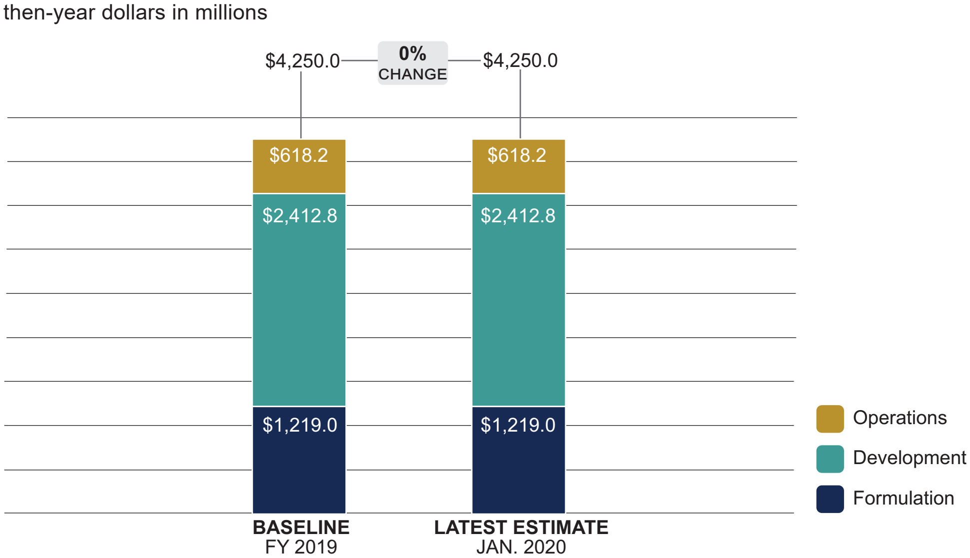
Budget Portfolio: **Science, Planetary Science**

PROJECT SUMMARY

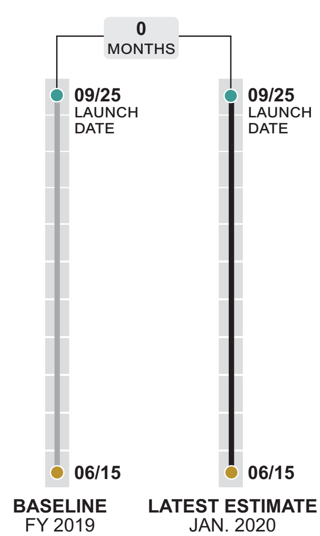
In August 2019, the Europa Clipper project formally established its cost and schedule baselines of $4.25 billion and September 2025. This cost baseline—$250 million above the top end of the project's preliminary cost estimate—reflects the costs associated with the new launch date, which is more than 2 years later than the project's preliminary launch readiness date of July 2023. The new launch baseline assumes the project will complete the spacecraft in 2023 and store it until the Space Launch System (SLS) is available for launch in 2025. The NASA Human Exploration and Operations (HEO) Mission Directorate informed the project's Mission Directorate that 2025 is the earliest the SLS could be available to launch the Europa Clipper. NASA officials stated they are pursuing legislative relief from the requirement to launch on SLS. The Science Mission Directorate Associate Administrator made a decision to descope one instrument—the Interior Characterization of Europa using MAGnetometry—due to its significant and persistent cost growth and replace it with the Europa Clipper Magnetometer.

COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The Europa Clipper project entered the implementation phase and established its cost and schedule baselines in August 2019. The project set a baseline life-cycle cost of $4.25 billion and a launch date of September 2025. This is $250 million above the top end of the project's preliminary cost estimate and more than 2 years after its preliminary launch readiness date of July 2023. According to the Consolidated Appropriations Act, 2020 the project shall use SLS as its launch vehicle. The NASA HEO Mission Directorate informed the Europa Clipper's Mission Directorate that the earliest an SLS launch vehicle would be available for the Europa Clipper project is 2025. According to the NASA officials, before that date, all SLS launch vehicles would be required for use by the Artemis program.

The $250 million increase above the project's preliminary cost estimate reflects the costs associated with this later launch date and assumes that Europa Clipper will complete development work in 2023 and be stored for 2 years. This amount includes the following costs: $1 million for physical storage; $129 million for workforce and potential staff requirements; $96 million for mission system impact and a change in cruise time to Europa from 2.4 to 3 years; and $24 million in cost reserves. According to NASA officials, it is possible that additional delays with SLS may lead to an SLS being unavailable for use by Europa Clipper in 2025, which could require the project to reset its cost and schedule baseline.

As of December 2019, the project reported that its cost reserve status is unacceptably low and that it is trying to identify ways to replenish it. The project has had to use reserves to address development challenges for both flight subsystems and instruments. The Science Mission Directorate Associate Administrator made a decision to descope one instrument—the Interior Characterization of Europa using MAGnetometry—due to its significant and persistent cost growth and replace it with the Europa Clipper Magnetometer. The project has also identified that three of its remaining eight instruments have hit or exceeded the 20 percent cost growth threshold and two more instruments are nearing it. Once the cost threshold is reached, the project is to conduct a review of cost control options. If the project cannot identify an acceptable recovery plan, the project's Mission Directorate conducts a descoping review. Such a decision could impact the project's ability to accomplish science requirements. As of December 2019, cost growth is a primary risk driver for accomplishing the project's mission.

Technology and Design

The Europa Clipper project completed its preliminary design review in June 2019 after a previous delay due to design challenges integrating its radar and solar array, since addressed by decoupling these instruments. The project has identified no critical technologies and reported that all of its heritage technologies were matured to technology readiness level 6, a best practice to help minimize development risks.

The project continues to maintain compatibility with three launch vehicles: the SLS, the Delta IV Heavy, and the Falcon Heavy. The Consolidated Appropriations Act, 2020 states that the project shall launch on an SLS by 2025. NASA officials told us that they are pursuing legislative relief from the requirement to use SLS because it could allow the project to avoid storage costs and possibly achieve an earlier launch date. The project reports that if a launch vehicle decision is not made before the project's critical design review in August 2020 (which was delayed three months because a launch vehicle has not been chosen) then significant resources will be required to maintain multiple launch and mission trajectory plans.

Other Issues to Be Monitored

The project continues tracking a risk regarding the number of available qualified staff in the mission assurance and systems engineering areas. If qualified staff cannot be provided by the institutions supporting the project, then there could be risk to the quality of the design.

PROJECT OFFICE COMMENTS

In commenting on a draft of this assessment, Europa Clipper project officials stated that maintaining compatibility with multiple launch vehicles is causing the project to expend significant resources maintaining multiple launch and mission trajectory plans. Officials stated it is also precluding the team from focusing on the detailed design, and validating that that design will meet the requirements for a specific launch vehicle and mission trajectory. Project officials said that this inability represents both cost risk and mission risk. Officials also 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 of facilities and ground support equipment 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, Artemis I.

Source: NASA. | GAO-20-405

PROJECT INFORMATION

NASA Lead Center: **Kennedy Space Center**

International Partner: **None**

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

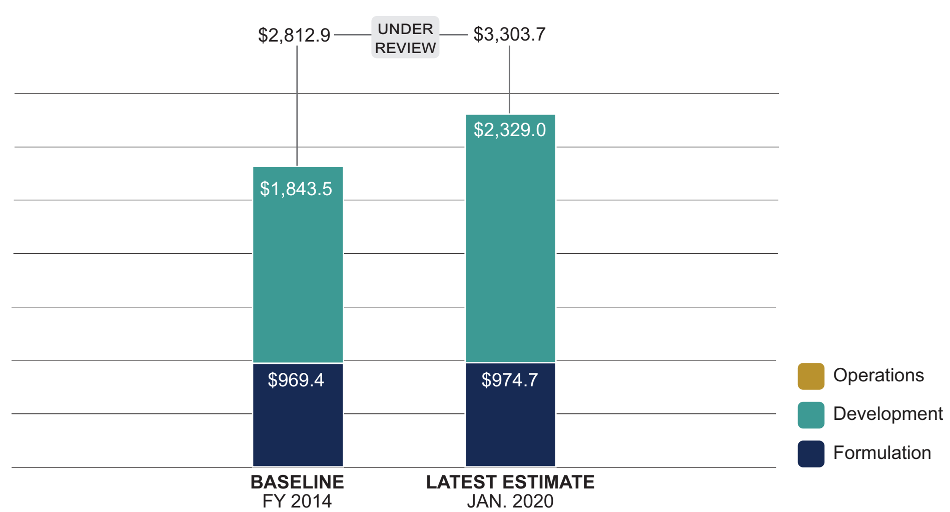
Budget Portfolio: **Exploration, Exploration Systems Development**

PROJECT SUMMARY

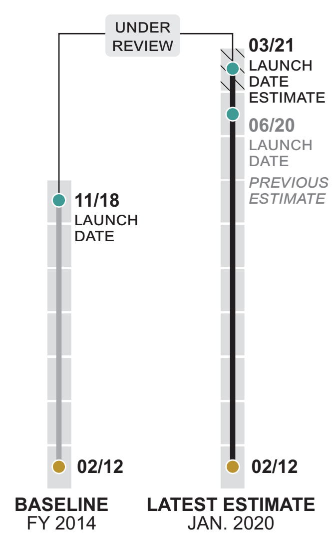
After a series of delays, NASA had planned to conduct the uncrewed demonstration of Artemis I in June 2020, but the agency is currently reevaluating this date. NASA officials stated that EGS is prepared to support an Artemis I launch date from November 2020 through March 2021 without impact to schedule and costs or to development plans for subsequent Artemis missions. However, according to officials, while most of the infrastructure needed for the Artemis I launch is nearing operational readiness, the delivery of Orion and SLS hardware is essential for successful EGS operations. Any delays in hardware delivery beyond the current schedule will impact the stacking of the vehicle in preparation for integrated test and checkout procedures before launch and will result in schedule and cost overruns. The EGS program's costs are currently estimated through a March 2021 launch date for Artemis I; however, costs will remain uncertain until a new launch date is established. The program continues to report progress and improvements to its launch software, which represents the program's critical path.

COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

After a series of delays, NASA had planned to conduct the uncrewed demonstration of Artemis I in June 2020, but the agency is currently reevaluating this date. NASA officials stated that EGS is working toward a November 2020 Artemis I launch date but is prepared to support a launch date through March 2021 without impact to schedule and costs or to development plans for subsequent Artemis missions. According to officials, however, the timely delivery of Orion and SLS hardware is essential for EGS to support any launch readiness date. Any delays in hardware delivery will delay the stacking of the vehicle in preparation for integrated test and checkout procedures—a series of final tests that ensures all Artemis hardware operates as expected following integration and stacking—and could result in schedule and cost overruns. Currently, the EGS program is measuring cost growth to a March 2021 baseline launch date for the uncrewed demonstration of Artemis I, although this date remains tentative until NASA officially establishes a new launch date.

Software

The EGS program has made 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, will culminate in the release and testing of SCCS 6.2 in May 2020 to support operations for Artemis I. In addition, development of the GFAS software is substantially complete with only verification and validation of the GFAS software remaining. Although software development is currently on track, 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.

Integration and Test

Before beginning integrated test and checkout procedures, the program must complete multi-element verification and validation as well as system acceptance and operational readiness reviews. Multi-element verification and validation is a process that determines if the launch and processing systems at Kennedy Space Center meet program requirements and specifications and can operate together to fulfill their intended purpose. According to officials, the EGS program completed multi-element verification and validation of the Mobile Launcher and the launch pad in January 2020. However, program officials stated that they are addressing challenges that emerged during integration and testing. For example, the Mobile Launcher's pressure panel—which monitors and regulates the flow of fuel, oxidizer, and conditioned air into and out of the Mobile Launcher—has ongoing issues with leaks. The leaks are difficult to detect and challenging to repair as they often occur in areas that are not easily accessible.

Following multi-element verification and validation, the program must undergo system acceptance and operational readiness reviews, which further demonstrate EGS's readiness to receive, process, integrate, and launch flight hardware. According to officials, most of the infrastructure needed for the Artemis I is nearing operational readiness. Currently, the program plans to finish the system acceptance and operational readiness reviews for vehicle stacking in September 2020.

Following these two series of reviews, the EGS program can begin integrated test and checkout procedures. According to current schedule estimates, the EGS program needs approximately 4 months to complete integrated test and checkout procedures prior to the Artemis I launch. However, the EGS program continues to track a risk that 4 months may be insufficient time for this process based on factors such as historical pre-launch integrated test and checkout delays and additional effort and time the program may need to test a new vehicle for the first time.

PROJECT OFFICE COMMENTS

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

Source: Northrop Grumman Aerospace Services. | GAO-20-405

James Webb Space Telescope

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

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

IMPLEMENTATION
- 03/10 Critical design review
- 10/19 System integration review
- **01/20 GAO review**
- 03/21 Committed launch readiness date

PROJECT INFORMATION

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

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

Launch Location: **Kourou, French Guiana**

Launch Vehicle: **Ariane 5**

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

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

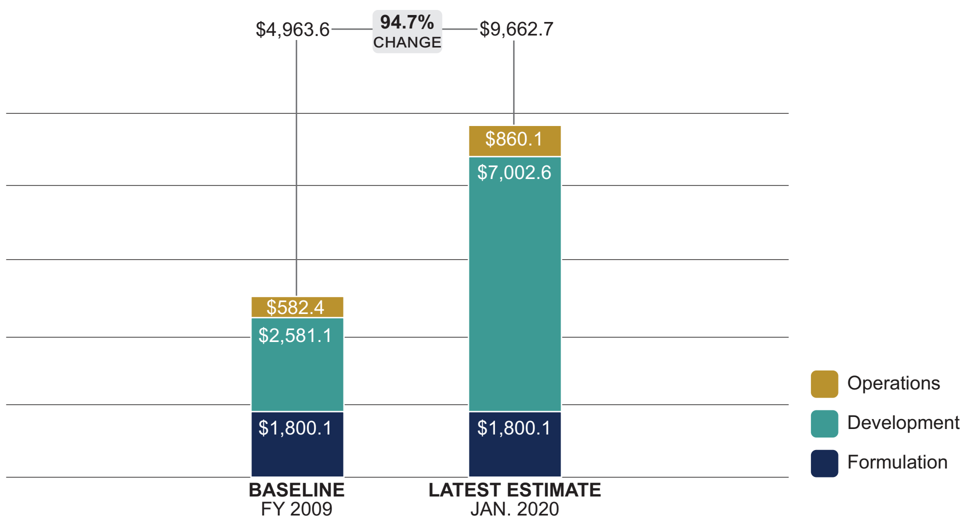
Budget Portfolio: **Science, Astrophysics**

PROJECT SUMMARY

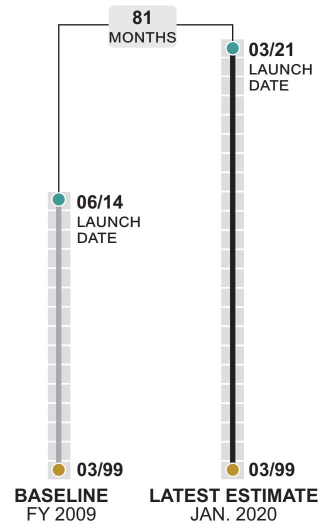
The project recently conducted a cost and schedule analysis, which indicated a 12 percent confidence level in achieving the current committed launch date of March 2021. However, the program has reported that planned funding and cost reserves are adequate to extend the schedule to launch by 3-4 months. Though the project has completed several integration and testing milestones, technical challenges have significantly reduced the amount of schedule reserves available to accommodate new risks identified during observatory integration and testing. For example, anomalies with two spacecraft parts needed to communicate data with ground control occurred during testing. Though NASA and the contractor have taken steps to recover schedule, the project must enter the final phase of testing, which includes another set of challenging environmental tests, with diminished schedule reserves. The project has already identified repairs needed for a stabilizing flap and the replacement of certain bolts as potential schedule risks going forward.

COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

Technical challenges since the JWST program's last replan have strained schedule and NASA has assessed the likelihood of meeting its March 2021 launch date to be relatively low. In June 2018, NASA established a new life cycle cost commitment of $9.7 billion and launch readiness date of March 2021—$828 million over and 29 months later than the baselines established by the project's previous replan in 2011. Though the replan replenished schedule reserve at a level greater than indicated by the center policy, technical challenges during spacecraft testing in 2019 required the project to use reserves faster than planned. Following these issues, the project completed a joint cost and schedule confidence level analysis in October 2019 that found the project had a 12 percent likelihood of meeting its revised launch date. As of February 2020, the project reports that it has 56 days, or about 16 percent, of its replenished schedule reserves left. Project officials noted that cost reserves were adequate to extend the launch date by 3-4 months, if necessary, and that they would reexamine the launch date prior to the pre-environmental test review in spring 2020.

Design

The project has approved design changes to address previously identified risks to the sunshield including cable snags and damage that could occur when the launch vehicle's fairing depressurizes in space. However, anomalies with the command and telemetry processor and traveling wave tube amplifier—which will communicate science and command data—were the two largest contributors to the loss of schedule reserve. These components shut down unexpectedly during spacecraft element testing and efforts to determine the causes and potential solutions for the anomalies required 120 days, or about 41 percent, of the project's replenished schedule reserves. Officials stated that workmanship issues are the likely cause for at least one of the anomalies and have taken steps to mitigate risk to the observatory. For example, the project has received replacement amplifiers and is in the process of upgrading an engineering model processor to replace the faulty one aboard the observatory if necessary.

Integration and Test

The project completed testing on the individual component elements and integrated them to begin observatory level testing, the last of five phases of integration and testing in August 2019. However, the project must complete another set of challenging environmental tests now that the observatory has been fully integrated. Our prior work has shown that integration and testing phase is when problems are most likely to be found and schedules tend to slip. The project is monitoring several technical issues and risks that could further affect the project's schedule. For example, the contractor determined on another program that certain bolts held in common with JWST did not meet specifications. JWST isolated the bolts but found that 501 were already installed on the observatory. The project is performing strength testing but has not yet determined how many will need to be replaced. Further, the project is investigating structural and electrical issues related to the deployment of the sunshield. Finally, the program must remove and make repairs to the spacecraft's momentum flap, which will act as a balance against solar pressure that could cause unwanted movement in orbit, prior to beginning observatory-level vibration testing.

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: Delivery Order NNG17VV00D w/Northrop Grumman Space Systems. | GAO-20-405

FORMULATION

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

IMPLEMENTATION

- **04/18** Critical design review
- **01/20 GAO review**
- **03/20** System integration review
- ***Under review*** Target launch readiness date
- **11/21** Committed launch readiness date

PROJECT INFORMATION

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

International Partner: **None**

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

Launch Vehicle: **Atlas V**

Mission Duration: **5 years**

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

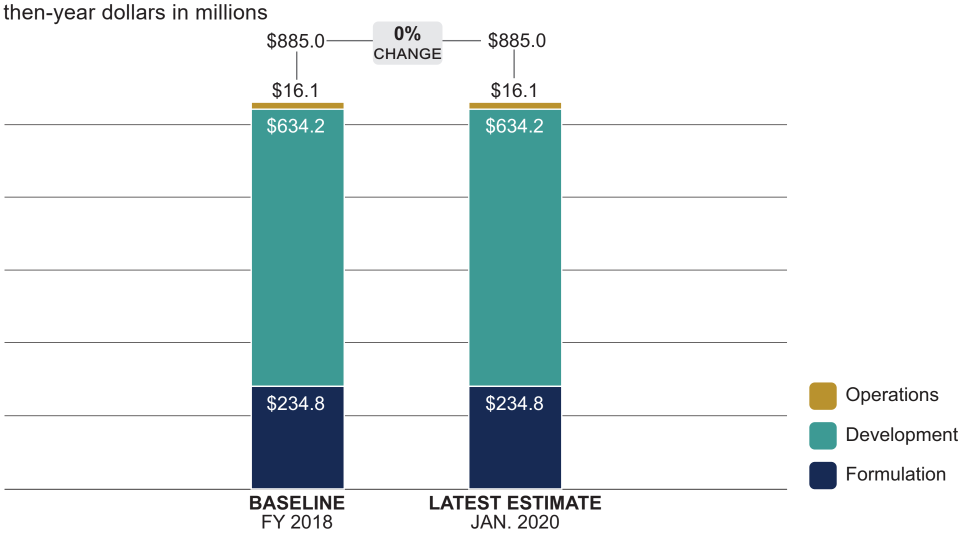
Budget Portfolio: **Science, Earth Science**

PROJECT SUMMARY

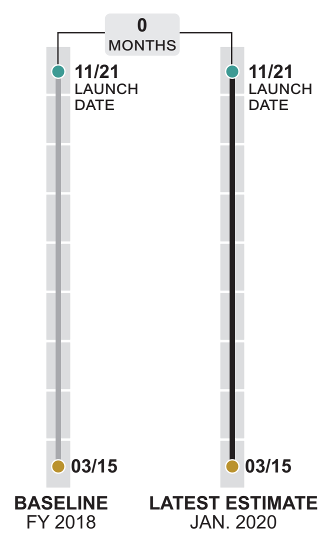
The Landsat 9 project is reevaluating its schedule to set a new internal launch readiness date, but project officials expect this date will still be before its November 2021 baseline date. The project was working to an earlier December 2020 date due to direction in the Explanatory Statement accompanying the Consolidated Appropriations Act, 2016. NASA officials told us that the schedule has slipped; however, cost and schedule baselines are not threatened because the project has sufficient reserves. Landsat 9 officials attribute recent delays to the spacecraft contractor's performance and stated that delays have been compounded by conflicts with testing facilities and equipment. Landsat 9 officials are coordinating with the contractor's executive management to mitigate these issues. Landsat 9's two primary instruments have both been delivered to the contractor and mechanically installed on the spacecraft.

COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The Landsat 9 project is reevaluating its schedule to set a new internal launch readiness date, but project officials expect this date will still be before its November 2021 baseline date. The project was working to an earlier December 2020 date due to direction in the Explanatory Statement accompanying the Consolidated Appropriations Act, 2016. NASA officials told us that the schedule has slipped, in part as the result of ongoing issues with the spacecraft contractor. Officials said despite this delay, their cost and schedule baselines are not threatened because the project has sufficient reserves. For example, as of September 2019, the project was maintaining cost reserves over 50 percent, which is more than double the project's planned level.

Technology

Both of Landsat 9's primary instruments—the Operational Land Imager 2 (OLI-2) and the Thermal Infrared Sensor 2 (TIRS-2)—have been delivered to the spacecraft contractor, successfully completed functional testing, and are mechanically installed on the spacecraft. As of January 2020, the project was working toward its system integration review scheduled for March 2020.

Contractor

The project is experiencing ongoing delays in spacecraft electronics fabrication, flight software, and simulators that affect system integration. Landsat 9 officials attribute these recent delays to issues with the spacecraft contractor's performance. The project has met with contractor management to discuss its performance, including concerns about the number and experience of staff available to complete remaining work. According to the contractor, additional staff that have prior space flight experience have been assigned to the project and received several weeks of project unique training. The contractor also reported that this additional staff allowed for second-shift capability and working extended shifts and weekends. To further mitigate schedule risk associated with the staffing concerns, Landsat 9 augmented contractor staff with an on-site presence and utilized expertise from other contractors for targeted technical support.

The project has also identified that recent delays have been compounded by conflicts with testing facilities and equipment. Testing equipment was allotted to another project, and Landsat 9 plans to complete environmental testing once the equipment is returned. According to the spacecraft contractor, Landsat 9 and the other project did not originally have any scheduling conflicts; however, both projects experienced part availability delays which contributed to the conflict. The contractor stated it used a multi-factor process for resolving schedule conflicts and the other project got priority use of testing facilities due to its closer launch date, among other factors. In addition to this schedule conflict, the project has identified that a second project may require the use of environmental testing facilities at the same time as Landsat 9. Project officials are coordinating with spacecraft contractor management to assess potential facility conflicts early; however, there is risk that additional schedule erosion could occur if the equipment return from the first project is delayed or if this second facility conflict materializes.

PROJECT OFFICE COMMENTS

Landsat 9 officials 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 with and will be a payload on a U.S. Air Force Space Test Program satellite.

Source: Universities Space Research Association (USRA). | GAO-20-405

PROJECT INFORMATION

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

International Partners: **N/A**

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

Launch Vehicle: **Atlas V 551**

Mission Duration: **2+ years**

Requirement Derived from: **NASA Strategic Plan**

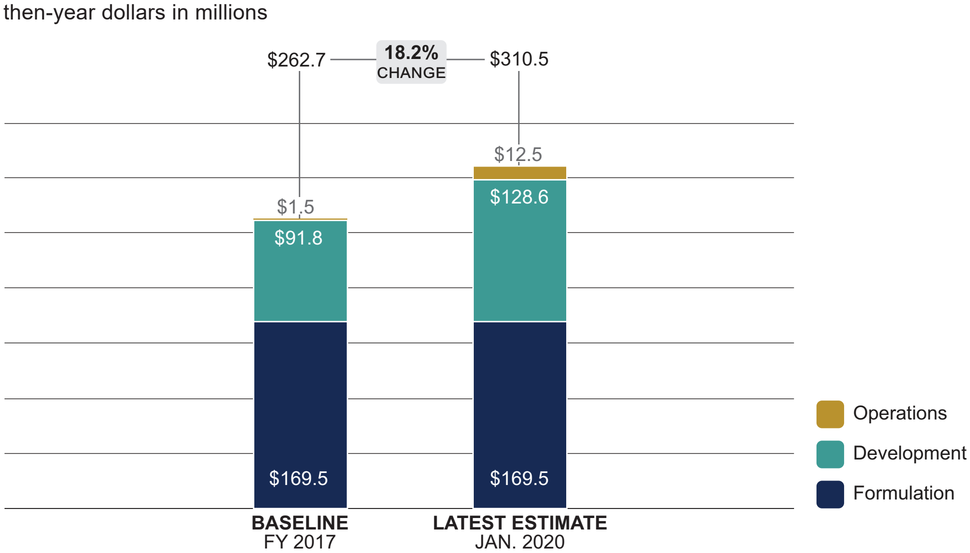
Budget Portfolio: **Space Technology, Research and Development**

PROJECT SUMMARY

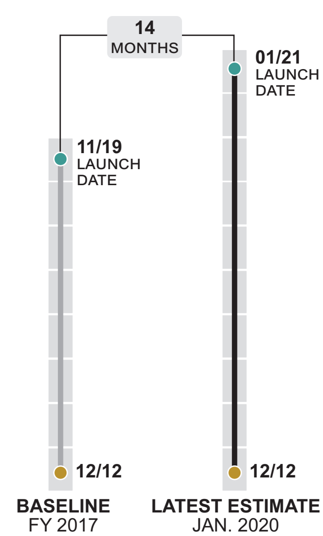
The LCRD project rebaselined its cost and schedule due, in part, to continued delays with the spacecraft bus on which the LCRD instrument will be hosted. In November 2019, NASA set a new life-cycle cost of $310.5 million and a new launch readiness date of January 2021, but the project's ability to meet the new schedule is already under pressure. The LCRD project is scheduled to deliver the payload to the spacecraft contractor for integration in January 2020, but the spacecraft contactor continues to experience schedule delays and there are now only 2 months schedule reserve remaining to the revised January 2021 launch readiness date. In addition to the spacecraft challenges, the project has experienced its own challenges with the instrument. For example, officials told us that during testing, they discovered that the capacitors on the flight modems and ground modems were reversed. The project fixed the capacitor configuration, which in the case of the flight modems involved removing the modem boxes from the instrument and then reinstalling them.

COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

In November 2019, NASA approved a rebaseline for the LCRD project reflecting both schedule delays and increasing costs, but the project's ability to meet the revised schedule is already under pressure. The project's revised development costs are $128.6 million, or 40 percent, higher than the baseline and the new launch readiness date of January 2021 is 14 months later than the original committed launch readiness date of November 2019. The LCRD project rebaselined its cost and schedule due, in part, to continued delays on the spacecraft for the Air Force Space Test Program on which the LCRD instrument will be hosted. According to officials, the spacecraft contractor, with whom the Air Force holds the contractual relationship, continues to experience integration and test delays. LCRD project officials told us that the issues the Air Force project has experienced stem from multiple issues including design disconnects, configuration control, and workmanship. Officials noted that senior management from NASA, the Air Force, and the contractor have increased their attention to the prioritization of work at that facility.

The LCRD project is scheduled to deliver its payload to the spacecraft contractor in January 2020, but NASA continues to track deteriorating schedule performance with the spacecraft contractor. The project now holds about two months of schedule reserve to the new January 2021 launch readiness date based on a schedule the spacecraft contractor presented in November 2019. According to officials, the project is meeting regularly with the Air Force and its contractor to gauge progress. In addition, officials noted that the contractor has made changes to its management team.

In addition, officials said that the Air Force has changed its contracting approach with the spacecraft contractor by shifting from a cost-plus-fixed-fee type contract to a firm fixed-price contract. Given the significant work ahead, the project is tracking this change as a risk to LCRD because any changes to the sequence of the contractor's integration and test activities or payload delivery schedules could result in increased costs to modify the fixed-price contract.

Integration and Test

In addition to issues with the spacecraft, the project has had to address technical and operational issues with the instrument. For example, officials told us that in the course of testing, the project noticed anomalies in the test data related to the instrument's flight modems. As a result, the project discovered that the capacitors on the flight modems were reversed, as were the capacitors on the ground modems. The project fixed the capacitor configuration, which in the case of the flight modems involved removing the modem boxes from the instrument and then reinstalling them. In addition, the project is addressing how the instrument will operate with the ground stations with which it communicates. For example, officials said that data from the LCRD instrument have to travel between multiple sites and they have been working on the timing of the flow of information between them.

The project has also identified and accepted a risk that LCRD's ability to aim precisely may degrade because of the spacecraft's vibration on orbit. This risk could result in issues with LCRD connecting with relay stations on the ground as much as one-third of the time the spacecraft is in orbit. If this risk were realized, it would result in the mission not meeting its technology demonstration objectives. To mitigate this risk, officials are negotiating changes to the spacecraft's on-orbit maneuvers with the Air Force to perform laser communications at the most optimal times. Officials noted they will need to observe how the spacecraft performs on orbit to determine the best way to operate the spacecraft in light of this risk. Officials stated they will not make design changes to the LCRD instrument due to limitations on cost and schedule.

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 that plans to show that noise from supersonic flight—sonic boom—can be reduced to levels acceptable to the public for commercial use in overland supersonic flight paths. In particular, the LBFD project plans to generate key data to inform the development of internationally accepted standards, such as noise standards, that are needed to open the market to supersonic flight. After airworthiness certification and acoustic validation, the project plans to transfer the flight-demonstration aircraft for use by the Commercial Supersonic Technology project to gather community responses to the flights and to create a database to support development of international noise standards for supersonic flight.

Source: Lockheed Martin. | GAO-20-405

PROJECT INFORMATION

NASA Lead Center: **Virtual project office**

International Partner: **None**

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

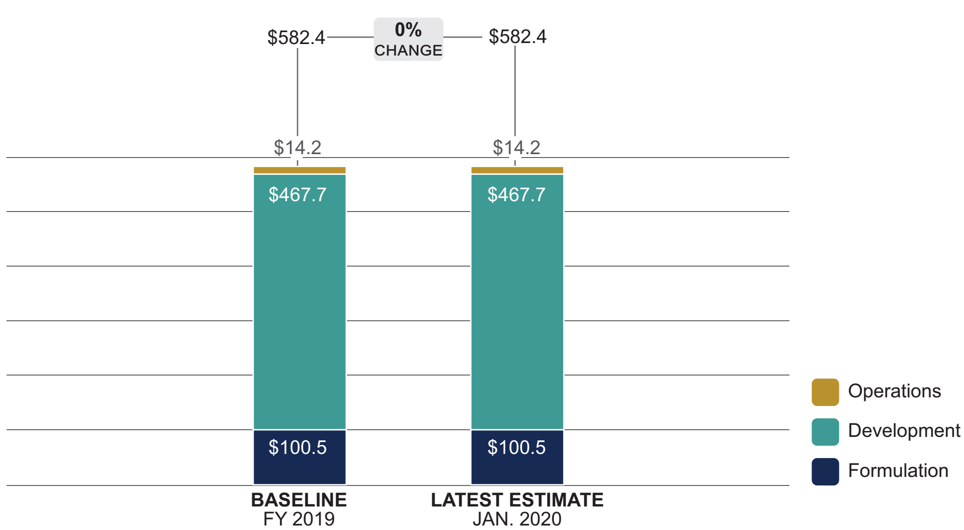
Budget Portfolio: **Aeronautics, Integrated Aviation Systems Program**

PROJECT SUMMARY

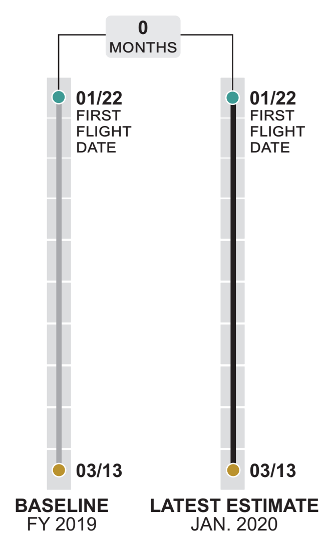
The LBFD project continues to meet its cost and schedule baselines with a life-cycle cost of $582.4 million and a first flight date of January 2022. As of November 2019, the project's contractor was running behind on its manufacturing schedule, which is affecting the critical path to first flight. The project will use cost and schedule reserves to address the issue and the contractor has instituted a schedule recovery plan. The LBFD project released 37 percent of design drawings by critical design review, which does not meet the GAO best practice of releasing 90 percent of design drawings by that point. According to officials, 37 percent was lower than planned. Officials also stated, however, that because the aircraft contractor is using a rapid prototype process in which they initiate early fabrication of the vehicle as key design drawings are completed, they never planned to meet the 90 percent metric. Project officials stated the contractor has taken steps to address the concern, and weekly tracking of drawing releases has indicated improvement. The project is also tracking risks regarding the aircraft's weight and ability to meet its sonic boom loudness level requirements.

COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The LBFD project continues to meet its cost and schedule baselines with a life-cycle cost of $582.4 million and a first flight date of January 2022. However, as of November 2019, the contractor was running behind on its manufacturing schedule due to delays in design drawing releases and challenges with supplier deliveries, which used 35 days of schedule reserves and put the contractor behind on the critical path to first flight. The contractor has instituted a schedule recovery plan that the project plans to fund using cost reserves. The plan includes running extra shifts and working additional days, and the project plans to return to its baselined schedule by spring 2020.

The project used 5 weeks of funded schedule reserves and $5.4 million of cost reserves to address effects of the government shutdown, which occurred shortly after LBFD's confirmation in November 2018. The project requested that NASA headquarters restore the $5.4 million expended as a result of the shutdown through NASA's annual budget process but a decision is still pending. The project completed its system integration review in December 2019, which allows the project to begin final assembly and integration of its systems.

Design

The LBFD project released 37 percent of design drawings by critical design review (CDR), which does not meet the GAO best practice of releasing 90 percent of design drawings by that point. Project officials stated they never anticipated meeting this 90 percent best practice because the aircraft contractor is using a rapid prototyping process that enables the contractor to initiate early fabrication of the vehicle as key design drawings are completed. The project had been targeting releasing 60-70 percent of drawings released by CDR, which they did not meet. Officials stated that drawing releases were delayed primarily due to a lack of experienced stress analysts dedicated to the project at the contractor, which has been exacerbated by delays from vendors whose part specifications are required to complete certain drawings. As noted above, officials report that that the contractor's management has taken steps to address these issues. Furthermore, they noted that most of the drawings for the aircraft's primary structures have been released to allow manufacturing to begin, with the remaining drawings mostly representing the secondary structures and subsystems.

Preceding CDR, the project declared that the Flight Test Instrumentation System (FTIS) was not mature enough to pass the review because of integration challenges with delivered components that caused the project to execute a trade study of possible design changes. The project has validated its approach for the system, officials are re-planning the FTIS schedule, and its CDR is planned for March 2020.

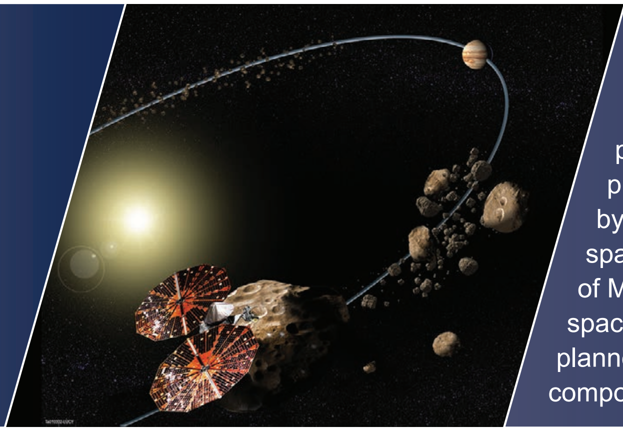
Technology

The project is tracking a risk that the aircraft will exceed the maximum design weight, which increases the likelihood that the aircraft will be too heavy for its landing gear. The project is working toward a margin of 4-5 percent of the maximum design weight but reported that it is within 2 percent of the maximum design weight. If they do not achieve the desired reductions, officials said they can fly the aircraft with less fuel. The project estimates a potential cost impact of $3.5 million and a schedule impact of 9 weeks, as well as increased risk of reduced mission performance, should the risk materialize.

The project is also tracking a risk that the predicted boom from the aircraft will be too loud, requiring design changes that would increase cost and delay the schedule. Officials said that how they mitigate this risk will depend on how close the project ultimately ends up to the loudness threshold, and that they set the threshold as low as possible given the project is a demonstration mission.

PROJECT OFFICE COMMENTS

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



Source: Southwest Research Institute (SwRI). | GAO-20-405

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.

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

IMPLEMENTATION
- 10/19 Critical design review
- **01/20 GAO 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: **ATLAS-V 401**

Mission Duration: **11.6 years**

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

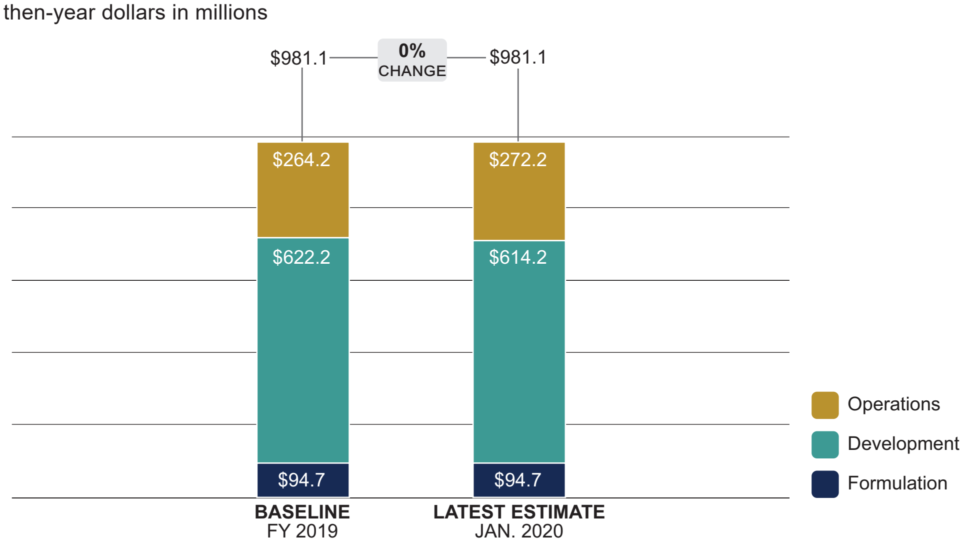
Budget Portfolio: **Science, Planetary Science**

PROJECT SUMMARY

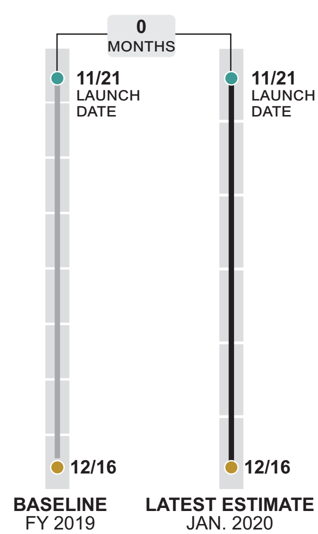
Lucy continues to operate within its cost and schedule baselines. The project's launch vehicle costs $12.9 million less than estimated, so NASA moved these savings to development and operational cost reserves. Project officials stated that they are retaining adequate schedule reserves to mitigate current difficulties faced with vendors, as well as other risks, and plan to hold to their committed launch readiness date of November 2021. The project held its critical design review in October 2019. Lucy continues to track issues with its solar array development, the schedule for which had experienced significant erosion, but officials report that strategies are in place to mitigate the factors that contributed to the schedule delays. Project officials also stated that mitigations are in place to manage risks the project is tracking relating to its ability to achieve baseline science requirements dependent on its guidance, navigation, and control system.

COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The Lucy project continues to operate within its cost and schedule baselines. In January 2019, NASA selected a launch vehicle for Lucy, which costs $12.9 million less than the project estimated at the time it established its cost baseline. NASA allocated $4.9 million of these savings to development cost reserves and the remaining $8.0 million to operations cost reserves. As a result, the overall life cycle cost estimate remains unchanged.

The Lucy project has experienced challenges with the solar array schedule, but as of February 2020, project officials stated that the schedule has held to the plan established at the October 2019 mission critical design review. Further, the project was holding schedule reserves as planned in accordance with NASA center policy. Multiple factors including issues with fabrication and component qualification testing at the contractors contributed to the schedule challenges. Project officials reported that they have established mitigations to manage schedule delays. For example, the contractor in charge of integrating the solar array onto the spacecraft has modified the flow of assembly, test, and launch operations to accept delivery as late as January 2021 to still support a launch date of November 2021. Also, the project reported that subcontractors have made some progress in addressing fabrication and qualification issues and are implementing second shift and weekend operations where feasible to make up for delays.

Design

Lucy held its critical design review in October 2019 with approximately 85 percent of design drawings released, which is slightly below the best practice of releasing 90 percent of design drawings at this review. Project officials stated that they primarily use this metric to assess schedule performance, which remains on target to meet their baseline. Our reviews of NASA and Department of Defense projects have found that knowledge that a project's design can be manufactured helps ensure that targets for cost and schedule will be met.

Technology

Lucy is tracking a risk related to a discovery that the contractor built the software for the guidance, navigation, and control system (GN&C) based on perfect knowledge of the binary orbit, or relative position of the two Trojans with regard to one another, which the project does not have. Officials stated that the project is currently mitigating this risk through assessment of existing observations and additional ground and space-based observation and plans to complete an algorithm capable of processing information from two orbiting bodies in March 2020. Another risk to science requirements connected to the GN&C system is the risk that uncertainty in the shape of the target asteroid could mean that the spacecraft cannot point itself adequately to collect data. The project continues to carry out mitigation procedures, such as assessing when the best times to take science measurements are given difficulties in spacecraft pointing relative to its targets.

Lucy is tracking an additional risk to the solar array that could degrade science capabilities. Specifically, foam particles from the cushions used to dampen launch vibration and prevent sticking during deployment could contaminate mirrors and instrument sensors, degrading science capabilities. The project is testing samples of the cushion to better understand how to reduce the number of particles it generates and inform cleaning recommendations.

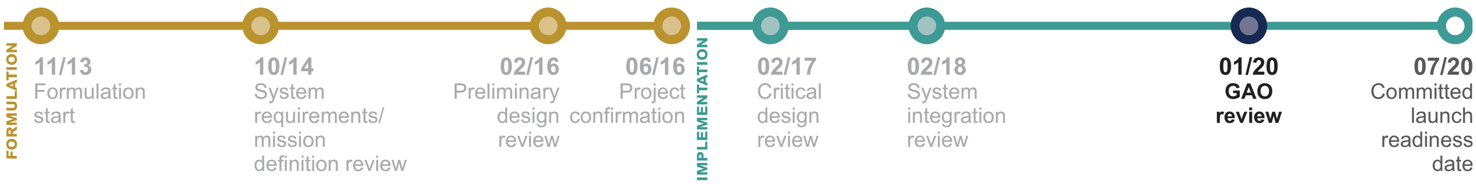
PROJECT OFFICE COMMENTS

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-20-405



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

Launch Vehicle: **Atlas V**

Mission Duration: **2 years**

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

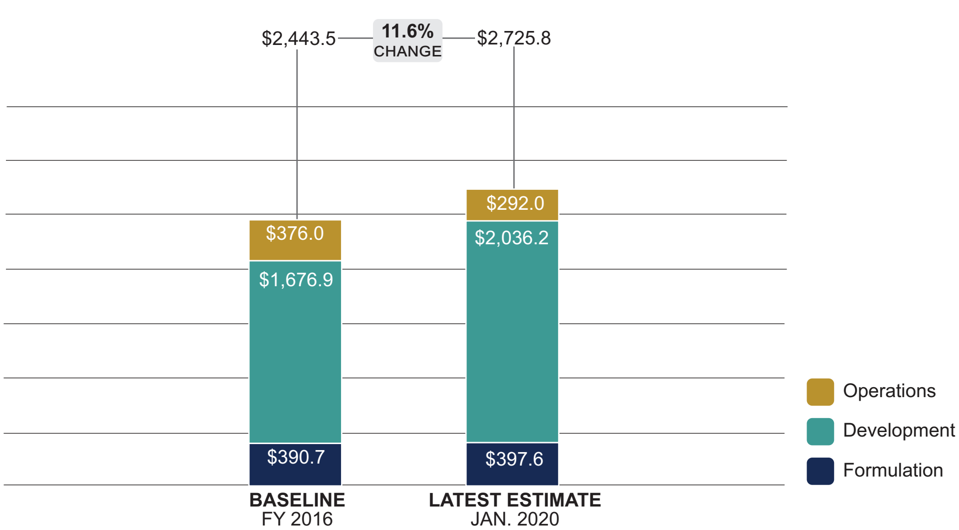
Budget Portfolio: **Science, Planetary Science**

PROJECT SUMMARY

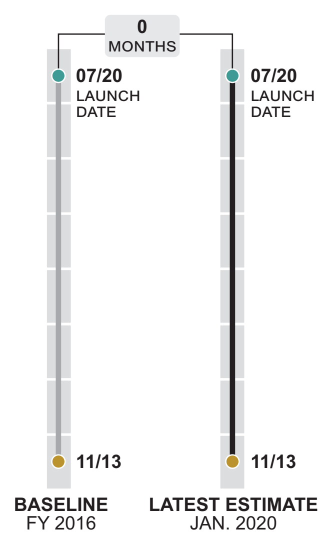
The Mars 2020 project has encountered development cost growth of almost $360 million, which exceeds the 15 percent congressional notification threshold at a critical point in the development process when problems are most commonly found and schedules tend to slip. This cost growth was due to multiple development difficulties, delayed deliveries, and higher than anticipated procurement costs. As of February 2020, the rover had shipped to Kennedy Space Center to begin preparing for launch, the majority of the project's flight hardware had been delivered and many of the project's top technical risks were closed. However, the project is tracking a risk that components of its most complex development—the Sample and Caching Subsystem—could be late.

COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The Mars 2020 project continues to meet its schedule baseline, but in October 2019, NASA approved a net $282.3 million increase over the life cycle cost estimate established at its confirmation review in June 2016. This constituted a development cost increase of 21.4 percent—or $359.3 million—exceeding the 15 percent development cost growth threshold triggering congressional notification of the breach and leading the project to replan. The development cost growth was partially offset by NASA's $84 million reduction in its operations cost estimate. The cost growth was due to multiple development difficulties, delayed deliveries, and higher than anticipated procurement costs. For example, several of the instruments and subsystems had cost growth, including the Planetary Instrument for X-ray Lithochemistry (PIXL), Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals (SHERLOC), and Sampling Caching Subsystem (SCS) as well as cost increases associated with mechanical fabrication. As of January 2020, the project has 29 percent cost reserves, which is above its plan of 20 percent.

Integration and Testing

As of February 2020, the rover had shipped to Kennedy Space Center to begin preparing for launch, the majority of Mars 2020's flight hardware deliveries were complete, and some of the project's top technical risks had been closed or accepted. The project's primary hardware focus areas are completing a second flight model assembly for a SCS component called the Sample Handling Arm as well as end-to-end testing of the SCS and SHERLOC. At this crucial point, the project redeployed key technical and management personnel to ensure that available schedule reserves are maintained and mistakes are avoided. The Mars 2020 environmental testing campaign started in September 2019 with residual schedule reserves to address necessary rework and late hardware installation.

The project's top risks include three aggregate risks that could result in total mission loss—related to entry, descent, and landing and rover single point failures—and a separate aggregate parts failure risk that, if realized, could cause schedule delays. In addition to the aggregate risks the project is tracking, the project is tracking a risk that SCS elements could be late. Additionally, the Mars 2020 launch requires a special launch approval process since its power system contains plutonium-238—a radioactive material—used in its multi-mission radioisotope thermoelectric generator. The project has completed the majority of the milestones and work associated with getting launch approval, and is working on finalizing a supplemental environmental impact statement. After the project completes the final steps, the NASA Administrator will need to make a launch authorization decision. Once approval is obtained, the project will install the nuclear power system ahead of launch.

Any major problems as the project works through final integration and test activities could result in delays. If delays are significant enough to cause Mars 2020 to miss the 2020 launch opportunity, the final option available would be to wait 26 months—until September 2022—for the next planetary launch window to open.

PROJECT OFFICE COMMENTS

Mars 2020 project officials provided technical comments on a draft of this assessment, 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-20-405

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
- **01/20 GAO review**
- ***Under review*** System integration review
- 05/22 Target 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**

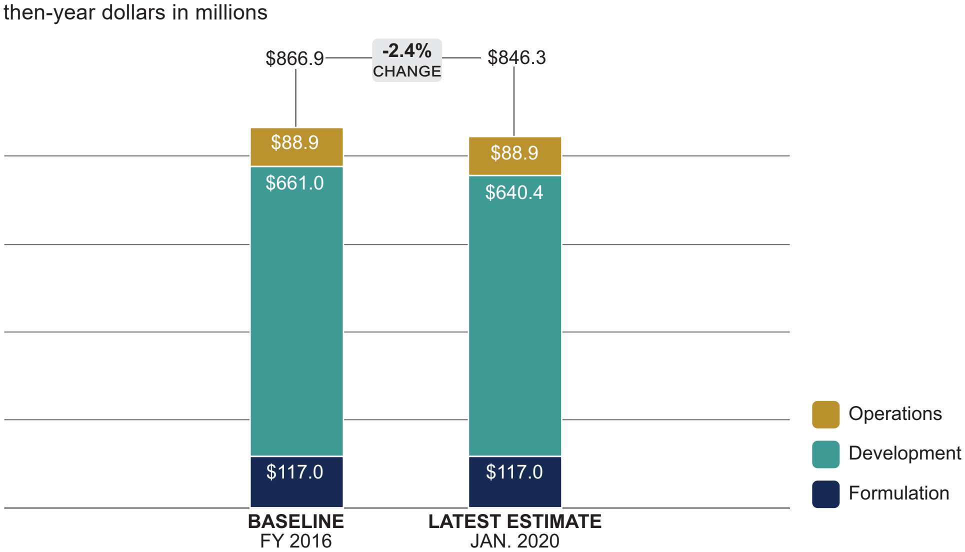
Budget Portfolio: **Science, Earth Science**

PROJECT SUMMARY

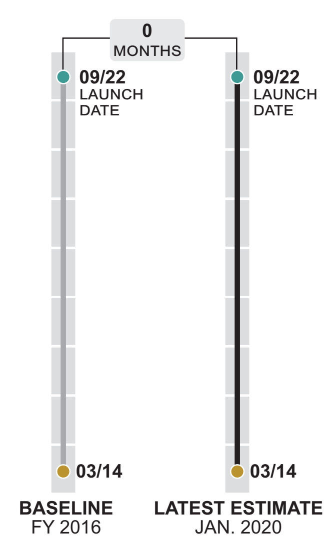
The NISAR project is operating within its schedule baseline, but has consumed 5 months of schedule reserve resulting from a late delivery of the S-band radar from the Indian Space Research Organisation (ISRO). The project now has 4 months of schedule reserve remaining to its September 2022 launch date, but NASA senior leadership is planning a further review of the project's schedule in early 2020. The project's cost estimate has decreased by $20.6 million below the cost baseline because of a decision by NASA to reduce the project's cost reserves. Since that decision, the project has had to use reserves to address technical problems and delayed deliveries, resulting in the project having no cost reserves remaining for fiscal year 2020. Further, with respect to the current cost estimate, NASA is no longer accounting for $30 million of costs associated with data collection efforts identified by an interagency working group in NISAR's cost estimate. NISAR will use a launch vehicle provided by ISRO, which must conduct an additional launch with a 4-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 is operating within its schedule baseline established at its confirmation review in August 2016, but the project is reassessing its internal schedule dates as a result of late delivery of flight hardware from its international partner. Delays with the S-band radar provided by ISRO have led the project to delay its internal launch readiness date by 5 months, from December 2021 to May 2022. As a result, the project now has 4 months of schedule reserve to its committed launch readiness date of September 2022. The project has begun integrating the L-band radar but the ISRO delay affects the schedule for upcoming system integration tests, which will be the first time that the two radars are integrated and tested together. Senior leadership are expected to review an updated schedule in early 2020.

In November 2018, NASA reduced the project's reserves by $20.6 million because it assessed that the project's risk posture had improved and these reserves were no longer necessary. We previously reported that NISAR was not meeting its cost baseline because of $30 million in cost growth associated with 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] While NISAR is continuing to develop the capabilities to collect these additional data, NASA has subsequently made a decision to no longer include these costs as part of NISAR's cost estimate because they were not part of the baseline plan.

Since that decision to reduce the reserves, the project's cost reserves remain lower than planned levels because of the need to address technical problems and delayed deliveries. The project currently has no reserves remaining for fiscal year 2020. The project is looking for ways to recover cost reserves going forward, including requesting additional reserves through NASA's annual budget process, but the project is still assessing the full cost impact of new hardware issues that may further threaten cost reserves.

Technology and Design

NISAR is addressing two issues related to the radar reflector boom assembly—used to deploy the radar reflector when the spacecraft reaches orbit. First, the contractor testing the parts of the boom which support the antenna had a mishap that involved applying too much force to part of the hardware. As a result, some of the hardware will be delivered 7 weeks late to the project for testing. Additionally, the project continues to track a risk that the boom could fail to deploy in orbit, which would compromise the mission. Since we reported last year, the project has taken steps to mitigate this risk including testing key components that help deploy the boom, such as hinges.

Launch Vehicle

The project will use a launch vehicle that ISRO is providing—the Geosynchronous Satellite Launch Vehicle (GSLV) Mark II—which must meet five criteria from NASA and ISRO before it may be used. Two of the five criteria have already been met. In addition, ISRO must conduct an additional launch with a 4-meter fairing, the nose cone of the rocket used to protect the payload. The remaining two criteria—a successful launch prior to NISAR's launch and a successful 4-meter fairing launch prior to NISAR's launch—are tied to launches prior to NISAR's launch.

PROJECT OFFICE COMMENTS

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

[1] GAO-19-262SP.

Orion Multi-Purpose Crew Vehicle

The Orion Multi-Purpose Crew Vehicle (Orion) is being developed to launch atop NASA's Space Launch System (SLS) to transport and support astronauts beyond low-Earth orbit, and the current design includes a crew module, service module, and launch abort system. The current cost and schedule baseline includes plans for one uncrewed and one crewed mission —Artemis I and II, respectively—with Orion. Although not included in the current baseline, NASA plans for Orion to later transport crew for a planned 2024 lunar landing mission called Artemis III. The Orion program is continuing to advance development of the vehicle started under the canceled Constellation program.

Source: NASA. | GAO-20-405

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

PROJECT INFORMATION

NASA Lead Center: **Johnson Space Center**

International Partner: **European Space Agency**

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

Launch Vehicle: **Space Launch System**

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

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

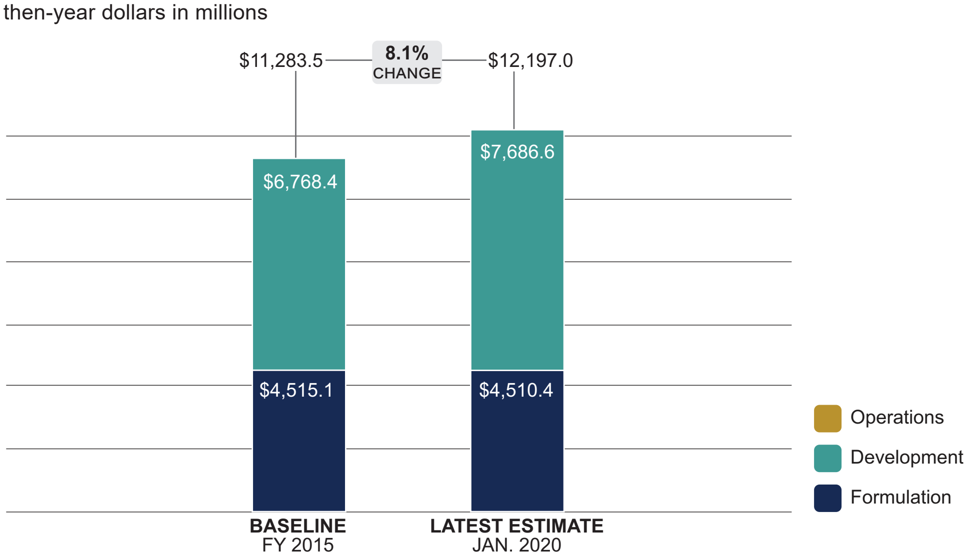
Budget Portfolio: **Exploration, Exploration Systems Development**

PROJECT SUMMARY

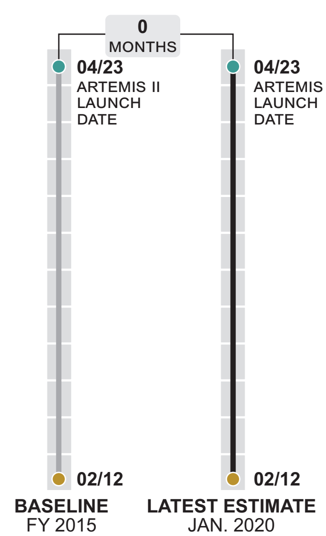
NASA planned to conduct the uncrewed demonstration of Artemis I in June 2020, but after a series of delays the agency is reevaluating this date. Orion program officials told us that, in the meantime, the program is currently working toward a November 2020 launch date for Artemis I. However, the program has only 1 week of schedule reserve remaining to that date. Within the last year, the Orion program successfully completed significant tests of Orion for Artemis I. Most recently, in November 2019, the program transported the integrated Orion crew service module to the Plum Brook test facility to begin testing the vehicle in space-like conditions. The program has also made progress toward readying Orion for Artemis II—the mission by which the program's cost and schedule performance is measured—by reducing schedule risk related to the Artemis II side hatch development. However, the program has also experienced delays related to the late deliveries of redesigned pressure control valves for the Artemis II European Service Module. The program has reported development cost growth of 13.6 percent, but officials said the program's cost estimate includes cost only to a December 2022 launch date, not the April 2023 committed baseline launch date.

COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

NASA had planned to conduct the uncrewed demonstration of Artemis I in June 2020, but after a series of delays the agency is currently reevaluating this date. The Orion program is currently planning to be ready for an Artemis I launch as early as November 2020, although this launch date is likely to be delayed, according to NASA. Despite a potential delay to the Artemis I launch, Orion program officials said the committed baseline date for the second mission remains April 2023. However, the program has experienced significant delays since 2018, placing pressure on that date. For example, late deliveries of redesigned pressure control valves for the Artemis II European Service Module contributed to a 5-month delay to module delivery and reduced program schedule margin, according to program officials.

NASA reported development cost growth of 13.6 percent, or about $918 million, due in large part to European Service Module delays and contractor performance; however, officials said that this cost growth is through a December 2022 Artemis II launch, not the program's committed baseline of April 2023. Program officials said they will complete an updated joint cost and schedule confidence level (JCL) before beginning the system assembly integration and test, and launch phase and the JCL will include costs through the program's committed baseline. NASA policy requires that the program update its JCL estimate because the program exceeded its development acquisition baseline cost by at least 5 percent.

Design

The Orion program decided to accelerate development of the crew module side hatch to reduce risk for Artemis II development. According to program officials, the Artemis I crew module was originally not going to have a functional side hatch, but the program changed course and completed important development and testing of the hatch early that helped to improve the Artemis II side hatch design. These activities reduced Artemis II hatch development risk since, according to program officials, about 80 percent of its design will now be shared with the Artemis I hatch.

Integration and Test

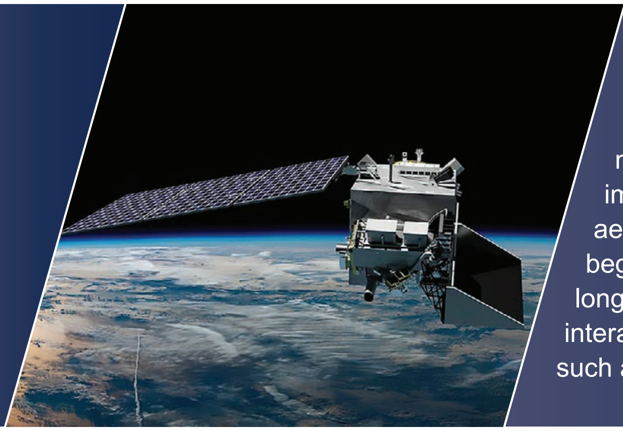
The program completed some significant test events to validate key mission components in the last year. For example, the program successfully tested the Launch Abort System in July 2019, about 5 months earlier than planned, as well as the Crew Module Uprighting System, which rights the crew module prior to an at-sea crew recovery.

After a series of delays, the Orion program was ready to start integrated module thermal vacuum testing in December 2019. The program expects to complete this testing in Spring 2020, after which the program will enter a pre-launch processing period. The Orion program plans to reduce the 7-month-long pre-launch processing period by 1.5 months. The program plans to use a mass simulator—instead of the Orion spacecraft—to conduct some pre-launch tests that would otherwise be done after integrating Orion with SLS—providing the program with extra time to complete work before delivering Orion for integration and further testing according to officials. With this shortened process, the program has only 1 week of schedule reserve remaining to the November 2020 launch date, and program officials have said this date will likely be delayed. Our prior work has shown that the integration and test phase often reveals unforeseen challenges that can lead to cost growth and schedule delays.

PROGRAM OFFICE COMMENTS

Orion program officials stated that NASA is making excellent progress on delivering the Orion spacecraft that will take the first woman to the moon. In addition to completing the ascent abort test, they said that the Artemis I spacecraft successfully completed thermal vacuum testing and is returning to Kennedy Space Center for final assembly. Program officials also said that the Artemis II spacecraft assembly is progressing. They noted that while it is true that the Orion life cycle development costs have grown 8 percent since NASA conducted a Key Decision Point review of the Orion program in 2015, the program is planning to a December 2022 Artemis II launch, which is well within the schedule commitment of April 2023. Orion 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-20-405

PROJECT INFORMATION

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

International Partner: **Netherlands**

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

Launch Vehicle: **Falcon 9**

Mission Duration: **3 years**

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

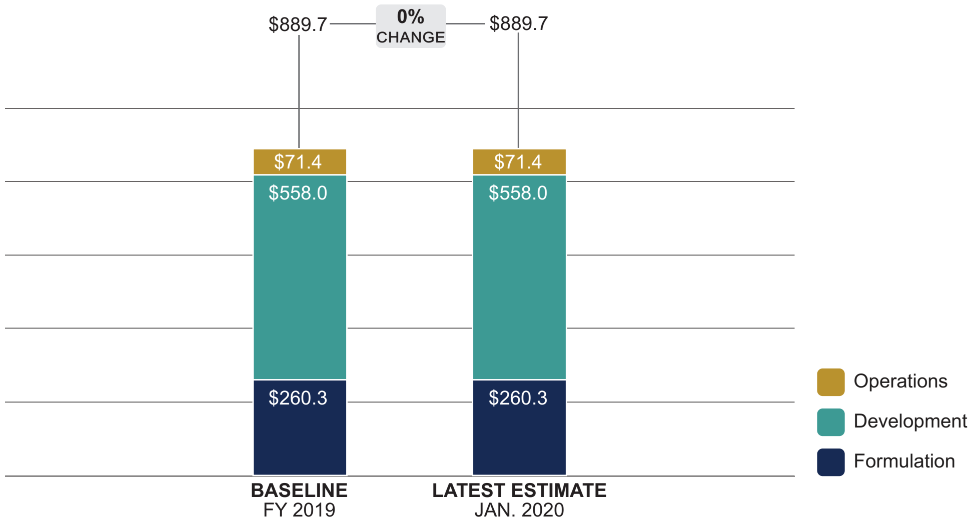
Budget Portfolio: **Science, Earth Science**

PROJECT SUMMARY

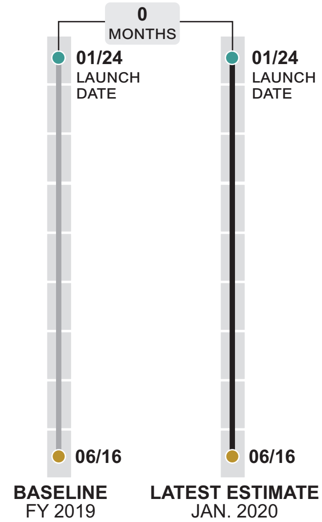
The PACE project entered the implementation phase and formally established its cost and schedule baselines in August 2019. The project set a baseline lifecycle cost of $889.7 million and a launch date of January 2024. The baseline is $39.7 million above the top-end of the project's preliminary cost estimate and is 9 months later than its preliminary schedule estimate. Similar to the previous 2 years, NASA did not request funding for PACE in its fiscal year 2020 budget request, but the explanatory statement accompanying the 2020 Consolidated Appropriations Act stated that the agreement included $131 million for PACE. A separate committee report related to the Act directed NASA to include adequate funding for PACE in the 2021 budget request, but NASA did not request funding for PACE in its fiscal year 2021 budget request. Despite funding uncertainty, the project is holding cost and schedule reserves consistent with NASA center policy and held its preliminary design review in June 2019 with mature technologies, as recommended by best practices. Moreover, PACE has taken actions to reduce risks to its mission, such as producing high-fidelity engineering models for parts of its main instrument.

COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The PACE project entered the implementation phase and formally established its cost and schedule baselines in August 2019. The project set a baseline lifecycle cost of $889.7 million and a launch date of January 2024, which is $39.7 million above the top-end of the project's preliminary cost estimate of $850 million and 9 months later than its preliminary schedule estimate of April 2023. The project continues to be cost-capped but NASA added $33.8 million to the project's baseline to account for a 2.5-month delay from the fiscal year 2019 government shutdown and interest payments on outstanding contractor invoices. For example, NASA reported that the shutdown delayed contractor deliverables because the project could not provide direction or funding on project activities. NASA calculated the project's joint cost and schedule confidence level—the likelihood a project will meet its cost and schedule estimates—as greater than 70 percent, as generally required by NASA policy.

Similar to the previous 2 years, NASA did not request funding for PACE in its fiscal year 2020 budget request, but the explanatory statement accompanying the 2020 Consolidated Appropriations Act stated that the agreement included $131 million for PACE. A separate committee report related to the Act directed NASA to include adequate funding for PACE in the 2021 budget request, but NASA did not request funding for PACE in its fiscal year 2021 budget request. Project officials said budget uncertainty has made it more challenging to find vendors willing to work with the project, which has resulted in the project receiving only one offer in response to about half of its competitive solicitations. Despite funding uncertainty, the project is holding cost and schedule reserves consistent with NASA center policy.

Technology and Design

PACE held its preliminary design review in June 2019 with all of its reported technologies matured to level 6, which is the level recommended by best practices. However, the project's main instrument—the Ocean Color Instrument (OCI), which will characterize global ocean biogeochemical cycling, ecosystem function, and aerosol-ocean dynamics—employs heritage components but, as a whole, has never been built before. The project is mitigating risks to flight development of the OCI by producing high-fidelity engineering models and proactively buying hardware to use as backups, if needed. The standing review board identified these actions as the project's strengths. However, the OCI is driving the project's schedule and the standing review board noted at the preliminary design review that various schedule metrics indicated the project was lagging behind OCI's baseline schedule by at least a year.

As of January 2020, the project has at least 9 months of schedule reserves that can be used should further delays materialize. NASA acknowledged this risk when setting the project's baseline by maintaining NASA headquarters-held cost reserves to defray potential launch delay costs.

Launch

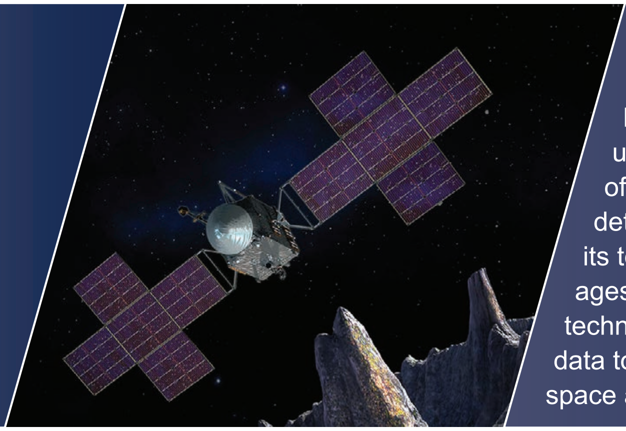
The project did not find a partner mission to share a launch vehicle, which project officials said would have significantly reduced costs. Instead, NASA's launch services program announced it had selected SpaceX to launch the spacecraft for approximately $80.4 million. This amount includes both the launch service and other mission related costs. This amount is within the project's budget to buy its own launch vehicle.

Development Partner

NASA reported that it signed agreements with the Netherlands Institute for Space Research and the University of Maryland-Baltimore County for two contributed polarimeter instruments, which will augment PACE's primary science objectives. The two polarimeters will characterize aerosols and clouds beyond what is required of the OCI. The mission success of each instrument is the responsibility of the partner rather than the PACE project. Both polarimeters are working toward a pre-environmental review in 2020. This review is a prerequisite to begin environmental testing.

PROJECT OFFICE COMMENTS

PACE project officials did not provide comments on a draft version of this assessment.



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-20-405

PROJECT INFORMATION

NASA Lead Center: **Jet Propulsion Laboratory**

International Partner: **None**

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

Launch Vehicle: **Falcon Heavy**

Mission Duration: **21 months science operation**

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

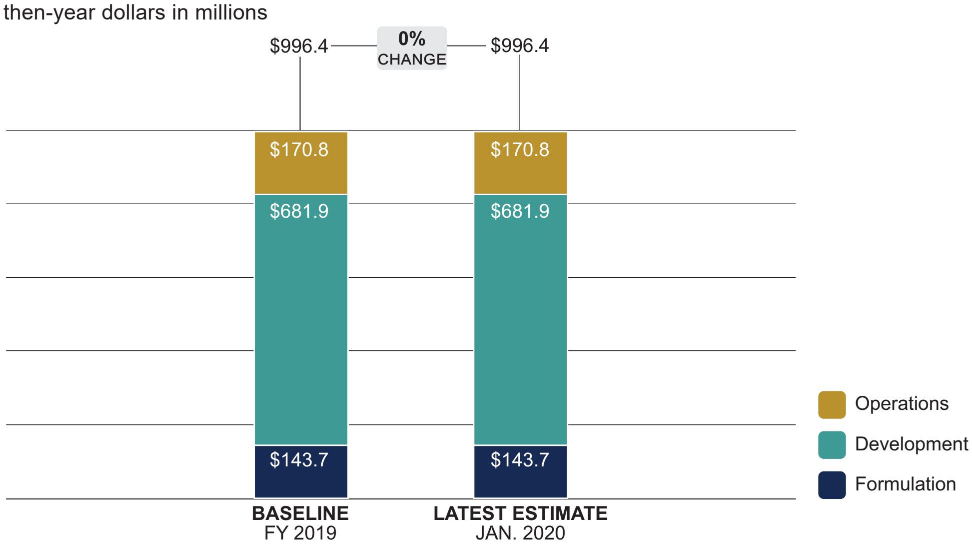
Budget Portfolio: **Science, Planetary Science**

PROJECT SUMMARY

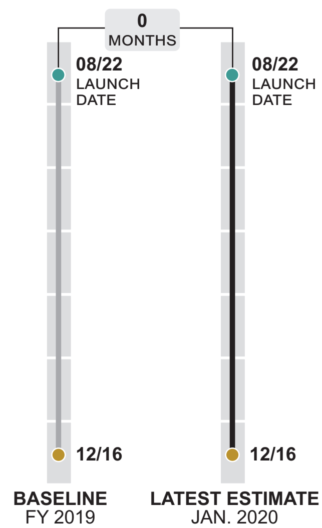
In May 2019, the Psyche project entered the implementation phase and formally established its cost and schedule baselines of $996.4 million and August 2022, respectively. According to project officials, the project's cost baseline increased over preliminary estimates because they completed a more thorough cost estimate and increased cost reserves. The Psyche project passed its preliminary design review in March 2019 with all of its heritage technologies mature. The project is tracking several risks, such as a potential delay in delivery of its magnetometer—used to detect and measure the magnetic field of the Psyche asteroid—and difficulties in acquiring advanced electronic parts. The project has taken some steps to address these difficulties, including hiring additional staff, pursuing alternate vendors, and elevating institutional attention to prioritize procurement of long-lead parts.

COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The Psyche project entered the implementation phase and formally established its cost and schedule baselines in May 2019. The project set a baseline lifecycle cost of $996.4 million and a launch date of August 2022. The baseline is $39.1 million above the top end of the project's preliminary cost estimate of $957.3 million, and matches the projected launch readiness date. According to project officials, the baseline represents a more thorough cost estimate than the preliminary cost estimate and an increase in headquarters-held cost reserves to be consistent with an independent cost assessment performed as part of the project confirmation process. As of October 2019, the project reported that while project cost reserves are slightly lower than recommended, the difference is manageable based in part on the project's use of fixed-price contracts.

Technology and Design

The Psyche project reported that its design is based heavily on heritage technologies with standard engineering modifications. Psyche held its preliminary design review in March 2019 with all of its heritage technologies matured to the level recommended by best practices.

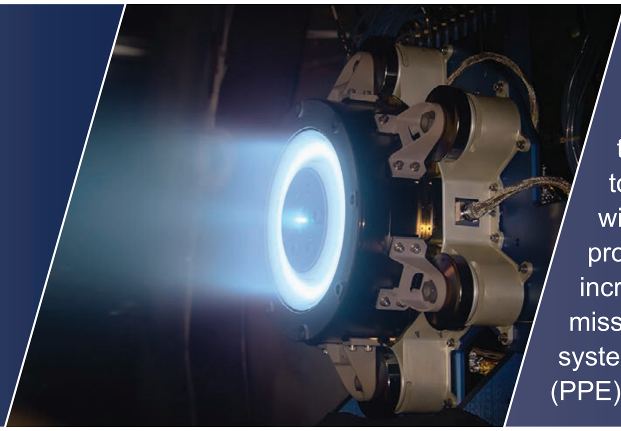
A top technical risk for the project is that the delivery of magnetometers—used to detect and measure the magnetic field of the Psyche asteroid—will likely be delayed up to 4 months due to the loss of experienced personnel and additional competing work responsibilities on the part of its contractor. The project has attempted to mitigate this risk by hiring additional staff, pursuing alternate vendors, and elevating institutional attention to prioritize procurement of long-lead parts. Project officials stated that because of the magnetometers' external location on the spacecraft, they could be integrated later in assembly, test, and launch operations if needed in order to provide some additional schedule margin and avoid delaying other work. As an added precaution, the project began pursuing a potential alternate vendor in November 2019 in case its mitigation efforts were not sufficient to meet project schedule needs.

According to project officials, the Psyche project is experiencing higher prices and longer than expected lead times for advanced electronic parts, due to competition in the aerospace industry. Officials stated that these long lead times have led to delays in the project's ability to acquire parts, which in turn has delayed the instrument critical design review for the Gamma Ray and Neutron Spectrometer (GRNS)—which will be used to determine Psyche's elemental composition—by approximately 3 months. While the project does not anticipate this issue to delay project-level milestones, they continue to monitor the acquisition of advanced electronic parts due to their necessity for ongoing work. Project officials said they are mitigating further delays by holding regular meetings with the GRNS provider to prioritize procurement of Psyche parts.

The project has identified risks associated with using heritage power converters based on technical issues experienced on other programs. According to officials, the technical problems discovered arise from difficulties the subcontractor has faced in maintaining institutional knowledge necessary to design and manufacture power converters that are sufficiently reliable for use in space applications. As of December 2019, project officials stated they are mitigating this risk through comprehensive testing of procured parts, and by maintaining designs that are able to accommodate converters from multiple contractors.

PROJECT OFFICE COMMENTS

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



Solar Electric Propulsion

The SEP project aims to develop high power electric propulsion technologies for NASA exploration and empower the U.S. space industry to accelerate the adoption of this technology. By augmenting propellant with energy from the sun, the mass of the propulsion system and amount of propellant can be reduced. In turn, this can enable spacecraft weight reduction, increase flexibility of mission design, and enable high-fuel-efficient spaceflight missions beyond low-Earth orbit compared to conventional chemical propulsion systems. NASA plans to demonstrate SEP on the Power and Propulsion Element (PPE) of the Gateway, which is a platform NASA is developing for lunar orbit.

Source: NASA. | GAO-20-405

FORMULATION

- **03/15** Formulation start
- **05/16** AEPS System requirements review
- **08/17** AEPS preliminary design review
- **05/19** PDP System requirements review
- **01/20 GAO review**
- **02/20** Project confirmation

IMPLEMENTATION

- **03/20** PDP Preliminary design review
- **09/20** AEPS Critical design review
- **01/21** PDP Critical design review
- **11/21 – 12/21** PDP delivery to PPE
- **12/24** AEPS qualification due to PPE

AEPS = Advanced Electric Propulsion System

PROJECT INFORMATION

NASA Lead Center: **Glenn Research Center**

International Partner: **None**

Launch Location: **N/A**

Launch Vehicle: **N/A**

Mission Duration: **N/A**

Requirement Derived from: **2018 Strategic Objectives 2.2, 3.1, 4.2**

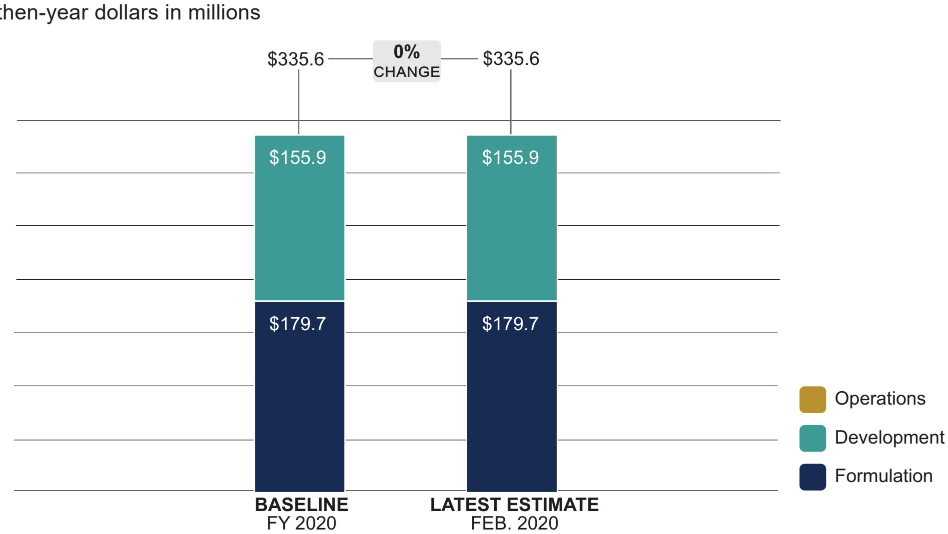
Budget Portfolio: **Exploration Technology, Technology Demonstration**

PROJECT SUMMARY

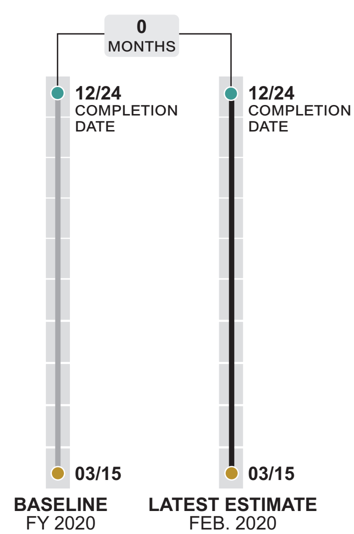
The SEP project entered the implementation phase and formally established its cost and schedule baselines in February 2020. The project set a baseline cost estimate of $335.6 million and a schedule of December 2024, which was above preliminary estimates. SEP's cost and schedule baselines include two sub-projects—one to develop and qualify an Advanced Electric Propulsion System (AEPS) and another to deliver a diagnostics package to characterize the electric propulsion system's performance in space. NASA delayed establishing a baseline for SEP partly because the AEPS contractor developing the solar electric propulsion system has struggled with its cost and schedule performance, which may threaten the project's ability to deliver qualification data to the PPE. NASA reported that it reduced the contractor's technical requirements as a result. The plasma diagnostics package sub-project plans to deliver the package 4 months after PPE's need date.

COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

The SEP project entered the implementation phase and formally established its cost and schedule baselines in February 2020. The project set a baseline cost estimate of $335.6 million and a schedule of December 2024, which was above preliminary estimates. SEP's cost and schedule baseline includes two sub-projects that entail: (1) qualifying an Advanced 12.5kw Electric Propulsion System (AEPS) for the PPE project and (2) delivering a plasma diagnostics package to the PPE project as government furnished equipment. This plasma diagnostics package will characterize high power electric propulsion system performance in space, which NASA expects will help to improve model fidelity and reduce SEP's operational risks. The SEP project's December 2024 schedule baseline date is based on when the project expects to complete qualification of AEPS; the plasma diagnostics package is expected to be delivered prior to that date.

Contractor

NASA officials stated that the original AEPS contract originated from the canceled Asteroid Redirect Robotic Mission. Work under this contract was to culminate in a critical design review following the development of an engineering development unit and engineering test unit. As of November 2019, NASA was in the process of modifying this contract to add two qualification units from which NASA expects to share testing data with the PPE project. The PPE project is responsible for acquiring its own solar electric propulsion flight hardware.

NASA told us that the contractor has struggled with its performance, which led NASA to reduce technical requirements. Officials noted that these actions contributed to multiple delays in establishing the project's cost and schedule baseline.

Technology and Design

SEP's ability to provide qualification data to the PPE project depends on completing development testing of the AEPS. NASA documents state that the qualification units will incorporate design updates from the development units and be subject to safety, quality and mission assurance requirements similar to flight units. Testing of the development units has started and will culminate in the critical design review, planned in September 2020. However, one of the project's top risks is that the availability of qualification data may be delayed if there are any major issues that require a late redesign based on development unit testing. Further, project officials stated that while they expect testing to be complete on the first qualification unit by the time the PPE project launches, testing of the second qualification unit will still be ongoing. As a result, SEP project officials stated they will have to prioritize testing data points that are most needed by the PPE project.

SEP plans to deliver the plasma diagnostics package 4 months after PPE's current integration need date of May 2021 and there are limited options to accelerate its schedule. Project officials said they are unable to descope the design to save time. However, officials said they recently accelerated delivery by two months by modifying their testing approach. They are also exploring opportunities to begin integration testing earlier. The project reported that the package design is based on heritage technologies with modifications. A top risk for the package is that because it is ahead of the PPE in development, there may be late rework of flight software development to maintain compatibility with the PPE.

PROJECT OFFICE COMMENTS

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

Source: NASA. | GAO-20-405

Space Launch System

The Space Launch System (SLS) is intended to be NASA's first human-rated heavy-lift 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 capability of 95 metric tons to low-Earth orbit, and be evolvable to 130 metric tons, enabling deep space missions. The 95-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.

FORMULATION

- 11/11 Formulation start
- 05/12 Mission/system design review
- 07/13 Preliminary design review
- 08/14 Project confirmation

IMPLEMENTATION

- 07/15 Critical design review
- **01/20 GAO review**
- ***Under revision*** Planned launch readiness date

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**

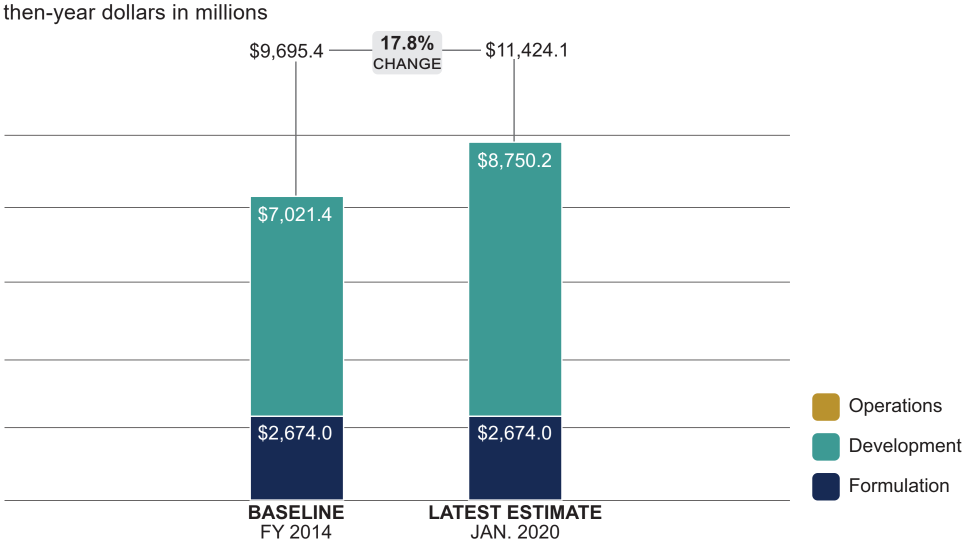
Budget Portfolio: **Exploration, Exploration Systems Development**

PROJECT SUMMARY

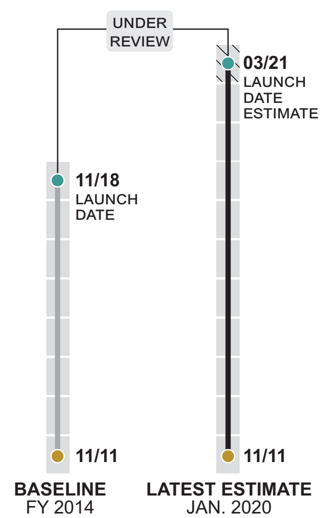
After a series of delays, NASA had planned to conduct the uncrewed demonstration of Artemis I in June 2020, but the agency is currently reevaluating this date. The program reported further development cost growth of $700 million since 2019, for a total increase of approximately $1.7 billion—or 24.6 percent —above the program's development baseline. This cost growth is tied to a delayed launch date of March 2021, but this date and the associated cost growth remains tentative until NASA officially establishes a new launch date. Although the SLS program has made progress in delivering the core stage for testing, the SLS program projects it cannot support an Artemis I launch until at least April 2021. The core stage is currently at Stennis Space Center for green run testing where it will be test fired in flight-like conditions. However, the program needs to complete some production work and software verification before it can test fire the engines. Other SLS elements, including the Interim Cryogenic Propulsion Stage (ICPS) upper stage, Solid Rocket Boosters, the Launch Vehicle Stage Adaptor, and the Orion Stage Adaptor are complete or nearing completion.

COST PERFORMANCE

then-year dollars in millions



SCHEDULE PERFORMANCE



Cost and Schedule Status

After a series of delays, NASA had planned to conduct the uncrewed demonstration of Artemis I in June 2020, but the agency is currently reevaluating this date. Program officials attributed the delays 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 it would need to complete the effort. As a result, the core stage was not fully assembled and shipped from the Michoud Assembly Facility to Stennis Space Center for testing until January 2020. As of January 2020, the SLS program estimated that it could be ready to support an Artemis I launch date no sooner than April 2021.

The SLS program reported an increase of Artemis I development costs of $700 million since 2019, for a total increase of approximately $1.7 billion—or 24.6 percent—above the program's development baseline. This cost growth is tied to a delayed launch date of March 2021, but this date and the associated cost growth remains tentative until NASA officially establishes a new launch date. Further, when updating its cost estimate to reflect current planning, the program reallocated some costs for liquid engine development and booster efforts that had been included as part of the SLS Artemis I baseline cost estimate to future missions. These costs remain in the baseline cost estimate but are not included in the updated program cost estimate, which results in an underreporting of cost growth.

Integration and Test

In January 2020, NASA shipped the core stage to Stennis Space Center to start green run testing, where multiple events take place including firing the four main engines for about 500 seconds under flight-like conditions. This test will stress the flight components as well as the ground equipment. However, program officials told us that some production work, originally planned for completion at Michoud Assembly Facility, remains to be completed in parallel with test preparation at Stennis Space Center before test firing the engines. Program 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 with fuel. 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 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 shipping the core stage to Kennedy Space Center and the enterprise integration and test schedule.

The green run test is also the first time NASA will test the SLS flight software on an integrated flight vehicle. The program is developing two versions of flight software—one to support green run testing and another to support the Artemis I mission. Program officials expect an updated version of the green run software—required to test fire the engines—to be released in April 2020. However, the program's current schedule leaves little margin between the release of this version and the engine test fire, and should there be any software issues, this could delay green run testing.

Other Hardware

In addition to the core stage, the SLS program has made progress in developing the Interim Cryogenic Propulsion Stage (ICPS) upper stage; Solid Rocket Boosters; the Launch Vehicle Stage Adaptor which connects the Core Stage with the ICPS upper stage; and the Orion Stage Adaptor which connects the Orion spacecraft with the upper stage. The ICPS upper stage was delivered in October 2018 and the Orion Stage Adaptor is ready at Kennedy Space Center. Additionally, the program expects the Launch Vehicle Stage Adaptor to be delivered in April 2020 and the Solid Rocket Boosters to be delivered in July 2020.

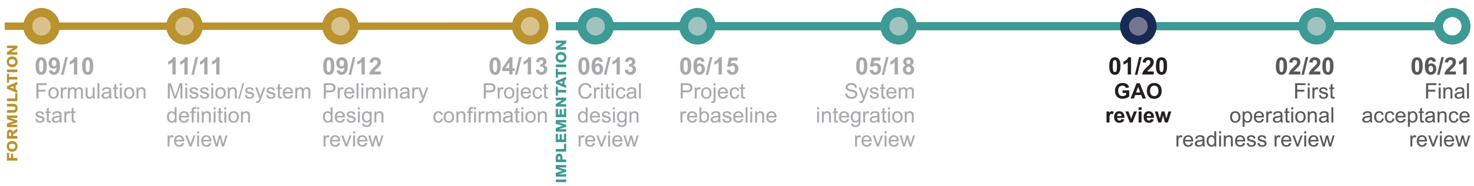
PROJECT OFFICE COMMENTS

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

Source: NASA. | GAO-20-405

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.



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**

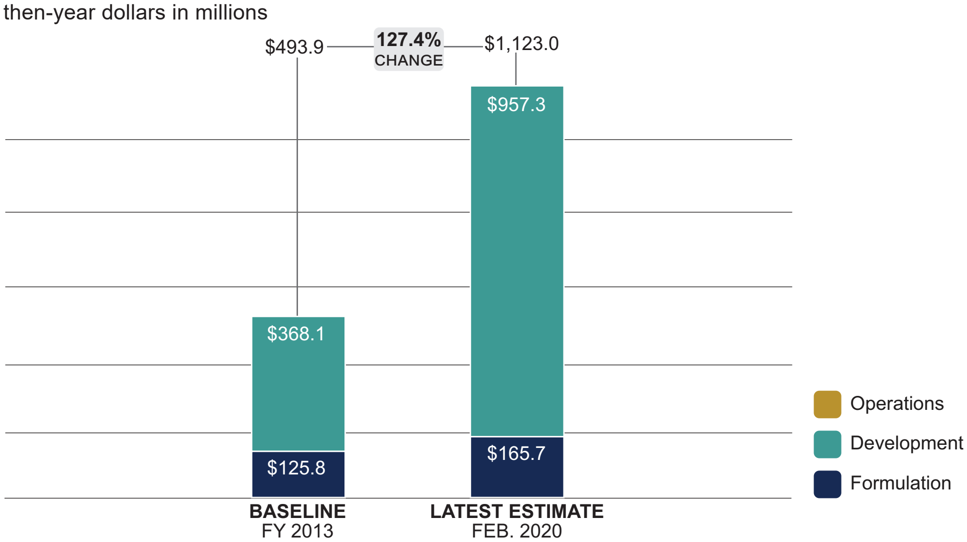
Budget Portfolio: **Space Operations, Space and Flight Support**

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—but risks remain to completing the project by this date. The SGSS project is working toward its first operational readiness review, which the project considers the most significant review since 95 percent of engineering work will be complete, but the project has had to delay the review because of issues related to system stability, software defect resolution progress, and antenna pointing restrictions.

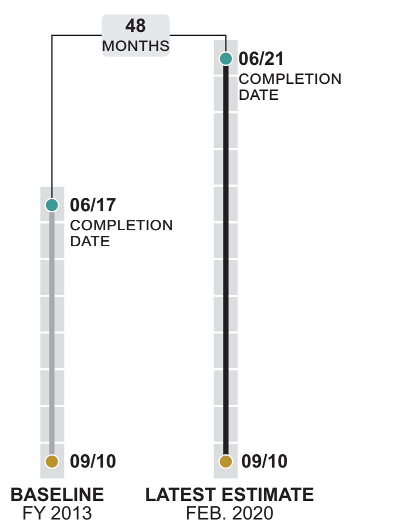
COST PERFORMANCE

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

The SGSS project continues to work to the revised cost and schedule estimates established in February 2019—which reflected four years of delays and cost increases of over 127 percent since NASA established a cost and schedule baseline for the project in 2013. NASA reports that the government shutdown and contractor performance are affecting project cost and have delayed the first operational readiness review. 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. In February 2019, the project was working towards a September 2019 operational readiness review date but had schedule reserves to push it as late as January 2020. As of February 2020, the review was not complete. The review was delayed because of issues related to system stability, software defect resolution progress, and antenna pointing restrictions. Project officials noted that the government shutdown in December 2018-January 2019 also contributed to some delays because the project was not able to complete integration and test activities that were on the project's critical path. Officials also noted a decline in contractor performance during this time due to loss of contractor focus. The project is currently working to resolve system stability issues, but testing has also revealed other technical challenges that will need to be resolved before the project will be ready for the operational readiness review, such as communication problems with the Antenna Management Unit (AMU) that failed a recent test. The project has identified the problem causing the AMU test failure and a fix was being devised as of January 2020.

As of January 2020, the project was determining whether the path from the first operational readiness review to the final acceptance review in June 2021 was still feasible.

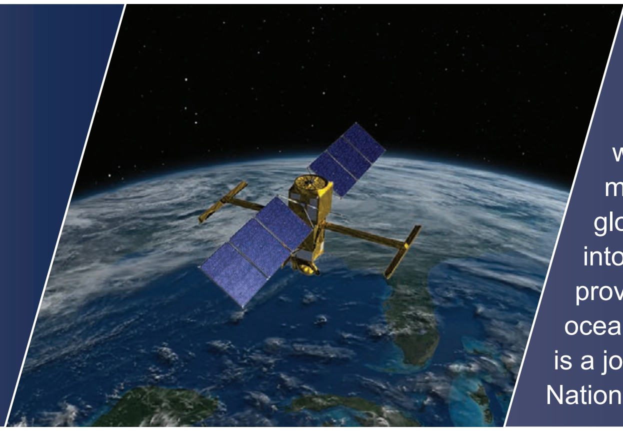
Integration and Test

The SGSS project completed a dry run of the first operational readiness review in December 2019 with its review board and a test readiness review in January 2020. Feedback from the review board during the dry run noted that the project had made notable progress but the contractor needed to remain focused on completing the remaining work. The project executed further testing in December 2019 and successfully received data from five missions currently in orbit, including the Global Precipitation Measurement and Landsat-8 spacecraft.

The project continues to track a risk that has been partially realized regarding SGSS antennas in certain configurations causing radio frequency interference with mission and satellite operations supported on other antennas at the White Sands Complex where testing is executed. The interference has affected end-to-end test events on one band length, and the project is mitigating the issue with workarounds to the test antenna configurations.

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-20-405

FORMULATION

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

IMPLEMENTATION

- 05/18 Critical design review
- **01/20 GAO review**
- *Under revision* System integration review
- *Under revision* Manifested launch readiness date
- 04/22 Committed launch readiness date

PROJECT INFORMATION

NASA Lead Center: **Jet Propulsion Laboratory**

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

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

Launch Vehicle: **Falcon 9**

Mission Duration: **3 years**

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

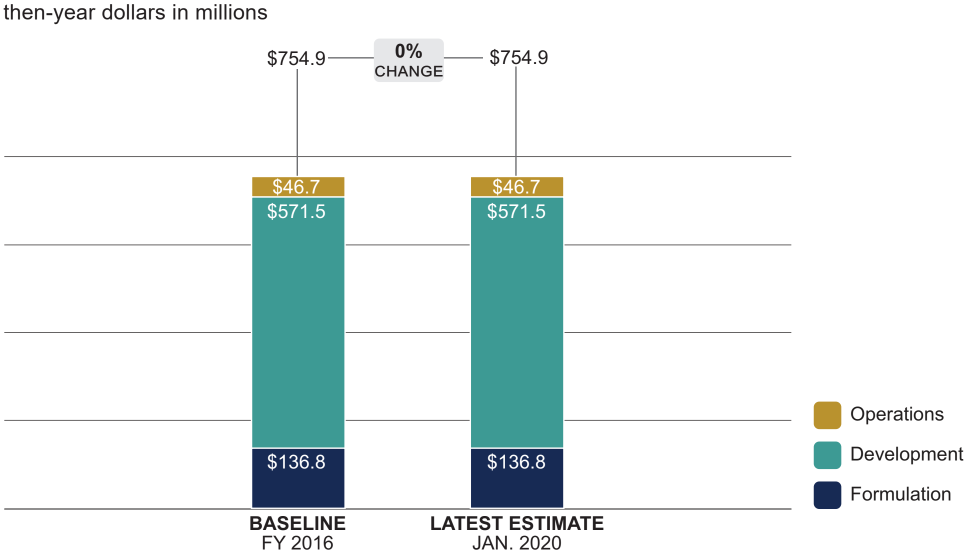
Budget Portfolio: **Science, Earth Science**

PROJECT SUMMARY

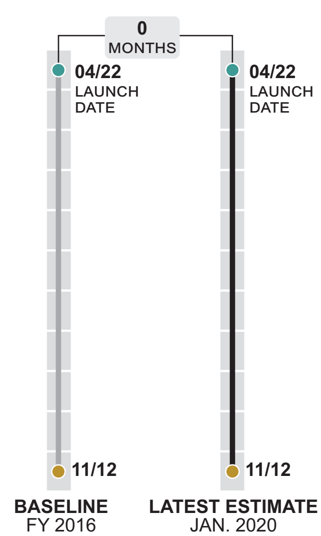
The SWOT project is still operating within its cost and schedule baselines despite delays with its primary instrument, the Ka-Band Radar Interferometer (KaRIn). The project was working toward a September 2021 launch date, but is reviewing this schedule after a 6-month delivery delay for the KaRIn instrument's radio frequency unit. The project has since integrated the radio frequency unit onto KaRIn and started testing. The project is preparing a schedule replan for approval by NASA because of these delays, but project officials expect the project will still launch by its April 2022 committed launch readiness date. In addition to challenges with the KaRIn instrument the project identified the likely root cause of an issue with the structure that supports the deployable antenna and has started testing its repair. The project is investigating an issue with the failure of bonds in joints of the structure that supports the spacecraft's deployable antennas. Finally, the project is refining its approach to calibrating and validating the measurements from the KaRIn instrument using an airborne sensor, Light Detection and Ranging, and other technologies.

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, but is reviewing its internal launch readiness date due to delays with its primary instrument. The project had been working towards a September 2021 launch date, which is 7 months earlier than its committed launch readiness date of April 2022. However, project officials stated that component delivery delays for the Ka-Band Radar Interferometer (KaRIn)—the project's most complicated technology development effort—have put this date at risk. As of January 2020, the project had consumed all payload schedule margin due to these delays. Additionally, the project is preparing a schedule replan for approval by NASA, but the project still expects to launch prior to its committed launch readiness date.

Technology

The project received the KaRIn instrument's radio frequency unit from CNES in August 2019, 6 months later than planned. This delay was due to issues with one of the unit's electrical components, which had to be replaced as a result of parts reliability concerns discovered on other projects and issues that we reported in 2019 related to the unit's digital assembly and power supply.[1] The project has since integrated the radio frequency unit onto KaRIn and performed basic functional testing. The project plans to perform environmental testing, including thermal vacuum testing, on the KaRIn instrument ahead of the system integration review.

In addition to challenges with the KaRIn instrument electrical systems, the project is repairing four joints of the structure that supports the KaRIn instrument's deployable antennas, which failed during static testing on more than 100 joints. The project identified surface contaminants as the likely root cause of the joint failure and has started thermal and static load testing on the repaired joints.

Other Issues to Be Monitored

The project continues to refine its approach to calibrating and validating the measurements from the KaRIn instrument. The project plans to use an airborne sensor as well as a combination of Light Detection and Ranging (LIDAR), gliders, and moorings. The airborne sensor will help calibrate and validate measurements for inland waters, whereas the LIDAR, gliders, and moorings 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. The project completed a LIDAR validation campaign off the coast of California in April 2019, and is conducting additional experiments at the California site with a glider and three moorings.

[1] GAO-19-262SP.

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 has made significant progress completing the heritage (Nadir) payload, and delivered key KaRIn radar electrical sub-systems to enable completion of the electrical portion of the KaRIn radar. The KaRIn radar testing shows excellent performance, according to officials, and the project is now focused on completing the mechanical subsystems and preparing for the integration of the complete payload module. Officials also provided technical comments on a draft of this assessment, which were incorporated as appropriate.

Agency Comments

We provided a draft of this report to NASA for comment. In written comments, NASA generally agreed with the findings of the report. The comments are reprinted in appendix VI. NASA also provided technical comments, which have been addressed in the report, 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) NASA's progress developing and maturing technologies and achieving design stability; and (3) progress NASA has made identifying and addressing challenges that contribute to acquisition risk. 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 an individual assessment for one project, Ionospheric Connection Explorer (ICON), which launched during our review, but included data from this project in other analyses, as appropriate.

This is our 12th annual report assessing selected large-scale NASA programs, 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 2018 assessment, we based the reporting period on data NASA provided to us in January and February 2018.[1] For our last assessment, due to the partial government shutdown, which occurred between December 2018 and January 2019 due to a lapse in appropriations for fiscal year 2019, we included data current as of December 2018, unless otherwise noted.[2] The current reporting period uses data NASA provided to us in January 2020.

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

[1] GAO-18-280SP.

[2] GAO-19-262SP.

requirements, technology, and design. We also analyzed questionnaire data from our prior reviews.

To assess the cost and schedule performance of NASA's major projects, we compared cost and schedule data as of January 2020 provided on questionnaires by NASA for the 18 projects in the implementation phase during our review to previously established cost and schedule baselines.[3] 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 from 2009 to January 2020 to examine longer-term trends. To determine cost performance, we compared the projects' baseline development costs and development costs as of January 2020. We included the Solar Electric Propulsion (SEP) project in our analysis even though NASA did not sign the baseline memo until February 2020 because the SEP project briefed NASA headquarters for its baseline approval in June 2019. We did not include the Wide Field Infrared Survey Telescope (WFIRST) project, whose baseline was also approved in February 2020, because this project did not brief headquarters or have a signed memo until February 2020. This was past our data cutoff date of January 2020. 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 January 2020. We also spoke to officials about the effects of the government shutdown to determine whether projects received an exception to continue operation or not, and to determine if projects experienced any cost or schedule impacts as a result of the shutdown. We used project reported data to characterize the effect of the shutdown. We also spoke to officials about

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

NASA's plans for upcoming lunar efforts and the extent to which these efforts may become major projects in the future.

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.

For the 17 projects in development that 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. This year, our analysis of technology maturity included two technology demonstration projects. The two technology demonstration projects were the Laser Communication Relay Demonstration (LCRD) and Restore-L. LCRD and Restore-L are managed by Goddard Space Flight Center. The Mission Directorate in charge of technology demonstration projects policy does not require technology demonstrations to mature all of their technologies to a technology readiness level (TRL) 6 by preliminary design review.[4]

[4]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.

NASA officials explained that this is because the purpose of some technology demonstration projects is to mature new technologies to TRL 6 or higher by the end of the demonstration, making it not feasible for these projects to achieve this level by preliminary design review (PDR). However, we included LCRD and Restore-L in our analysis because they planned to mature their technologies prior to launching or reaching completion. Therefore, the same risks of subsequent technical problems that can result in cost growth and schedule delays identified in our best practices work apply to these projects. We excluded two other technology demonstrations from our analysis—Solar Electric Propulsion and Low Boom Flight Demonstrator—because they did not plan to mature technologies before operations or qualification testing.

For our analysis of critical technologies, we compared the number of these technologies being developed per project with those in prior years to determine how the number of critical technologies developed per project had changed. We also collected information on the use of heritage technologies in the projects, including what heritage technologies were being used; what effort was needed to modify the form, fit, and function of the technology for use in the new system; and whether the project considered the heritage technology as a risk to the project.

To assess design stability, we asked project officials to complete a 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.[5] 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

[5]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.

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 challenges—in addition to cost and schedule performance—NASA faces in reducing acquisition risk for major projects and what progress has been made, we reviewed prior work including our High-Risk report, NASA's Corrective Action Plan in response to high-risk, and NASA identified risks.[6] From there, we determined that programmatic workforce and tools and NASA's independent assessment function were priority with respect to acquisition risk at NASA, but acknowledged that success also hinges on leadership commitment, accountability, and demonstrated progress. To assess the status of NASA's transition to its new independent project assessment process, we analyzed relevant transition documentation such as the agency's white paper and mission directorate implementation plans. We also interviewed officials at multiple levels—such as officials from the Office of the Chief Financial Officer and the Office of the Chief Engineer, mission directorates, projects, and standing review boards—to determine the status of the transition, including the benefits and outstanding challenges. To assess potential challenges that pertain to programmatic workforce and tools, we analyzed the relevant initiatives from NASA's 2018 Corrective Action Plan. We then interviewed officials in the Office of the Chief Financial Officer to determine the progress made in relation to milestones cited in the plan and reviewed relevant documentation provided by NASA.

Our work was performed primarily at NASA headquarters in Washington, D.C. In addition, we and other GAO teams working on related reviews 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 24 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

[6]GAO-19-157SP.

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.

Project timelines are 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 that 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.[7] 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

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

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 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 May 2019 to April 2020 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 2020 Report

In 2020, we assessed 25 major National Aeronautics and Space Administration (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 2020 Report by Phase

Phase	Acronym	Project name	Preliminary launch readiness date	Preliminary cost estimate (in millions)
Formulation	Dragonfly	Dragonfly	2026	Not to exceed $850
Formulation	IMAP	Interstellar Mapping and Acceleration Probe	October 2024 – December 2024	$707.7 - $776.3
Formulation	PPE	Power and Propulsion Element	December 2022	$375[a]
Formulation	Restore-L	Restore-L	December 2023	Under revision
Formulation	SPHEREx	Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ices Explorer	2nd quarter fiscal year 2024	$394.9 – 426.9
Formulation	WFIRST	Wide Field Infrared Survey Telescope[b]	September 2026	$3,193.2 – $3,798.2

Phase	Acronym	Project name	Current launch readiness date	Current cost estimate (in millions)
Implementation	CCP	Commercial Crew - Boeing[c]	Under revision	$7,157.2
Implementation	CCP	Commercial Crew - SpaceX[c]	Under revision	
Implementation	DART	Double Asteroid Redirection Test	February 2022	$313.9
Implementation	EGS	Exploration Ground Systems	Under revision *(cost tied to March 2021 planning LRD)*	$3,303.7
Implementation	Clipper	Europa Clipper	September 2025	$4,250.0
Implementation	ICON	Ionospheric Connection Explorer	October 2019	$260.1
Implementation	JWST	James Webb Space Telescope	March 2021	$9,662.7
Implementation	LBFD	Low Boom Flight Demonstrator	January 2022	$582.4
Implementation	LCRD	Laser Communications Relay Demonstration	January 2021	$310.5
Implementation	L9	Landsat 9	November 2021	$885.0
Implementation	Lucy	Lucy	November 2021	$981.1
Implementation	Mars 2020	Mars 2020	July 2020	$2,725.8
Implementation	NISAR	NASA-Indian Space Research Organisation Synthetic Aperture Radar	September 2022	$846.3
Implementation	Orion	Orion Multi-Purpose Crew Vehicle	April 2023	$12,197.0
Implementation	PACE	Plankton, Aerosol, Cloud, ocean Ecosystem	January 2024	$889.7
Implementation	Psyche	Psyche	August 2022	$996.4
Implementation	SEP	Solar Electric Propulsion	December 2024	$335.6
Implementation	SGSS	Space Network Ground Segment Sustainment[d]	June 2021	$1,123.0
Implementation	SLS	Space Launch System	Under revision *(cost tied to March 2021 planning LRD)*	$11,424.1
Implementation	SWOT	Surface Water and Ocean Topography	April 2022	$754.9

Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-20-405

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]This is the contract value for the PPE project. A full life cycle cost estimate that includes costs above the contract will be higher when the project establishes a cost and schedule baseline.

[b]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.

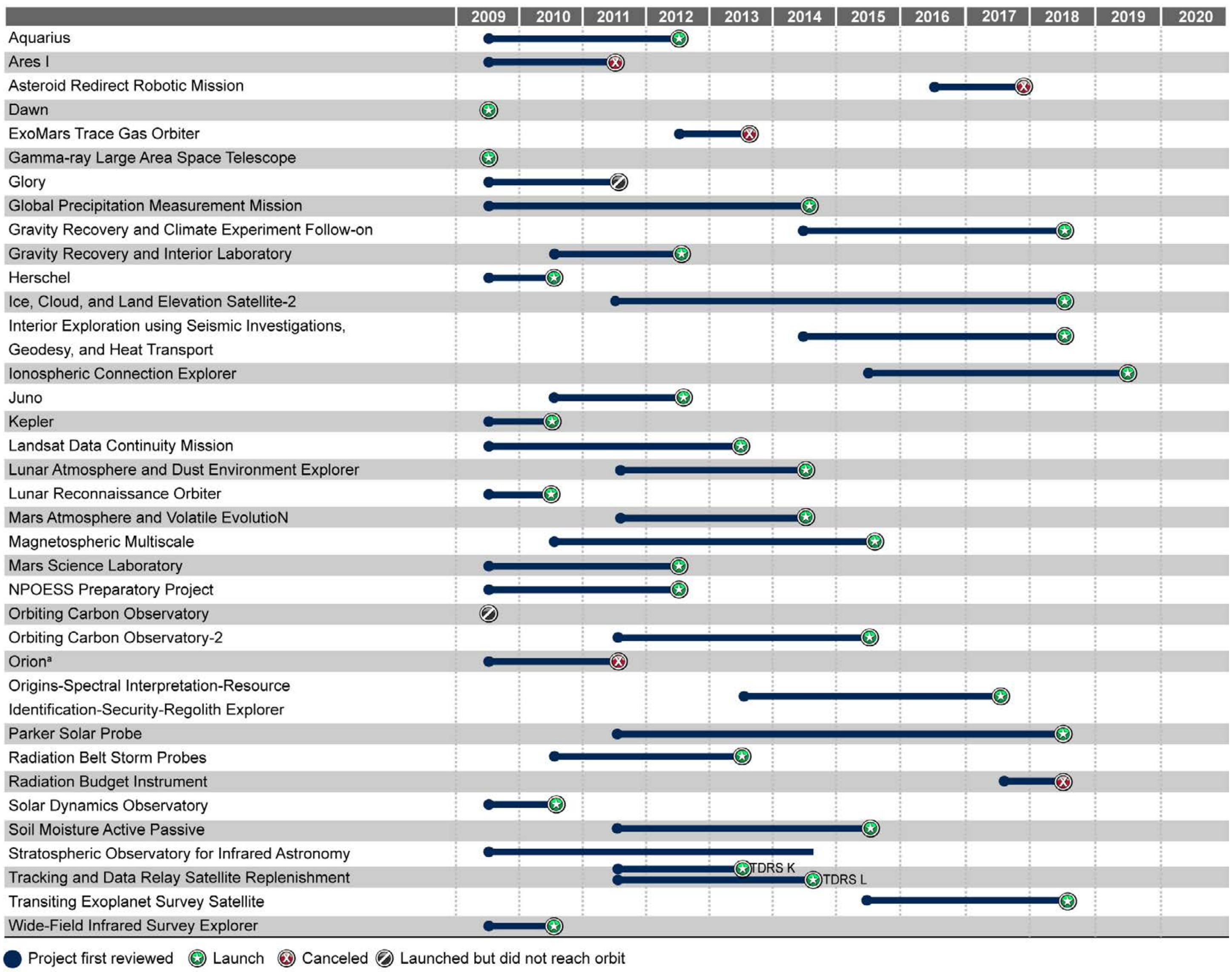
[c]The launch readiness date for the Commercial Crew Program is for the certification reviews for Boeing and SpaceX. The Commercial Crew Program is implementing a tailored version of NASA's space flight project life cycle, but it is currently completing development activities typically associated with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

[d]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 59 major National Aeronautics and Space Administration (NASA) projects or programs since our initial review in 2009. See figure 11 below for a list of projects included in our assessments from 2009 to 2019. These projects were not included in the 2020 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 2009-2019

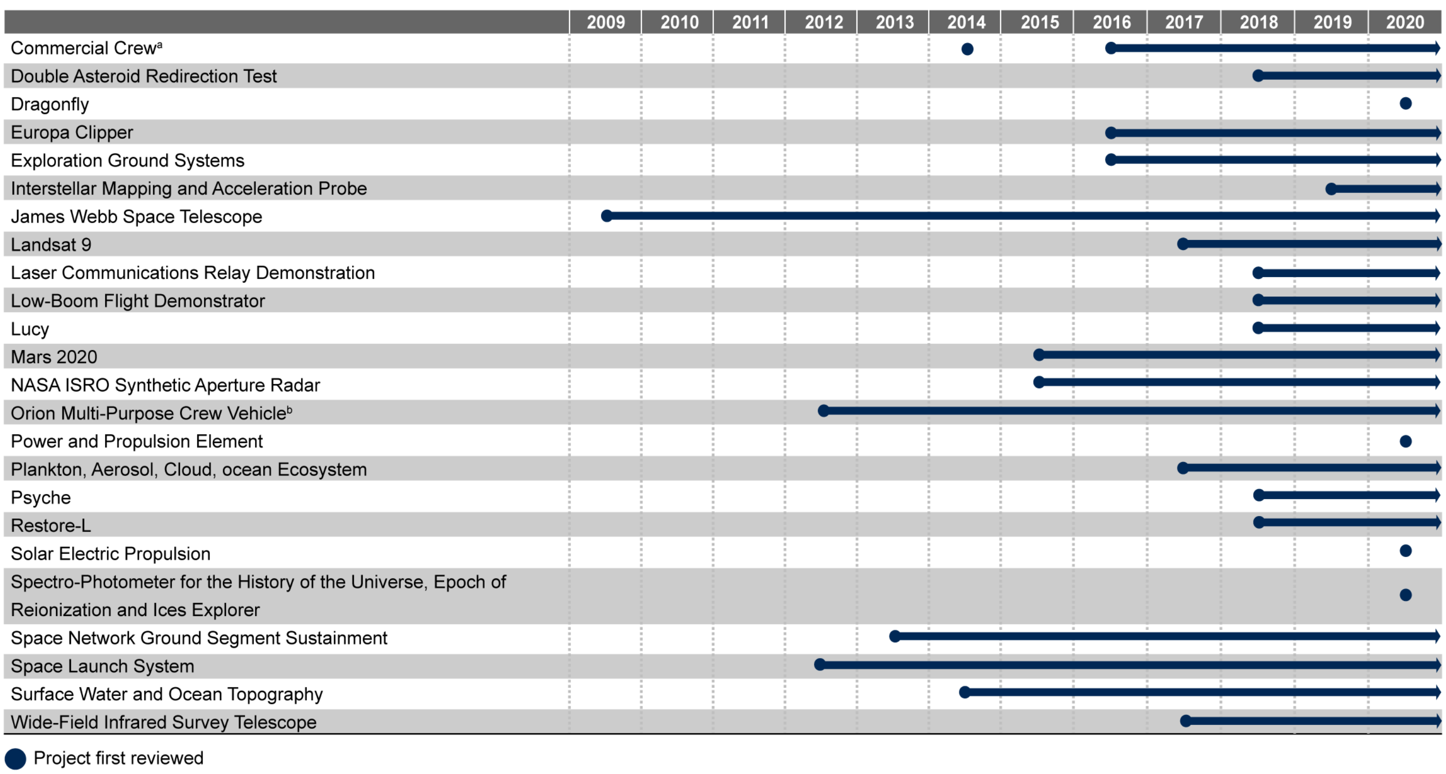


Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-20-405

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

See figure 12 below for a list of projects included in our 2020 assessment, including when the projects were first included in the review.

Figure 12: Major NASA Projects Reviewed in GAO's 2020 Assessment



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-20-405

[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.

Appendix IV: Technology Readiness Levels

Table 4: Characteristics of Technology Readiness Levels

Technology readiness level	Description	Hardware	Demonstration environment
1. Basic principles observed and reported.	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties.	None (paper studies and analysis)	None
2. Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be invented. The application is speculative and there is no proof or detailed analysis to support the assumption. Examples are still limited to paper studies.	None (paper studies and analysis)	None
3. Analytical and experimental critical function and/or characteristic proof of concept.	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.	Analytic studies and demonstration of nonscale individual components (pieces of subsystem)	Lab
4. Component and/or breadboard Validation in laboratory environment.	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of ad-hoc hardware in a laboratory.	Low fidelity breadboard (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 TRLs from NPR 7123.1B, Appendix E. | GAO-20-405

Appendix V: Elements of a Sound Business Case

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

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

[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).

development continues without design stability, costly redesigns to address changes to project requirements and unforeseen challenges can occur.

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

Appendix VI: Comments from the National Aeronautics and Space Administration

National Aeronautics and
Space Administration

Office of the Administrator
Washington, DC 20546-0001

April 13, 2020

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-20-405SP). 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. While a portion of our major project portfolio enables sustained scientific observations and improves upon legacy missions, the diversity of novel missions has notably expanded. NASA is redoubling its efforts to enable human expansion across the solar system and bring new knowledge and opportunities back to Earth. It is imperative to seek efficiencies wherever possible to enable this bold endeavor.

This year's report represents the 12th 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. NASA has worked closely with GAO to find and implement improvements in our programs. However, as the NASA portfolio expands mirroring increasing appropriated funding, the number of major projects in this annual engagement is expected to continue to grow. The 2020-2021 engagement cycle has the potential to include as many as 37 projects, which would represent a greater than 50 percent increase over this past year. NASA is concerned with this expansion and the associated demands it places on management and coordination of the audit. We may have to institute additional strategies going forward to phase in reviews on a more doable or realistic basis, given the growing scope of activities assigned to the Agency by the Administration. We want to work closely with GAO to identify any options for streamlining the process without sacrificing the net result: safe and efficiently managed programs.

NASA recognizes the inherent challenges in managing large, complex space flight and aeronautical programs that are uniquely designed to expand the boundaries of science and technology and achieve unprecedented capabilities and accomplishments. Therefore,

1

NASA has accordingly worked over many years to improve policies and procedures that control cost and schedule while ensuring mission success. In December 2018, NASA established the Corrective Action Plan (CAP) in response to GAO's continued designation of NASA's acquisition management practices on its High-Risk List. 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 has made substantial progress in the implementation of the CAP and is in the process of updating the document this summer to include new initiatives geared to improving our acquisition outcomes. 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.

NASA has continued development of the Space Launch System (SLS), Orion, and Exploration Ground Systems (EGS) programs, making major progress, including delivery of the SLS core stage to Stennis Space Center and completion of Orion testing at Plum Brook Station. As GAO has observed in audits since 2017, the launch date for Artemis I, which serves as the main development milestone for their life-cycle costs, has been under review pending a formal rebaseline analysis. NASA utilized an Independent Review Team to study the SLS and EGS costs using a joint cost and schedule confidence level (JCL) model. The results are being shared with Agency leadership to inform an Agency decision on a new launch readiness date for Artemis I. Orion's life-cycle costs are anchored around the Artemis II mission, which will receive an independent programmatic assessment, including a JCL model as recommended by the GAO, as part of Orion's upcoming Key Decision Point D review.

The report includes findings on the current state of independent assessment at NASA following the 2015 dissolution of the Independent Program Assessment Office (IPAO), which distributed independent assessment responsibility to the individual Mission Directorates as opposed to a central Agency office. The report focuses on just one of the many goals of this restructuring – programmatic capability improvement. Other drivers behind the restructuring are outlined in documentation provided to the GAO, including Mission Directorates taking greater ownership of the independent assessment for their programs and projects to enhance mission success and to increase management accountability. Under the leadership of the Program Management Improvement Officer (PMIO) and with the support of the Office of the Chief Financial Officer the Agency continues to improve the consistency and effectiveness of independent assessment with a focus on insuring lessons learned are captured and communicated with review chairs and board members.

The report also discusses the feedback GAO received from a Mission Directorate regarding differences in interpretation of Standing Review Board (SRB) conflict of interest rules across the Centers. GAO mentioned that NASA Headquarters and the Office of the General Counsel (OGC) are aware of this challenge. It is important to elaborate that NASA is not only aware but is also taking definitive action to resolve this concern. It is currently being actively worked by the Science Mission Directorate, OGC, and the Program Management Improvement Officer. OGC is examining specific examples to address any perceived differences in vetting standards and resulting updates to the SRB Handbook are in work to further ensure a homogeneous interpretation across the Centers.

2

As NASA previously noted, GAO continues to apply its design stability best practice metric of 90 percent of design drawings completed by the Critical Design Review; however, NASA no longer uses this metric internally to measure design stability. 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 appreciates that GAO recognizes this and the evolving nature of measuring design stability and looks forward to continuing work in partnership with GAO to reach an acceptable broadly applied design stability metric.

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

3

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, Daniel Singleton, Analyst-in-Charge, Pete Anderson; Tina Cota-Robles; Kurt Gurka; Chad Johnson; Erin Kennedy; Joy Kim; Natalie Logan; Jonathan Munetz; Jose A. Ramos; Carrie Rogers; Zachary Sivo; Juli Steinhouse; Eli Stiefel; Roxanna T. Sun; Tom Twambly; John Warren; Alyssa Weir; Tonya Woodbury; Kristin Van Wychen; and Erin Guinn Villareal made significant contributions to this report

Related GAO Products

James Webb Space Telescope: Technical Challenges Have Caused Schedule Strain and May Increase Costs, GAO-20-224 (Washington, D.C.: Jan. 28, 2020)

NASA Commercial Crew Program: Significant Work Remains to Begin Operational Missions to the Space Station, GAO-20-121 (Washington, D.C.: Jan. 29, 2020)

NASA Lunar Programs: Opportunities Exist to Strengthen Analyses and Plans for Moon Landing, GAO-20-68 (Washington, D.C.: Dec. 19, 2019)

NASA Commercial Crew Program: Schedule Uncertainty Persists for Start of Operational Missions to the International Space Station, GAO-19-504 (Washington, D.C.: June 20, 2019)

NASA Human Space Exploration: Persistent Delays and Cost Growth Reinforce Concerns over Management of Programs, GAO-19-377 (Washington, D.C.: June 19, 2019)

James Webb Space Telescope: Integration and Test Challenges Have Delayed Launch and Threated to Push Costs Over Cap, GAO-18-273. Washington, D.C.: Feb. 28, 2018

NASA Commercial Crew Program: Continued Delays Pose Risks for Uninterrupted Access to the International Space Station, GAO-18-317T. Washington, D.C.: Jan. 17, 2018

NASA Human Space Exploration: Integration Approach Presents Challenges to Oversight and Independence, GAO-18-28. Washington, D.C.: Oct 19, 2017

NASA Human Space Exploration: Delay Likely for First Exploration Mission, GAO-17-414. Washington, D.C.: Apr. 27, 2017

NASA Commercial Crew Program: Schedule Pressure Increases as Contractors Delay Key Events, GAO-17-137. Washington, D.C.: Feb. 16, 2017

NASA Human Space Exploration: Opportunity Nears to Reassess Launch Vehicle and Ground Systems Cost and Schedule, GAO-16-612. Washington, D.C.: July 27, 2016

Orion Multi-Purpose Crew Vehicle: Action Needed to Improve Visibility into Cost, Schedule, and Capacity to Resolve Technical Challenges, GAO-16-620. Washington, D.C.: July 27, 2016

James Webb Space Telescope: Project on Track but May Benefit from Improved Contractor Data to Better Understand Costs, GAO-16-112. Washington, D.C.: Dec. 17, 2015

Space Launch System: Management Tools Should Better Track to Cost and Schedule Commitments to Adequately Monitor Increasing Risk, GAO-15-596. Washington, D.C.: July 16, 2015

James Webb Space Telescope: Project Facing Increased Schedule Risk with Significant Work Remaining, GAO-15-100. Washington, D.C.: Dec. 15, 2014

Space Launch System: Resources Need to be Matched to Requirements to Decrease Risk and Support Long Term Affordability, GAO-14-631. Washington, D.C.: July 23, 2014

James Webb Space Telescope: Project Meeting Commitments but Current Technical, Cost, and Schedule Challenges Could Affect Continued Progress, GAO-14-72. Washington, D.C.: Jan. 8, 2014

James Webb Space Telescope: Actions Needed to Improve Cost Estimate and Oversight of Test and Integration, GAO-13-4. Washington, D.C.: Dec. 3, 2012

GAO's Mission

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

Obtaining Copies of GAO Reports and Testimony

The fastest and easiest way to obtain copies of GAO documents at no cost is through our website. Each weekday afternoon, GAO posts on its website newly released reports, testimony, and correspondence. You can also subscribe to GAO's email updates to receive notification of newly posted products.

Order by Phone

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

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

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

Connect with GAO

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

To Report Fraud, Waste, and Abuse in Federal Programs

Contact FraudNet:

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

Automated answering system: (800) 424-5454 or (202) 512-7700

Congressional Relations

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

Public Affairs

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

Strategic Planning and External Liaison

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