United States Government Accountability Office

Report to Congressional Committees

May 2021

NASA

Assessments of Major Projects

A Century of Non-Partisan Fact-Based Work

GAO-21-306

GAO@100 Highlights

Highlights of GAO-21-306, a report to congressional committees

May 2021

NASA

Assessments of Major Projects

Why GAO Did This Study

This report provides a snapshot of how well NASA is planning and executing its major projects, which are those with costs of over $250 million. NASA plans to invest at least $69 billion in its major projects to continue exploring Earth and the solar system.

Congressional conferees included a provision for GAO to prepare status reports on selected large-scale NASA programs, projects, and activities. This is GAO's 13th annual assessment. This report assesses (1) the cost and schedule performance of NASA's major projects, including the effects of COVID-19; and (2) the development and maturity of technologies and progress in achieving design stability. The report also includes assessments of 33 major projects.

To conduct its review, GAO collected questionnaire data; analyzed cost, schedule, technology maturity, and other data; reviewed project status reports; and interviewed NASA officials. The reviewed projects include those in formulation, which takes a project through preliminary design, and those in development, which includes building and launching the system.

What GAO Recommends

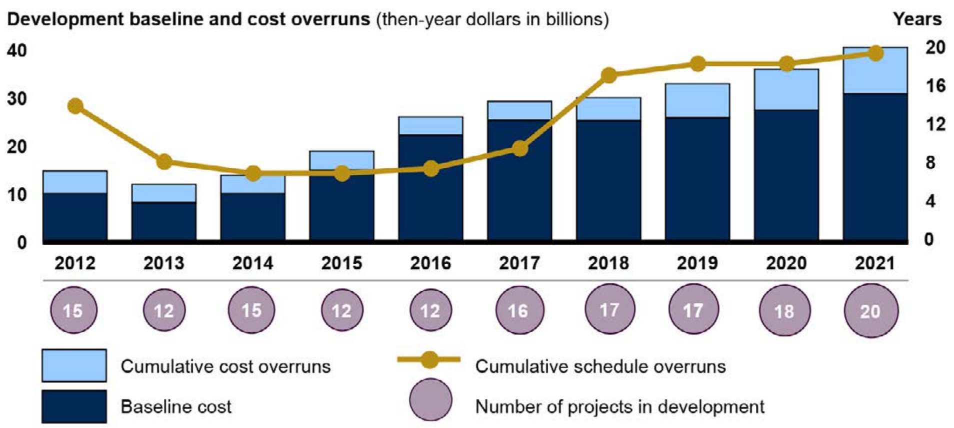
In prior work, GAO has made multiple recommendations to improve NASA's acquisition of major projects. NASA generally agreed with those recommendations and implemented changes in response to many. However, NASA has not fully addressed 21 recommendations as of March 2021.

View GAO-21-306. For more information, contact W. William Russell at (202) 512-4841 or russellw@gao.gov.

What GAO Found

The National Aeronautics and Space Administration's (NASA) portfolio of major projects in the development stage of the acquisition process continues to experience cost increases and schedule delays. This marks the fifth year in a row that cumulative cost and schedule performance deteriorated (see figure). The cumulative cost growth is currently $9.6 billion, driven by nine projects; however, $7.1 billion of this cost growth stems from two projects—the James Webb Space Telescope and the Space Launch System. These two projects account for about half of the cumulative schedule delays. The portfolio also continues to grow, with more projects expected to reach development in the next year.

Cumulative Cost and Schedule Performance for NASA's Major Projects in Development



Source: GAO analysis of National Aeronautics and Space Administration (NASA) data. | GAO-21-306

The majority of projects are managing the effects of the pandemic by using cost and schedule reserves—extra money or time set aside to accommodate unforeseen risks or delays. However, the full effects of COVID-19 are not yet known, and these reserves may be insufficient for several projects.

Most projects met a GAO best practice related to technology maturity, but few met a best practice to demonstrate a stable design.

- Most projects that held a preliminary design review demonstrated that the project's critical technologies—new or novel technologies needed to meet requirements—were mature. By doing so, the projects demonstrated the technologies can perform as needed under realistic conditions before committing to use them in the system.
- Most projects that held a critical design review fell short of meeting the best practice of releasing 90 percent of design drawings at that review. The average was approximately 70 percent. Design stability is important because late design changes can lead to costly rework and delays.

NASA and GAO have taken steps to identify and assess metrics that contribute to project success. For example, GAO is conducting work to determine if there are updated best practices for product development. In the interim, GAO continues to believe design drawings are a useful indicator of design stability.

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Abbreviations

AEPS	Advanced Electric Propulsion System
AO	announcement of opportunity
ATLO	assembly, test, and launch operations
CCP	Commercial Crew Program
CDR	critical design review
CGI	Coronagraph Instrument
CLPS	Commercial Lunar Payload Services
CNES	Centre National d'Etudes Spatiales
COVID-19	Coronavirus Disease 2019
DAA	Deployable Antenna Assembly
DART	Double Asteroid Redirection Test
DRACO	Didymos Reconnaissance and Asteroid Camera for OpNav

DrACO	Drill for Acquisition of Complex Organics
DraMS	Dragonfly Mass Spectrometer
DSL	Deep Space Logistics
EGS	Exploration Ground Systems
EIS	Europa Imaging System
EPFD	Electrified Powertrain Flight Demonstration
ESA	European Space Agency
ESM	European Service Module
ESPRIT-RM	European System Providing Refueling, Infrastructure, and Telecommunications Refueler Module
EUS	Exploration Upper Stage
GERS	Gateway External Robotic System
GRNS	Gamma Ray and Neutron Spectrometer
GSLV	Geosynchronous Satellite Launch Vehicle
HALO	Habitation and Logistics Outpost
HLS	Human Landing System
i-Hab	International Habitat
I&T	integration and test
ICON	Ionospheric Connection Explorer
ICPS	Interim Cryogenic Propulsion Stage
IMAP	Interstellar Mapping and Acceleration Probe
IOC	initial operations capability
ISRO	Indian Space Research Organisation
ISS	International Space Station
JAXA	Japan Aerospace Exploration Agency
JCL	joint cost and schedule confidence level
JWST	James Webb Space Telescope
KaRIn	Ka-band Radar Interferometer
KASI	Korea Astronomy and Space Science Institute
KDP	key decision point
L9	Landsat 9
LBFD	Low Boom Flight Demonstrator
LCRD	Laser Communications Relay Demonstration
LICIACube	Light Italian CubeSat for Imaging of Asteroids
LIDAR	Light Detection and Ranging
MASPEX	MAss Spectrometer for Planetary EXploration
MDR	mission definition review
MISE	Mapping Imaging Spectrometer for Europa
ML2	Mobile Launcher 2
MPM	Multipurpose Module
NASA	National Aeronautics and Space Administration
NEO	Near Earth Object

NEOCam	NEO Camera
NEXT-C	NASA Evolutionary Xenon Thruster-Commercial
NISAR	NASA ISRO – Synthetic Aperture Radar
NPR	NASA Procedural Requirement
OCI	Ocean Color Instrument
Orion	Orion Multi-Purpose Crew Vehicle
OSAM-1	On-Orbit Servicing, Assembly and Manufacturing 1
PACE	Plankton, Aerosol, Cloud, ocean Ecosystem
PDP	Plasma Diagnostics Package
PDR	preliminary design review
PICA-D	Domestic Phenolic-Impregnated Carbon Ablator
PPE	Power and Propulsion Element
PUNCH	Polarimeter to Unify the Corona and Heliosphere
Roman	Nancy Grace Roman Space Telescope
SCaN	Space Communication and Navigation
SDO	Solar Dynamics Observatory
SDR	system definition review
SEP	Solar Electric Propulsion
SGSS	Space Network Ground Segment Sustainment
SIR	system integration review
SLS	Space Launch System
SPHEREx	Spectro-Photometer for the History of the Universe, Epoch of Re-ionization and Ices Explorer
SPIDER	SPace Infrastructure DExterous Robot
SWOT	Surface Water and Ocean Topography
TAG	Two Axis Gimbal
TDRS	Tracking and Data Relay Satellites
TRL	Technology Readiness Level
VIPER	Volatiles Investigating Polar Exploration Rover
WFI	Wide-Field Instrument
WFIRST	Wide-Field Infrared Survey Telescope
xEVA	Exploration Extravehicular Activity

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May 20, 2021

Congressional Committees

The National Aeronautics and Space Administration (NASA) plans to invest at least $69 billion to develop, build, test, and operate the systems included in its growing portfolio of major projects. We define major projects as those projects or programs with an estimated life cycle cost of over $250 million. NASA's projects aim to continue exploring Earth and the solar system, extend human presence beyond low Earth orbit to the lunar surface, and understand climate change, among other things.

This report provides an overview of NASA's planning and execution of 34 major projects across multiple mission areas. Examples of missions include the Space Launch System (SLS) for human exploration; Volatiles Investigating Polar Exploration Rover (VIPER) for planetary science; Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) for Earth science; and the Nancy Grace Roman Space Telescope (Roman) for astrophysics. NASA acquisition management has been on GAO's high-risk list since 1990.[1]

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 13th annual report responding to that mandate. This report assesses (1) the cost and schedule performance of NASA's portfolio of major projects, including the effects of the Coronavirus Disease 2019 (COVID-19) pandemic on the portfolio's performance; and (2) the development and maturity of technologies and progress in achieving design stability. This report also includes individual assessments of 33 of the 34 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 through launch or completion. Accordingly, we did not complete an individual

[1]*GAO, High-Risk Series: Dedicated Leadership Needed to Address Limited Progress in Most High-Risk Areas,* GAO-21-119SP *(Washington, D.C.: Mar. 2, 2021).*

[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.

project assessment for the 34th project, Mars 2020, because it launched in July 2020.

To respond to the objectives of this review, we collected information on cost and schedule performance, technology maturity, and design stability using a questionnaire; analyzed projects' monthly status reports; interviewed NASA project and headquarters officials; and reviewed project documentation. The information available for each project depended on where each was in its life cycle. To assess the cost and schedule performance of NASA's portfolio, we compared current cost and schedule estimates as of January or February 2021 for 20 projects in the implementation phase to their original cost and schedule baselines.[3] In addition, to estimate the future effects of COVID-19, we compared the latest cost and schedule estimates, including project and headquarters-held cost and schedule reserves, to projects' reported COVID-19-related cost and schedule threats. We also analyzed whether the risks or threats tracked by projects were estimated to exceed current cost or schedule reserves. We also interviewed project officials and officials with the Office of the Chief Financial Officer, and reviewed recurring baseline performance review data that included NASA's Office of Chief Financial Officer's assessment of how the pandemic was affecting major projects' costs and schedules.

To assess the development and maturity of technologies, we used questionnaire data that provided the technology readiness levels (TRL) of each of the projects' critical technologies at various stages of project development, and compared technology maturity levels at the projects' preliminary design review (PDR) against GAO best practices and NASA policy.[4] This year, we updated our analysis to align with GAO's January 2020 Technology Readiness Assessment Guide's definition of critical technologies, and we stopped collecting discrete information on heritage

[3]The Commercial Crew Program is in the implementation phase but 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. In addition, 13 projects were in an early stage of development, called formulation, where there are still unknowns about requirements, technology, and design. For those projects, we reported preliminary cost ranges and schedule estimates.

[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).

technologies (such as those flown on prior missions). As a result, we did not include historical data on technology maturity in this year's assessment.

To assess the stability of project designs, we compared each project's design drawings status at the critical design review (CDR) against GAO's best practice of releasing at least 90 percent of drawings by this review.[5] We also analyzed subsequent changes in the number of design drawings. We reviewed historical data on 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 complete our project assessments, we reviewed monthly status reports, analyzed questionnaire data, and interviewed project officials to identify major sources of risk and the strategies that projects are using to mitigate them. Appendix I contains detailed information on our scope and methodology.

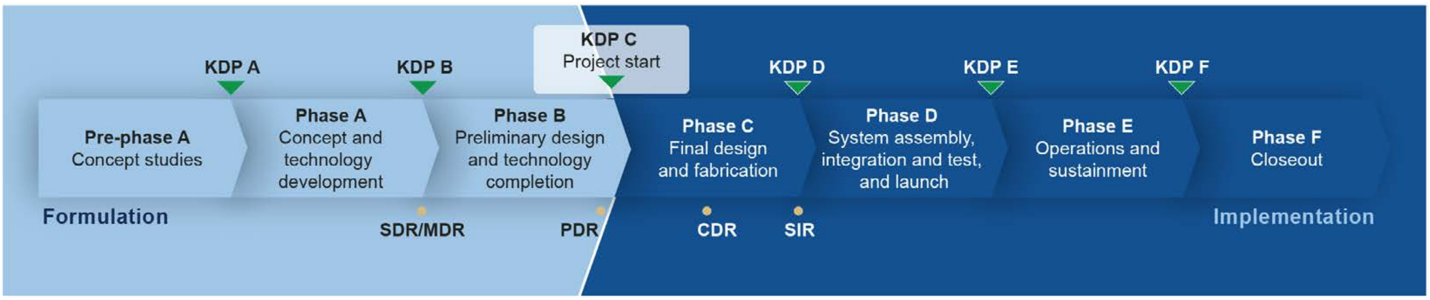
We conducted this performance audit from April 2020 to May 2021 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

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

[5]GAO, *Best Practices: Capturing Design and Manufacturing Knowledge Early Improves Acquisition Outcomes*, GAO-02-701 (Washington, D.C.: July 15, 2002).

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



Management decision reviews

KDP = key decision point

Technical reviews

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

Source: GAO analysis of National Aeronautics and Space Administration (NASA) data. | GAO-21-306

Project formulation consists of phases A and B, during which a project develops and defines requirements, cost and schedule estimates, and the system's design for implementation. Prior to entering phase B, a project develops a range of expected cost and schedule estimates, which are used to inform its budget planning. 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 PDR, 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.

After a project is confirmed, it begins implementation, consisting of phases C, D, E, and F. In this report, we refer to projects in phases C and D as being in development. A CDR is held during the latter half of phase C in order to determine if the design performs as expected and is stable enough to support proceeding with the final design and fabrication. After the CDR 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 Cost and Schedule Commitments

NASA's major projects have two sets of cost and schedule commitments—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 is 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) unless NASA waives the requirement. A JCL is an integrated analysis of a project's cost, schedule, risk, and uncertainty, the result of which indicates a project's likelihood of meeting a given set of cost and schedule targets.[6]

When certain conditions in the agency baseline commitment are no longer met, among other reasons, NASA replans or rebaselines projects. See table 1 for an overview of NASA replans and rebaselines.

Table 1: Characteristics of Program Replans and Rebaselines

	Description	Potential Congressional Reporting
Replan	A replan is a process by which a program updates or modifies its plans. It generally is driven by changes in program or project cost parameters, such as if development cost growth is 15 percent or more of the estimate in the baseline report or a major milestone is delayed by 6 months or more from the baseline's date. A replan does not require a new project baseline to be established.	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.[a]

[6]National Aeronautics and Space Administration, *NASA Cost Estimating Handbook Version 4.0* (February 2015).

	Description	Potential Congressional Reporting
Rebaseline	Rebaselining is the process that results in a change to the project's Agency Baseline Commitment. A rebaseline is initiated if the estimated development cost exceeds the baseline development cost estimate by 30 percent or more, or if the NASA Associate Administrator determines 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.[a] Should a program exceed its development cost baseline by more than 30 percent, the program must be reauthorized by Congress and rebaselined in order for the contractor to continue work beyond a specified time frame.[b]

Source: GAO analysis of National Aeronautics and Space Administration (NASA) policy and 51 U.S.C. § 30104. | GAO-21-306

[a]51 U.S.C. § 30104(e)(1).

[b]51 U.S.C. § 30104(f).

Schedule and Cost Reserves for NASA Projects

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, NASA headquarters may allocate headquarters-held reserves, which represent the difference between the agency baseline commitment and the management agreement.

The total amount of cost and schedule reserves held at the project level varies based on where the project is in its life cycle. NASA's policy on whether projects are required or recommended to hold certain levels of cost and schedule reserves at key project milestones varies by NASA

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

center.[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 site. Projects track their reserves between phases to help ensure they hold reserves consistent with these requirements.

NASA Projects Reviewed in GAO's Annual Assessment

Figure 2 includes a list of all projects included in this report. Over one-third of the projects are part of Artemis missions, which encompass NASA's efforts to return to the moon and beyond. 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 reviewed from 2009 to 2020.

[8]National Aeronautics and Space Administration, *Funded Schedule Margin and Budget Margin for Flight Projects,* Goddard Procedural Requirements 7120.7B (Sept. 17, 2018); *Marshall Space Flight Center Engineering and Program/Project Management Requirements,* Marshall Procedural Requirements 7120.1 (Oct. 20, 2016); 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 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).

Figure 2: Major NASA Projects Reviewed in GAO's 2021 Assessment

Phase	Artemis-related	Project
13 Formulation Projects		Dragonfly
		Electrified Powertrain Flight Demonstration (EPFD)
	●	**Gateway - Deep Space Logistics (DSL)**
	●	**Gateway - Exploration Extravehicular Activity (xEVA)**
	●	**Gateway - Habitation and Logistics Outpost (HALO)**
	●	**Gateway - Power and Propulsion Element (PPE)**
	●	**Human Landing System (HLS)**
		Interstellar Mapping and Acceleration Probe (IMAP)
	●	**Mobile Launcher 2 (ML2)**
		Near Earth Object Surveyor (NEO Surveyor)
		Polarimeter to Unify the Corona and Heliosphere (PUNCH)
	●	**Space Launch System Block 1B (SLS Block 1B)**
	●	**Volatiles Investigating Polar Exploration Rover (VIPER)**
21 Implementation Projects		Commercial Crew Program (CCP)
		Double Asteroid Redirection Test (DART)
		Europa Clipper
	●	**Exploration Ground Systems (EGS)**
		James Webb Space Telescope (JWST)
		Landsat 9 (L9)
		Laser Communications Relay Demonstration (LCRD)
		Low Boom Flight Demonstrator (LBFD)
		Lucy
		Nancy Grace Roman Space Telescope (Roman) (*formerly WFIRST*)
		NASA Indian Space Research Organisation - Synthetic Aperture Radar (NISAR)
		On-Orbit Servicing, Assembly and Manufacturing 1 (OSAM-1) (*formerly Restore-L*)
	●	**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)
		Spectro-Photometer for the History of the Universe, Epoch of Re-ionization and Ices Explorer (SPHEREx)
		Surface Water and Ocean Topography (SWOT)
		Mars 2020--Launched

● Artemis-related project

Source: GAO analysis of National Aeronautics and Space Administration (NASA) data. | GAO-21-306

Recent GAO Work on Selected NASA Projects

Over the past 9 years, we issued numerous reports assessing NASA's progress in acquiring its largest projects and programs in more depth.[9] A number of these reports assessed NASA's human spaceflight efforts, including efforts to return U.S. astronauts to the surface of the moon by the end of 2024. To accomplish this ambitious goal—known as Artemis III—NASA is working with industry to develop and acquire a Human Landing System, redesigning space suits, and planning to execute uncrewed and crewed demonstration missions (Artemis I and II) of the Orion Multi-Purpose Crew Vehicle (Orion) and SLS.

Orion, SLS, and the associated ground systems at Kennedy Space Center (Exploration Ground Systems, or EGS) have been under development for several years. In December 2020, we found that, after a series of delays, NASA reevaluated the launch date for Artemis I and set a new baseline for November 2021.[10] To facilitate Artemis missions, NASA is also developing the Gateway program, which will be an outpost orbiting the moon to act as a habitat and safe work environment for astronauts, and as a communications relay between the lunar surface and the Earth. Achieving Artemis III and future missions will also require extensive coordination with a wide range of contractors to ensure systems operate together seamlessly and safely.

We have also reported for several years on the James Webb Space Telescope (JWST) project, which has experienced significant cost increases and schedule delays. The project revised its cost and schedule multiple times in response to significant cost increases and launch delays from technical, management, funding, and testing challenges. In 2011, Congress placed an $8 billion cap on the project's formulation and development costs. NASA then rebaselined JWST with a life-cycle cost estimate of $8.835 billion, which included additional funding for operations and a planned launch in October 2018. Subsequently, multiple delays from testing problems led NASA to replan the project in June 2018 with the current life-cycle cost estimate of $9.7 billion.

In January 2020, we found that the JWST project had made significant progress, such as completing testing of the observatory's individual

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

[10]GAO, *NASA Human Space Exploration: Significant Investments in Future Capabilities Require Strengthened Management Oversight,* GAO-21-105 (Washington, D.C.: Dec. 15, 2020).

elements and integrating them together. But we also found that technical challenges required the use of most of the project's available schedule reserve, and that the project had little margin for error with challenging integration and test work ahead.[11] Subsequently, in July 2020, NASA delayed JWST's launch readiness date by another 7 months to October 2021 as a result of environmental and deployment test schedule risks and COVID-19.

Since we initially designated NASA's acquisition management as high-risk, we have made numerous recommendations to reduce acquisition risk. NASA generally agreed with these recommendations and implemented changes in response to many. As of March 2021, a total of 21 recommendations related to this high-risk area remain open. Through these recommendations, we have identified multiple areas where NASA should take action to improve the management of its portfolio of major projects. NASA has generally agreed with these recommendations, but additional action is needed to fully address the recommendations. For example, NASA needs to establish cost and schedule baselines for additional human spaceflight capabilities in a timely manner to ensure the baselines are a useful programmatic tool, develop a life-cycle cost estimate for the Artemis III mission, and define and determine a schedule to ensure requirements are aligned across programs.

COVID-19

In March 2020, the President declared a nationwide state of emergency as a result of the spread of COVID-19. States and many employers—including locations where work on NASA's major project activities was ongoing—implemented changes to curb the spread of the virus. In some instances these changes included closing facilities, affecting NASA's major project work for varying lengths of time.

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

Continued Cost Increases and Schedule Delays Will Likely Be Exacerbated by COVID-19 While Portfolio Grows

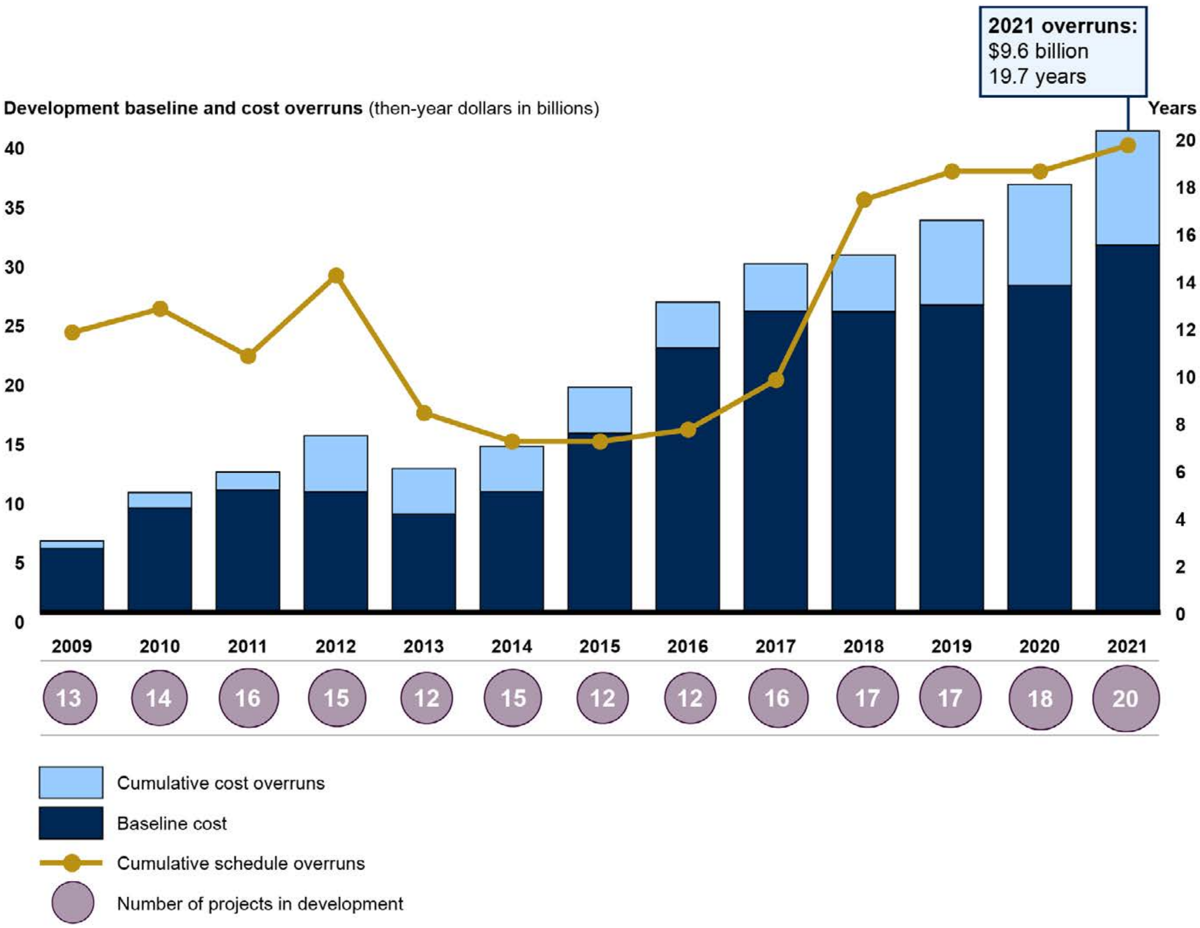
NASA's cumulative cost and schedule performance for its portfolio of major projects in development deteriorated for the fifth year in a row while the agency managed its largest number of projects since 2009. The number of projects in development is expected to grow further as the agency plans for eight of the 13 major projects currently in formulation—including six Artemis projects—to set baselines in 2021. The total cumulative cost growth across the major projects in development is currently $9.6 billion, driven primarily by nine projects. Included in that total is over $1 billion of cost growth from four projects since our last report.[12] Also, $631 million of that cost growth stems from the SLS project's previously unaccounted-for cost growth. In addition, since our last report, six major projects delayed their schedules collectively by more than 3 years. While NASA did not cite COVID-19 effects as a driver for the majority of cost increases or delays in the past year, COVID-19 continues to present challenges that will likely affect the future cost and schedule performance of major projects.

NASA's Portfolio of Major Projects in Development Continues to Face Cost Increases and Schedule Delays with Portfolio Growing

NASA is managing its largest number of major projects in development since 2009 while cost and schedule overruns continue to increase (see fig. 3). This is the fifth year in a row that cost and schedule deteriorated. Specifically, total cumulative cost overruns increased from the $3.9 billion we reported in 2016 to the $9.6 billion we are reporting this year, and total cumulative schedule delays increased from 7.7 years to 19.7 years. In addition, over this same period, the number of projects in development increased from 12 to 20.

[12] GAO, *NASA: Assessments of Major Projects*, GAO-20-405 (Washington, D.C.: Apr. 29, 2020).

Figure 3: Cumulative Cost and Schedule Performance for NASA's Major Projects in Development



Source: GAO analysis of National Aeronautics and Space Administration (NASA) data. | GAO-21-306

Notes: The years in the figure are the years we issued our annual assessment of NASA's major projects. Data for 2021 were collected as of January or February 2021. This analysis captures the cost and schedule performance for projects in development under our review during each reporting period. We excluded the Commercial Crew Program from this analysis because it has a tailored project life cycle and project management requirements and did not establish a baseline.

The total cumulative cost and schedule performance in 2021 for major projects in development was driven by nine projects. Cumulative cost overruns associated with some of the most expensive projects in development—Orion, SLS, and JWST—are driving the total cost overruns for the portfolio. We have previously reported on key cost drivers for these projects including poor contractor performance and schedule delays for Orion and SLS, and how management oversight issues and technical challenges increased costs for JWST.[13] In addition, two smaller projects—Space Network Ground Segment Sustainment (SGSS) and the Laser Communications Relay Demonstration (LCRD)—are overrunning their baselines by a significant percentage. With the exceptions of Mars 2020 and the NASA Indian Space Research Organisation (ISRO) – Synthetic Aperture Radar (NISAR) project, the projects experiencing cost overruns are also experiencing schedule delays.

Table 2 shows the cumulative cost and schedule changes for NASA's major projects in development as measured from their original baseline approved at their project confirmation review. It highlights the projects anticipating no change in cost or a lower cost than originally baselined, as well as those estimating cost increases and schedule delays.

Table 2: Cumulative Cost and Schedule Performance of NASA's Major Projects Currently in Development

			Changes from original baseline to current assessment		
Cumulative performance status	**Project(s)**	**Baseline development cost estimate (millions of dollars)**	**Schedule delay (months)**	**Cost overrun (millions of dollars)**	**Percent cost growth**
No variance expected from cost or schedule baselines	DART; OSAM-1; PACE; Roman; SEP[a]; SPHEREx; and SWOT[a]	5,784.0 (total)	0	0.0	0.0
Lower than expected cost	Landsat 9	634.2	0	(46.5)	-7.3
	Psyche	681.9	0	(38.8)	-5.7
	Europa Clipper[a]	2,412.8	0	(66.0)	-2.7
	Lucy	622.2	0	(8.0)	-1.3
Higher than expected cost	NISAR[a]	661.0	0	58.6	8.9
	Orion	6,768.4	4	887.6	13.1
	LBFD	467.7	5	64.5	13.8
	Mars 2020	1,676.9	0	356.2	21.2
	EGS	1,843.5	36	652.8	35.4
	LCRD[a]	91.8	19	36.8	40.1
	SLS	6,390.0	36	2,718.3	42.5

[13]GAO, *James Webb Space Telescope: Actions Needed to Improve Cost Estimate and Oversight of Test and Integration,* GAO-13-4 (Washington, D.C.: Dec. 3, 2012); *NASA: Assessments of Major Projects*, GAO-19-262SP (Washington, D.C.: May 30, 2019); GAO-20-405; and GAO-21-105.

Cumulative performance status	Project(s)	Baseline development cost estimate (millions of dollars)	Changes from original baseline to current assessment: Schedule delay (months)	Cost overrun (millions of dollars)	Percent cost growth
	SGSS	368.1	48	589.2	160.1
	JWST	2,581.1	88	4,421.0	171.3
Totals		**30,983.6**	**236**	**9,625.7**	**31.1**

Legend: DART: Double Asteroid Redirection Test; OSAM-1: On-Orbit Servicing, Assembly and Manufacturing 1; PACE: Plankton, Aerosol, Cloud, ocean Ecosystem; Roman: Nancy Grace Roman Space Telescope; SEP: Solar Electric Propulsion; SPHEREx: Spectro-Photometer for the History of the Universe, Epoch of Re-ionization and Ices Explorer; SWOT: Surface Water and Ocean Topography; NISAR: NASA Indian Space Research Organisation - Synthetic Aperture Radar; Orion: Orion Multi-Purpose Crew Vehicle; LBFD: Low Boom Flight Demonstrator; EGS: Exploration Ground Systems; LCRD: Laser Communications Relay Demonstration; SLS: Space Launch System; SGSS: Space Network Ground Segment Sustainment; JWST: James Webb Space Telescope.

Source: GAO analysis of National Aeronautics and Space Administration (NASA) data. | GAO-21-306

Notes: Positive values indicate cost growth or launch delays. Values in parentheses indicate cost decreases. Data for our current assessment were collected as of January or February 2021.

[a]The SWOT, Europa Clipper, LCRD, SEP, and NISAR projects are currently under review. Until those reviews are complete, information presented above is based on the latest estimates we received from NASA for the projects.

The number of NASA major projects in development is expected to grow as a large number of projects in the formulation phase plan to set baselines in 2021. Of the 13 projects in formulation, eight of them currently plan to set a baseline and enter the implementation phase by the end of 2021. Included in this list are six major projects related to Artemis. In March 2021, while our report was with NASA for review and comment, NASA approved one of these projects, VIPER, to enter implementation. We previously reported that projects associated with Artemis have an aggressive schedule with longer-term risk.[14] The complexity of these efforts presents additional cost and schedule risks for NASA's major projects over the next couple of years. According to NASA officials, the agency weighs a variety of factors in addition to the performance of the current portfolio when determining the time line for approving projects to begin development and establish baselines. These factors include national priorities, workforce availability, budget availability, and the opportunity cost of waiting to invest in the mission.

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

Annual Cost and Schedule Performance of NASA's Major Projects Does Not Yet Fully Reflect COVID-19 Effects

Since our last report, NASA's portfolio of major projects in development increased its estimated costs by $1.1 billion and delayed its collective schedule by more than 3 years. These year-to-year cost overruns and delays—most of which were not a result of COVID-19—were driven by seven projects. Table 3 provides data on the cost and schedule performance of the 20 major projects in development since our last assessment.[15]

Table 3: Cost and Schedule Changes for NASA's Major Projects in Development since GAO's 2020 Assessment

		Changes between last GAO assessment and current assessment	
Annual performance status	**Project(s)**	**Schedule delay (months)**	**Cost growth (millions of dollars)**
First year estimate reported[a]	OSAM-1; Roman; and SPHEREx	N/A	N/A
No change from prior year	DART; Lucy; PACE; SEP[b]; SGSS; and SWOT[b]	0	0.0
Underrunning prior estimate	Europa Clipper[b]	0	(66.0)
	Landsat 9	0	(46.5)
	Psyche	0	(38.8)
	Mars 2020	0	(3.1)
Mixed cost or schedule performance from prior year	Orion	4	(30.6)
	JWST	7	(0.5)
Overrunning prior estimate	LCRD[b]	5	0
	LBFD	5	64.5
	NISAR[b]	0	79.2
	EGS	8	167.3
	SLS[c]	8	989.5
Totals		**37**	**1,115.0**

Legend: OSAM-1: On-Orbit Servicing, Assembly and Manufacturing 1; Roman: Nancy Grace Roman Space Telescope; SPHEREx: Spectro-Photometer for the History of the Universe, Epoch of Re-ionization and Ices Explorer; DART: Double Asteroid Redirection Test; ; PACE: Plankton, Aerosol, Cloud, ocean Ecosystem; SEP: Solar Electric Propulsion; SGSS: Space Network Ground Segment Sustainment; SWOT: Surface Water and Ocean Topography; Orion: Orion Multi-Purpose Crew Vehicle; JWST: James Webb Space Telescope; LCRD: Laser Communications Relay Demonstration; LBFD: Low Boom Flight Demonstrator; NISAR: NASA Indian Space Research Organisation - Synthetic Aperture Radar; EGS: Exploration Ground Systems; SLS: Space Launch System.

Source: GAO analysis of National Aeronautics and Space Administration (NASA) data. | GAO-21-306

Notes: Positive values indicate cost growth or launch delays. Values in parentheses indicate cost decreases. Data for our current assessment were collected as of January or February 2021.

[a]Project moved from formulation to implementation during our review period and, therefore, did not report cost or schedule performance against a baseline in our prior report against which to assess a change.

[15]GAO-20-405.

[b]The SEP, SWOT, Europa Clipper, LCRD, and NISAR projects are currently under review. Until that review is complete, information presented above is based on the latest estimates we received from NASA for the projects.

[c]The SLS program lowered its original baseline by $631.4 million in the past year to better align with its new scope and now accounts for these costs incurred in prior years as cost overruns. The remaining $358.1 million is cost growth recognized in the past year.

About 90 percent of the portfolio's annual cost growth and nearly half of its schedule delays experienced in the past year were from two programs—SLS and EGS. The annual cost growth for these programs reflects effects from COVID-19 to a minimal extent.

- NASA rebaselined the SLS program in June 2020. As part of this effort, and, in response to our June 2019 recommendation, NASA also adjusted the SLS program's original baseline downward to align with the current scope of the program. We had previously found that NASA shifted some planned SLS scope to future missions but did not reduce the program's cost baseline accordingly, resulting in previous cost growth calculations being understated.[16] NASA's rebaseline also took into account 8 months in schedule delays and additional cost growth, which NASA attributed to manufacturing challenges and increased development costs associated with the delayed Artemis I launch readiness date. In general, project delays often lead to cost increases to maintain staff and associated resources for longer than expected. NASA stated that this latest rebaseline estimate preceded the agency's response to the pandemic and did not reflect any risks or delays resulting from COVID-19.
- NASA also rebaselined the EGS program in June 2020 and attributes associated annual cost growth and schedule delays to increased development costs associated with the delayed Artemis I launch readiness date. After the rebaseline, the project experienced an additional $57.9 million in cost growth, which officials attribute primarily to structural repairs to the Mobile Launcher and software delays. NASA stated that the rebaseline did not reflect any risks or delays resulting from COVID-19, but that the recent cost growth incorporated $12 million of cost effects from schedule delays caused by COVID-19 inefficiencies. For example, officials explained that social distancing restrictions resulted in slowed software testing to ensure a safe work environment. Officials stated that the pandemic

[16]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).

affected other areas as well, but that costs beyond this $12 million are too difficult to quantify.

Three other projects—the Low Boom Flight Demonstrator (LBFD), LCRD, and NISAR—experienced cost growth or schedule delays within the last year, but only LBFD's overruns incorporated some effects from COVID-19. The LCRD and NISAR projects are under review, but their latest reported overruns were due to challenges not related to COVID-19.

- The LBFD project reported that its development costs grew by $64.5 million, and the project was delayed by 5 months primarily because of the contractor's delayed design drawings releases and its quality issues with supplier deliveries. According to NASA documentation, the revised estimates also reflect the effect of contractor facility shutdowns due to COVID-19.
- The LCRD project's launch readiness date has been delayed 5 months due to continued technical issues associated with the U.S. Space Force's spacecraft—which hosts the LCRD payload. The costs associated with the latest launch date are currently under review. Officials said the project needs additional funding to support the latest June 2021 launch date. Officials expect to finalize costs in June 2021 as part of the project's decision to enter the operations and sustainment phase.
- The NISAR project reported an estimated $79.2 million in cost increases, which officials attribute in part to delays with the ISRO-provided radar. However, the project is reassessing its cost and schedule estimates following continued delays with both the NASA- and ISRO-provided radars, which the project reports were exacerbated by COVID-19. In addition, in February 2021, NASA notified Congress that it expected NISAR's development costs to increase by more than 15 percent above the approved baseline commitment and the schedule to be delayed by more than 6 months past its approved baseline launch date.

Two projects—JWST and Orion—had mixed performance in the past year. In both cases, the projects reported that they expected additional schedule delays but lower costs than what was estimated last year. Both projects attributed some of their delays to the effects of COVID-19.

- The JWST project is now planning to launch in October 2021, which is an additional 7 months in delays since our last annual assessment primarily because of test schedule risks that were occurring before the pandemic.[17] The pandemic began while the project was analyzing its schedule, and, according to NASA documentation, approximately 2.5 months in COVID-19 delays were incorporated into the 7-month delay. The project estimates it has sufficient cost reserves to accommodate the delay. In addition, the project also moved some estimated funding originally set aside for development to operations.

- Orion program officials estimate that the project's launch readiness date will be delayed by 4 months because of delays to the Artemis I mission and production issues for the Artemis II spacecraft. Orion is baselined to the Artemis II mission, but any delay to Artemis I will affect the timing of the Artemis II mission due to Orion spacecraft work that is planned to occur between these two missions. The 4-month delay also incorporated some pandemic-related delays to the European Service Module for Artemis II. The project currently estimates $30.6 million less in development costs than last year's estimate, which officials told us was due to some accounting adjustments, but the project's total estimated costs still exceed its baseline by over $887 million.

Four projects reported decreases in their estimated costs since the last update.

- The Europa Clipper project's latest development estimate is $66 million below its development cost baseline because the project moved some estimated development funding into its operations phase. Officials said this change was made to accommodate a longer flight time to get to Europa that is associated with a commercial launch vehicle.
- The Landsat 9 project's mature flight hardware, progress toward deliveries, and low-risk posture led NASA to reduce the project's available headquarters-held cost reserves by $46.5 million in May 2020. As a result, NASA is now estimating that the project will complete development at a lower cost than its original baseline. According to project documentation, COVID-19 effects were not reflected in the decision to reduce the project's available cost reserves.
- The Mars 2020 Perseverance Rover launched on schedule in July 2020 with its latest cost estimates falling slightly below what we reported last year. According to officials, this change moved estimated funding for selected development activities, such as testing of the

[17] GAO-20-405.

system used to collect samples from the surface of Mars, to the operations and sustainment phase. While the project had to incorporate schedule work-arounds and had increased costs to maintain schedule because of the pandemic, the project was able to accommodate COVID-19 effects on development costs within its reserves.

- The Psyche project reported $38.8 million less in development costs due to the launch vehicle procurement cost being less than the original estimate when NASA approved the project's cost and schedule baseline.

While our analysis reflects the cost and schedule status for these major programs and projects as of early 2021, it does not account for expected changes to the portfolio's cost and schedule performance due to pending cost and schedule revisions for five projects. For example, the Europa Clipper project is currently reviewing its cost and schedule baselines following NASA's decision in January 2021 to launch the spacecraft on a commercial launch vehicle. Project officials said they will need to make adjustments to the project's cost estimates and schedule after determining the effects of carrying designs for both a commercial launch vehicle and the SLS for 12 months longer than planned in the baseline, as well as effects from COVID-19.

COVID-19 Will Continue to Affect Cost and Schedule Performance

NASA's major projects in development have yet to experience the full extent of COVID-19 effects, and challenges will remain as the pandemic continues. Nearly all of the projects report having experienced some challenges related to COVID-19 in the past year, including lack of access to facilities, reduced efficiency due to social distancing protocols, travel restrictions that limited progress and delayed or changed oversight, and supply chain inefficiencies. As previously discussed, there are limited instances where projects have incorporated some COVID-19 effects into current cost and schedule estimates. Our analysis found that looking ahead, five projects are at risk of exceeding their current estimates, and it is too soon to tell whether the current estimates for 14 more projects will be affected by COVID-19 (see table 4).

Table 4: Anticipated Coronavirus Disease 2019 (COVID-19) Effects on Cost and Schedule Performance for NASA's Major Projects in Development Based on January 2021 Project Reporting

COVID-19 effects on cost or schedule performance	Projects	Total
Current estimates at risk of being exceeded	DART; NISAR; Orion; PACE; and SWOT	**5**
Total effect too early to be determined	Europa Clipper; EGS; JWST; Landsat 9; LCRD; LBFD; Lucy; OSAM-1; Psyche; Roman; SEP; SLS; SGSS; and SPHEREx	**14**

Legend: DART: Double Asteroid Redirection Test; NISAR: NASA Indian Space Research Organisation – Synthetic Aperture Radar; Orion: Orion Multi-Purpose Crew Vehicle; PACE: Plankton, Aerosol, Cloud, ocean Ecosystem; SWOT: Surface Water and Ocean Topography; EGS: Exploration Ground Systems; JWST: James Webb Space Telescope; LCRD: Laser Communications Relay Demonstration; LBFD: Low Boom Flight Demonstrator; OSAM-1: On-orbit Servicing, Assembly, and Manufacturing 1; Roman: Nancy Grace Roman Space Telescope; SEP: Solar Electric Propulsion; SLS: Space Launch System; SGSS: Space Network Ground Segment Sustainment; SPHEREx: Spectro-Photometer for the History of the Universe, Epoch of Re-ionization and Ices Explorer.

Source: GAO analysis of National Aeronautics and Space Administration (NASA) data. | GAO-21-306

Note: At the time of our review, the most consistent data available across all projects in development were based on January 2021 project reporting.

The information below provides additional detail.

COVID-19 effects put current estimates at risk of being exceeded. Our analysis shows that five projects will likely exceed their latest estimates because existing cost and schedule reserves are insufficient to accommodate anticipated COVID-19-related effects.

- The Double Asteroid Redirection Test (DART) project was tracking cost risks prior to COVID-19 that the pandemic exacerbated. In February 2021, the project delayed its internal launch date by at least 4 months due in part to technical challenges associated with its navigation imager, which needs to be reinforced to ensure it withstands the stress of launch, and supply chain issues with the solar arrays. According to NASA, while COVID-19 was not the sole factor for the delay, it has been a significant and critically contributing factor because of reduced staff availability and the supply chain effects. The project is at risk of exceeding its cost baseline as a result of these delays.
- The NISAR project began reviewing its cost and schedule prior to COVID-19, and the pandemic has exacerbated cost and schedule concerns. The project began reviewing its cost and schedule because ISRO delayed the delivery of its radar due to delayed hardware deliveries. Since then, the pandemic and technical issues with a

NASA-provided radar caused further delays. The project will seek approval from NASA for new cost and schedule estimates when the project enters the system assembly, integration and test, and launch phase in spring 2021. According to officials, the plan that the project submitted for approval exceeds the project's cost and schedule baselines and incorporates COVID-19 effects such as delays from facility closures.

- The Orion program will complete an updated joint cost and schedule confidence level analysis at its fall 2021 key decision point D review—which initiates the system assembly, integration and test, and launch phases—because its development costs have increased by more than 5 percent. Project officials told us that they expect to have to rebaseline the project to incorporate additional scope. At that time, they also plan to assess and incorporate effects from COVID-19.
- PACE was not tracking cost and schedule concerns prior to the pandemic, having just set baselines in fiscal year 2019, but COVID-19 costs and delays now threaten the project's baseline. PACE used the entirety of its cost reserves since the pandemic began to mitigate COVID-19-related schedule delays such as a 5-month delay to a Netherlands Space Office-contributed instrument and project officials' inability to access NASA facilities to work on hardware. As of January 2021, the project estimated that any additional cost reserves needed to accommodate further delays would cause the project to exceed its cost baseline.
- The Surface Water Ocean Topography (SWOT) project tracked cost and schedule problems prior to COVID-19 that the pandemic exacerbated. SWOT used most of its cost and schedule reserves to mitigate instrument delivery delays prior to the pandemic and, as a result, did not have sufficient reserves to cover additional delays related to COVID-19. For example, the pandemic resulted in facility shutdowns and other inefficiencies, such as an inability to conduct on-site testing with the project's international partner. As of January 2021, SWOT was in the process of reviewing its baselines.

COVID-19 effects on total cost and schedule performance too early to be determined. For other projects continuing development in 2021, while some have experienced cost or schedule effects due to the pandemic, it is too soon to know how COVID-19 will affect their ability to adhere to current estimates in the future. In some cases, the uncertainty surrounding future COVID-19 effects is because a project is in the process of revising its estimates for reasons unrelated to the pandemic, such as with Europa Clipper, the Solar Electric Propulsion (SEP) project, and LCRD. NASA has not yet determined if it will need to incorporate COVID-19 effects into the revised estimates of these three projects.

One project, SGSS, has not experienced cost and schedule estimate changes in the past year; however, the project is planning to use remaining funding for a planned transition within the Space Communication and Navigation program (SCaN). Unsatisfactory contractor performance, the timing of Artemis I operational support needs, and COVID-19-related delays all contributed to the need to make these adjustments. The project is making decisions to minimize any potential for future cost growth, but that potential remains as a result of the ongoing pandemic until the project has transitioned within SCaN.

For the remaining 10 major projects in development, the total effect of COVID-19 on cost and schedule performance is unknown. As previously discussed, two of these projects—JWST and LBFD—incorporated initial COVID-19 effects into recent cost and schedule estimates. Another project—the Spectro-Photometer for the History of the Universe, Epoch of Re-ionization and Ices Explorer (SPHEREx) project—recently set its baseline, and included extra reserves for some anticipated COVID-19 effects. The other seven projects have been able to accommodate effects within existing cost and schedule reserves. However, for all of these projects, it is too soon to determine whether reserves will remain sufficient to cover COVID-19's total effects as well as other technical challenges projects may encounter prior to launch or completion because the pandemic is ongoing.

NASA officials told us the agency's strategy is for projects to manage COVID-19 effects with current program or project resources, such as cost reserves. Depending on the ultimate effect of the pandemic and whether or not the agency receives supplemental funding, they said the strategy could include replanning or rebaselining affected programs, or reassessing plans for future projects and programs. Officials said these plans are highly contingent on a number of significant unknowns, including the duration of the pandemic and the agency's ability to restart normal operations once the pandemic has passed.

If a project does not have reserves available to cover COVID-19 effects, officials said NASA mission directorates will decide how to balance funds across the mission directorate portfolio. For example, the Science Mission Directorate could move funds between Landsat 9 and PACE. NASA officials stated that the agency's approach for assessing COVID-19 effects for projects in formulation is the same as for projects in development, but there is no risk against a cost or schedule commitment because these projects have not yet established them. As of January 2021, we identified that four of the 13 formulation projects in NASA's current portfolio of major projects had delayed key decision point reviews due to COVID-19.

NASA received $60 million in funding as part of the CARES Act, which passed in March 2020. NASA officials stated that this funding is not intended to nor has it been used to supplement NASA's other appropriations for major programs and projects. The appropriation is to prevent, prepare for, and respond to COVID-19.[18] NASA officials explained that NASA is using the funding to provide operational support in response to the pandemic, such as personal protective equipment, or for contractor claims. According to NASA officials, as of December 2020, NASA has not received any additional appropriations related specifically to COVID-19.

Most Projects Demonstrate Technology Maturity but Continue to Have Challenges with Design Stability

Most of NASA's major projects are demonstrating technology maturity, but projects continue to experience design stability challenges. Ten of the 14 NASA major projects that reported having critical technologies met GAO's best practice of achieving a technology readiness level 6 by preliminary design review. Maturing technologies by this review can minimize risks for projects entering product development.[19] The number of projects meeting the design stability best practice remains low—three of 13—and most projects have late design drawing growth, which is similar to recent years. This can lead to costly changes and schedule delays because it may lead to hardware rework.

Projects Identified More Technologies as Critical, and Most Projects Are Demonstrating Technology Maturity

Correctly identifying and selecting critical technologies can prevent waste of valuable resources—funds and schedule—later in an acquisition

[18]Coronavirus Aid, Relief, and Economic Security Act, Pub. L. No. 116-136, division B, title II (2020).

[19]GAO-20-48G.

project.[20] Further, there can be an underrepresentation of technical risk if all critical technologies are not identified for a project.[21] The 19 projects in the current portfolio that were in development as of January 2021—meaning the project held both a PDR and a confirmation review—reported an average of 3.9 critical technologies.[22] This is an increase from last year, when projects reported an average of 2.1 critical technologies. The current portfolio of projects identifying critical technologies reflects the addition of two projects, Roman and SPHEREx, which collectively identified 10 critical technologies, and the removal of the Ionospheric Connection Explorer (ICON), which launched in 2019.

Another contributor to the higher average number of critical technologies this year is a change in our methodology for collecting data on critical technologies for each project. In prior years, we requested that projects report data on both heritage technologies—technologies flown on prior missions—and critical technologies. We also instructed projects in prior years to categorize technologies as critical if they are being used in a new or novel manner.

This year, we updated our critical technology definition to align with GAO's January 2020 Technology Readiness Assessment Guide, which states that heritage technologies being used in a new or novel manner should be considered critical technologies.[23] As part of this update, we

[20]Technologies are considered critical if they are new or novel, or used in a new or novel way, and needed for a system to meet its operational performance requirements within defined cost and schedule parameters (i.e., cost and schedule targets set at key decision point B or C). Technologies identified as critical may change as programmatic or mission-related changes occur, system requirements are revised, or if technologies do not mature as planned. These critical technologies should be defined at a testable level, including any software needed to demonstrate their functionality, using a work breakdown structure or similar approach. In addition, a heritage technology can become critical if it is being used in a new or novel way 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.

[21]GAO-20-48G.

[22]We excluded two projects in development from our technology maturity and design stability analyses—the Commercial Crew Program because it has a tailored project life cycle and project management requirements, and Exploration Ground Systems because the program consists of several major construction and ground support equipment projects and does not report technologies. The number of projects included in these analyses varies depending on which milestones a project has passed and whether the project reports critical technologies. For a full explanation of methodology, see Appendix I.

[23]GAO-20-48G.

stopped collecting information on heritage technologies unless projects identified them as critical. As a result of our changed methodology, several projects identified technologies as critical this year that they previously classified as heritage (and not critical). For example, the Europa Clipper and On Orbit Assembly and Manufacturing 1 (OSAM-1) projects identified a total of 16 technologies across both projects as critical this year that in prior years they classified as heritage.[24]

Further, according to GAO's Technology Readiness Assessment Guide, a program identifying and maturing its critical technologies by PDR to a Technology Readiness Level (TRL) 6—which includes demonstrating a representative prototype of the technology in a relevant environment that simulates the harsh conditions of space—can minimize risks for the systems entering product development. If a project has a critical technology that has not reached TRL 6 by PDR, then the project does not have a solid technical basis of its design and the program could put itself at risk of approving a design that is less likely to remain stable.[25] Appendix IV provides a description of technology readiness levels, which are the metrics used to assess technology maturity.

We found that most of NASA's major projects past PDR that identified critical technologies—10 of 14—met the best practice of maturing all critical technologies to TRL 6 by PDR (see fig. 4).[26]

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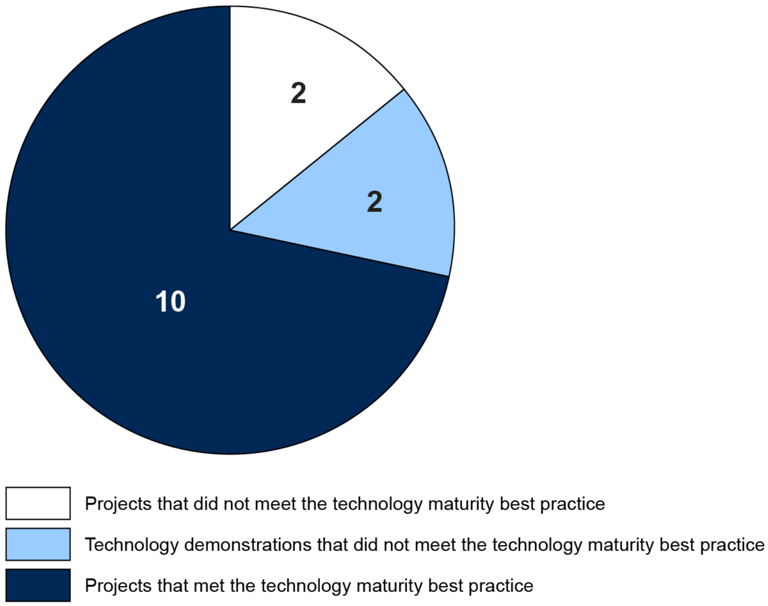
[24]Two projects—DART and SEP—had changes to their reported number of critical technologies for other programmatic reasons, such as changes to design or requirements. For example, DART decided to use the NASA Evolutionary Xenon Thruster-Commercial technology demonstration, which added two critical technologies.

[25]GAO-20-48G.

[26]Of the 21 projects past PDR that we reviewed for technology maturity, we excluded five projects from this analysis because they did not report any critical technologies and two because they are technology demonstrations that did not intend to mature their technologies before PDR.

Figure 4: Number of NASA's Major Projects Meeting GAO's Best Practice of Achieving a Technology Readiness Level 6 by Preliminary Design Review as of Early 2021



Source: GAO analysis of National Aeronautics and Space Administration (NASA) data. | GAO-21-306

Note: This includes projects that completed preliminary design review and identified critical technologies. We included two technology demonstration missions in our analysis—the Laser Communication Relay Demonstration and On-Orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1) projects—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. We did not include OSAM-1's technologies related to the SPace Infrastructure DExtrous Robot (SPIDER) because they were added after the project's preliminary design review.

The two projects that did not meet the technology maturity best practice are Mars 2020 and the Nancy Grace Roman Space Telescope (Roman), which we previously reported held PDR with immature technologies.[27] Two other projects, LCRD and OSAM-1, are defined as technology demonstrations and did not meet the best practice. As we have previously reported, NASA's view is that these projects should not be included in the analysis because the purpose of technology demonstration missions is to demonstrate the maturity of new technologies during operations.[28] However, we included technologies from these projects because both

[27]GAO, *NASA: Assessments of Major Projects,* GAO-17-303SP (Washington, D.C.: May 16, 2017); and GAO-20-405.

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

projects planned to mature the technologies prior to launch, making the project susceptible to the same risks projects might experience if they fall short of the best practice. Two projects that held PDR and also identified critical technologies were added to our analysis this year—SPHEREx and VIPER. Both projects met the best practice and matured all of their reported critical technologies to TRL 6.

Five projects did not report critical technologies and have previously reported that they rely on heritage technologies. For example, officials for one of these projects said they consider reliance on heritage technologies to be a risk-mitigating measure because these technologies have often been previously operationally demonstrated. However, heritage technologies can still present technical issues and may still require modifications for new missions. For example, the Lucy project's solar arrays are considered heritage technologies; however, the size of the arrays has increased compared to previous demonstrations, and the arrays have had significant technical issues. Project officials said that, while the arrays are larger, they use heritage components and procedures established in prior builds; healthy cost and schedule reserves as well as a rigorous risk management process are usually sufficient to mitigate the potential challenges associated with incremental changes.

In June 2020, NASA published a Technology Readiness Assessment Best Practices Guide that aligns with GAO's definition of critical technologies.[29] This guide was published as part of the agency's Corrective Action Plan, which was established in December 2018 to address NASA's inclusion in GAO's biennial High-Risk Report and after several of its highest-profile missions experienced cost and schedule growth.[30] NASA's new guide establishes standard definitions and best practices for conducting technology readiness assessments for in-flight projects and NASA's research and technology missions, including detailed processes for identifying critical technologies. For example, the guide includes a flow chart that provides a systematic way to identify whether a technology is classified as new, engineering, or heritage. Any technology—including a technology previously classified as heritage—used in a new way or environment could be identified as a critical

[29]National Aeronautics and Space Administration, Office of the Chief Technologist, *Technology Readiness Assessment Best Practices Guide,* SP-20205003605 (June 30, 2020).

[30]GAO-21-119SP.

technology, which is consistent with GAO's Technology Readiness Assessment guide. It is too soon to determine the extent to which NASA projects are using NASA's guide to identify critical technologies.

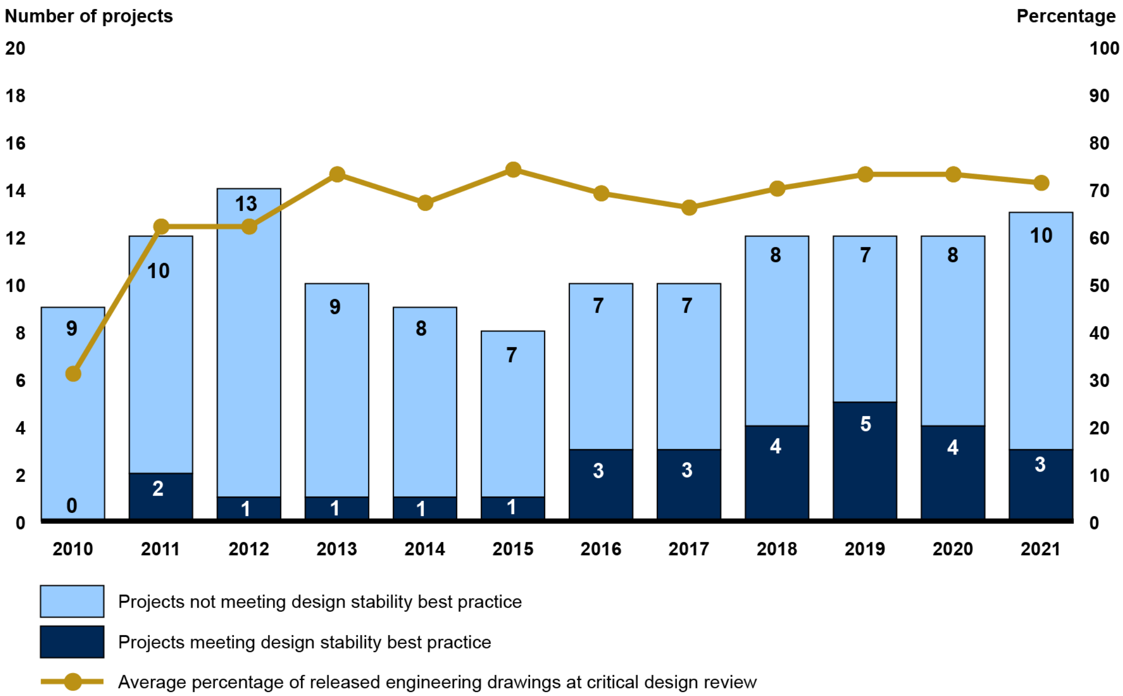
Number of Projects Meeting Design Stability Best Practice Remains Low

The number of projects with stable designs at critical design review (CDR) remains low. A CDR 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 in the area of product development has shown that releasing at least 90 percent of engineering drawings by CDR lowers the risk of projects experiencing design changes and manufacturing problems that can lead to cost and schedule growth.[31] 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 for fabrication and testing. Once the design of a product is finalized, the drawing is "releasable" to manufacturers.

Of the 13 projects we reviewed that held CDR as of January 2021, three projects met the best practice of releasing 90 percent of design drawings by CDR, which is similar to recent years. The average percentage of drawings releasable at CDR is 71.2 percent, a 2-percent decrease from last year (see fig. 5).

[31] GAO-02-701.

Figure 5: NASA’s Major Projects Performance against Best Practice for Design Stability



Source: GAO analysis of National Aeronautics and Space Administration (NASA) data. | GAO-21-306

Notes: The years in the figure are the years we issued our annual assessment of NASA’s major projects. Data for 2021 were collected as of January or February 2021. GAO’s best practice for design stability calls for releasing at least 90 percent of engineering drawings by critical design review.

We have seen little change in this analysis from last year. One reason is that the ICON project launched in 2019 and exited the portfolio. Additionally, only three projects—Psyche, PACE, and Europa Clipper—held CDR during this reporting period, and one of these three projects did not use drawings.

- Psyche did not use engineering drawings as a metric of design stability and was excluded from this analysis. Psyche officials explained that Psyche is a heritage design, and that the project assesses its design through detailed technical peer reviews of each system by subject matter experts.
- PACE held its CDR in February 2020 and did not meet the best practice, having released 61 percent of design drawings at that time. Project officials said they were able to focus on engineering drawings during COVID-19 while they were required to work remotely and could

not physically access labs and other facilities needed to complete work on hardware. Within 11 months of CDR, the project released 99 percent of its drawings.

- Europa Clipper held its CDR in December 2020 and did not meet the best practice, having released 81.5 percent of design drawings at that time. According to officials, the bulk of the remaining drawings are assembly drawings and support equipment drawings that are used for integration and have maturity schedules later than the project's CDR. Some remaining drawings are associated with the previous uncertainty of the project's launch vehicle. Officials said they expect the rate of release to pick up as subsystems and instruments transition to their flight build over the next several months.

Since we last reported, we have seen poor outcomes for a project that did not meet the design stability best practice. We reported last year that the LBFD project held CDR in September 2019 with 37 percent of drawings released.[32] Since our report, the project increased its estimated cost by $74.7 million and delayed its schedule by 5 months, which NASA attributes to the contractor's delayed releases of design drawings and its quality issues with supplier deliveries. As of January 2021, LBFD had released 98 percent of drawings, which marks a significant improvement.

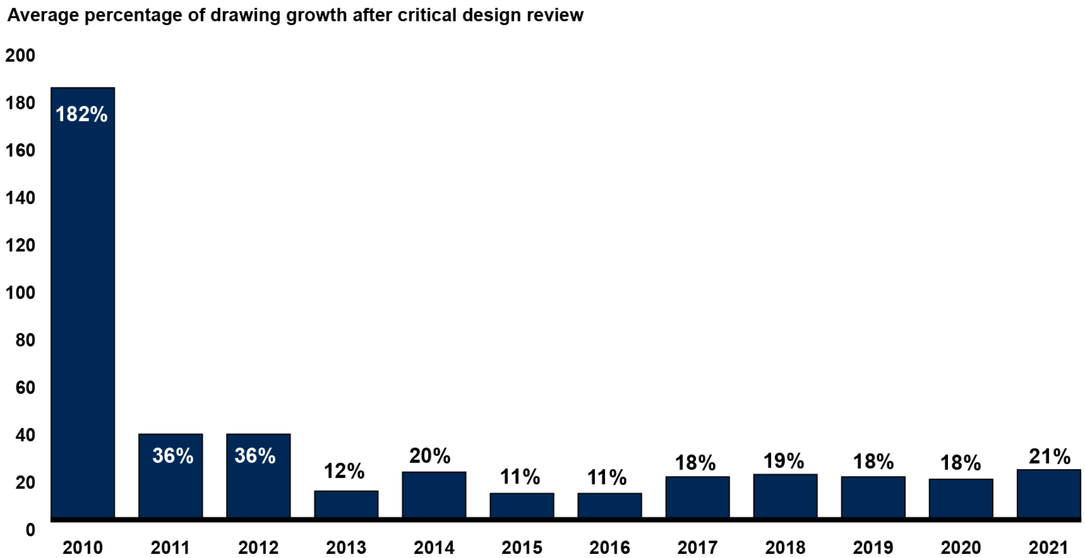
Design drawing growth after CDR has also generally remained steady since 2017, fluctuating between 18 and 21 percent (see fig. 6).[33] Experiencing a large amount of design drawing growth after CDR may be an indicator of instability in a project's design late in the development cycle. Design changes 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, 10 of 13 projects experienced drawing growth, which is one more than last year. This change is because of the launch of ICON, which had no drawing growth, and the addition of Europa Clipper and PACE to the analysis. Europa Clipper has not had drawing growth in the month since the project's CDR, but PACE experienced 37 percent drawing growth in the 11 months after CDR. The project's CDR occurred just before the start of the pandemic, and, as discussed above, project officials attributed the drawing growth to an increased focus on

[32]GAO-20-405.

[33]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.

design maturity during the COVID-19 remote work environment while project officials were unable to work on hardware.

Figure 6: Average Percentage of Engineering Drawing Growth after Critical Design Review among NASA's Major Projects from 2010 to 2021



Source: GAO analysis of National Aeronautics and Space Administration (NASA) data. | GAO-21-306

Notes: Drawing growth in 2010 was primarily attributed to the Solar Dynamics Observatory (SDO) because it did not have a stable design at its critical design review. Because drawings for SDO's instruments were not included in this review, there was large drawing growth after the review occurred, as seen here. The project launched in 2010 and exited the portfolio. The years in the figure are the years we issued our annual assessment of NASA's major projects. Data for 2021 were collected as of January or February 2021.

As we previously reported, NASA officials raised concerns about our use of the engineering drawing best practice to assess design stability because they raised questions about its applicability for modern NASA projects.[34] We reported last year that there are a variety of potential tools—design drawings, mass and power margins, growth in requirements, and schedule performance—to measure design stability and no clear consensus on the topic within NASA.[35] NASA's Corrective Action Plan included an initiative to identify indicators that will advance NASA's ability to detect emerging issues that may affect a project's

[34]GAO-19-262SP.

[35]GAO-20-405.

implementation. In December 2019, NASA reported that the research did not identify a “silver bullet” predictive metric or set of metrics. The study collected over 100 potential indicators, including drawing count metrics, and concluded that metrics work cohesively. One of the recommendations from the study was that NASA create a catalog of metrics to provide options from which projects can choose. In January 2021, NASA published this document titled “NASA Common Leading Indicators Detailed Reference Guide.”

We recently started a body of work to update our best practices for product development. We anticipate that an important component of this work will be to identify current leading practices that facilitate design stability. We will continue to collaborate with NASA as we conduct this work, including leveraging information in the leading indicators guide, as appropriate. In the meantime, the design drawing metric remains a useful indicator. We continue to use engineering design drawings released by CDR 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—including former NASA officials—convened by the National Academy of Sciences for GAO in 2013.

Project Assessments

In the following section, we present the individual assessments of the 33 projects and one capability upgrade within a project that we reviewed in a two-page or one-page profile. Each assessment generally 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 time line identifying key project dates, and a brief narrative describing the current status of the project. Assessments describe the challenges we identified and include an analysis of the challenges. In addition, we outline the extent to which each project faces cost, schedule, or performance risks because of these challenges, if applicable. Also included is an infographic of all projects involved in Artemis missions and a summary of the Gateway program. The information presented in these assessments and summary was obtained from NASA documentation, interviews with project staff, as well as data provided by NASA officials in our questionnaires covering cost and schedule updates and other project details. The assessments also include our analysis of the project cost and schedule information provided. NASA’s project offices were provided an opportunity to review drafts of the assessments and summary prior to their inclusion in this report, and the project offices 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 or summary.

See figure 7 for an illustration of a sample assessment layout.

Figure 7: Illustration of a Sample Project Assessment

A B H C D E F G I

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. The purpose of the project is to better understand our impact mitigation posture, and to respond 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, a collaboration with the European Space Agency and the Italian Space Agency.

Source: NASA/Johns Hopkins University/Applied Physics Lab/Steve Gribben. | GAO-21-306

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; 03/20 Integration and test readiness review; 01/21 GAO review; 11/21 Target launch readiness date; 02/22 Committed launch readiness date

PROJECT INFORMATION

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

International Partners: **Italian Space Agency**

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

Launch Vehicle: **Falcon 9**

Mission Duration: **10 or 17 months (launch dependent)**

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 development cost and schedule baselines, but is exceeding its operations cost estimate. Delays related to the development and delivery of its solar arrays and COVID-19 effects are using cost and schedule reserves. The project is no longer working to its target launch readiness date of July 2021 --seven months earlier than the project's baseline schedule -- because late delivery of the solar arrays and an issue with the navigation instrument made the target date no longer viable The next available launch window does not start until November 2021.The project had reported concerns regarding the NASA Evolutionary Xenon Thruster-Commercial (NEXT-C) in the past; however, NEXT-C has successfully been delivered to the project. The project reported that integration and test is proceeding well, but the project is tracking several risks related to delayed components that could affect the integration and test schedule.

SCHEDULE PERFORMANCE

COST PERFORMANCE
then-year dollars in millions

COMMON NAME: DART 45 Assessments of Major NASA Projects GAO-21-306

DOUBLE ASTEROID REDIRECTION TEST

Cost and Schedule Status

The DART project continues to operate within its development cost and schedule baselines, but is exceeding its operations cost estimate. The project is using cost and schedule reserves to address delays resulting from the development and delivery of its solar arrays, technical issues discovered in testing, and COVID-19 effects. DART has struggled with the development of its solar array, primarily due to COVID-19 effects on efficiency and safety precautions, and engineering issues that required design changes and more rigorous testing. The project has rearranged the integration and testing schedule to accommodate delays in the delivery of the solar arrays; however they remain on the project's critical path. Including late delivery of the solar arrays, the project is tracking two risks that have caused it to miss its internal launch date, and the project estimates the delay will cause it to exceed its cost baseline. The project is experiencing delays to the navigation imaging instrument --Didymos Reconnaissance and Asteroid Camera for OpNav (DRACO) --after a primary mirror bond failed on the spare during testing. DRACO is now on the project's primary critical path and a failure review board concluded that the mirror mount attaching DRACO to the spacecraft will need to be redesigned. The delays from the solar arrays and DRACO caused the project to miss its target launch readiness window. A new window opens between November 2021 and February 2022, which aligns with the project's baseline schedule. The latter launch date carries a cost effect that the project estimates to be about $10 million and will reduce operations time by seven months since the end date of the mission is still tied to the date of impacting the asteroid.

NASA released $12.5 million of the project's headquarters-held reserves to help address the cost growth from solar array development and to ensure the project has necessary funding and reserves to meet its target launch readiness date. As of January 2021, the project is estimating that it will require $3 million more from its remaining headquarters-held reserves to mitigate COVID-19 costs and solar array delays among other things. The project is also tracking threats that could affect costs over and above available cost reserves. For example, the project estimates that that solar array cost growth could increase another $1 million.

Integration and Testing

In July 2020, the project entered the assembly, integration and test, and launch phase, and the project reports that spacecraft integration and test is performing well. For example, the project had previously reported concerns about the on-time delivery of the NASA Evolutionary Xenon Thruster Commercial (NEXT-C) --an electric propulsion technology demonstration project --due to development issues. The project previously reported in June 2020 that NEXT-C was successfully qualified and delivered to the project. As of November 2020, the NEXT-C thruster was installed and began testing in December 2020.

International Partner

Due to COVID-19, subject matter experts from the Italian Space Agency cannot travel to the United States to assist in testing the Light Italian CubeSat for Imaging of Asteroids (LICIACube). In light of the restrictions, project officials developed a modified testing plan for the LICIACube radio. For example, the radio will now be tested by a contractor with project personnel on site.

PROJECT OFFICE COMMENTS

DART project officials stated that they agreed with a draft of this assessment and provided technical comments that were incorporated as appropriate.

COMMON NAME: DART 46 Assessments of Major NASA Projects GAO-21-306

A Illustration of the spacecraft, instrument, aircraft, launch vehicle, or ground system.

B General description of the mission's objectives.

C Time line 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 **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.

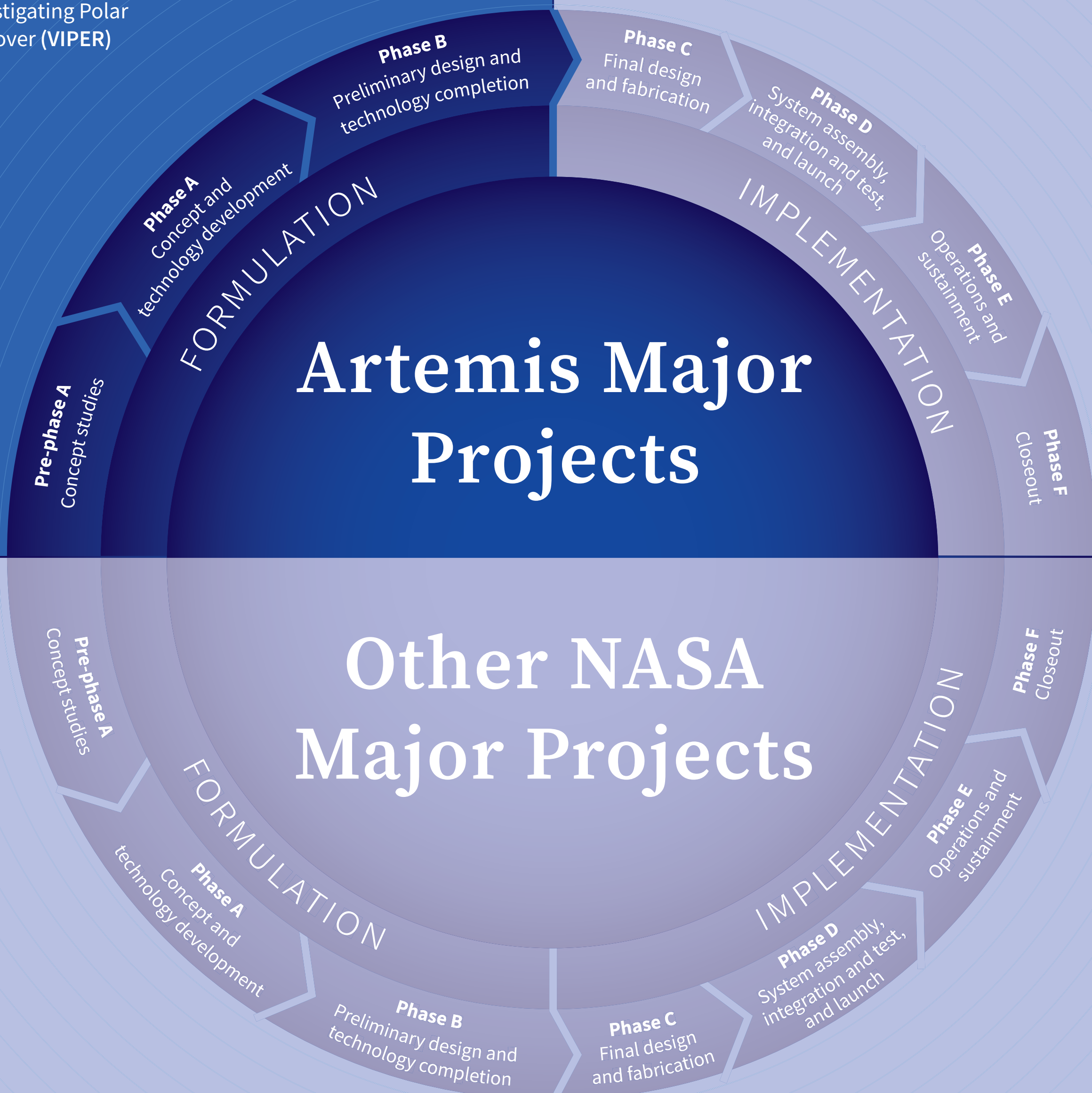
G **Cost:** For projects in formulation, the preliminary cost estimate. For projects in implementation, the approved cost baseline and latest estimate.

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-21-306

- Gateway
- Gateway - Deep Space Logistics **(DSL)**
- Gateway - Exploration Extravehicular Activity **(xEVA)**
- Gateway - Habitation and Logistics Outpost **(HALO)**
- Gateway - Power and Propulsion Element **(PPE)**
- Human Landing System **(HLS)**
- Mobile Launcher 2 **(ML2)**
- Space Launch System Block 1B **(SLS Block 1B)**
- Volatiles Investigating Polar Exploration Rover **(VIPER)**



Source: GAO analysis of National Aeronautics and Space Administration (NASA) data. | GAO-21-306

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Artemis

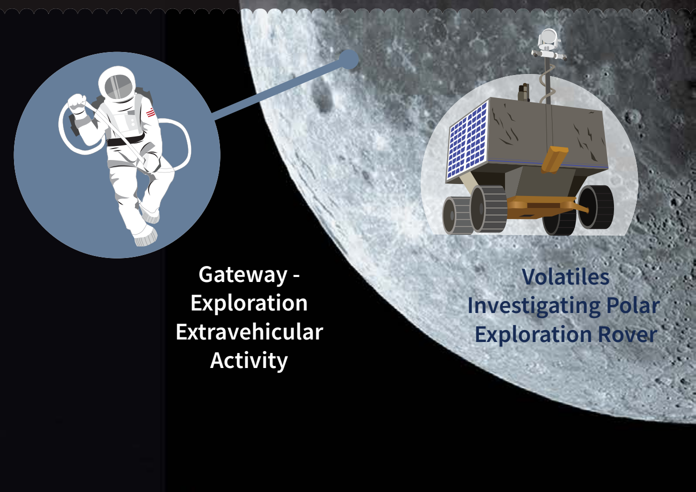
MAJOR NASA PROJECTS AND PROGRAMS SUPPORTING ARTEMIS MISSIONS

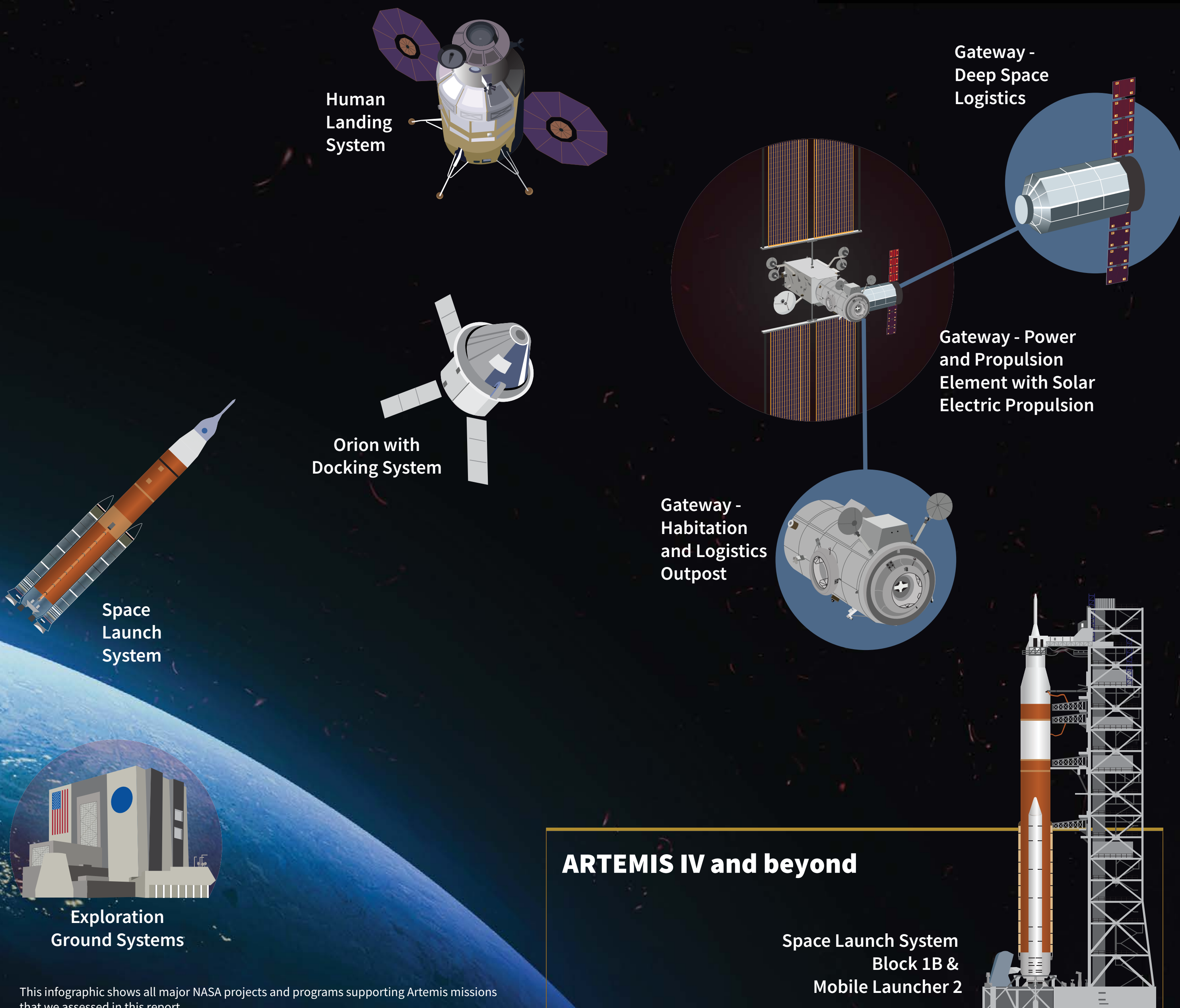
ARTEMIS I & II

Planned for November 2021 and August 2023, respectively; these will be uncrewed and then crewed test flights demonstrating the Space Launch System, Exploration Ground Systems, and Orion Multi-Purpose Crew Vehicle.

ARTEMIS III

Planned for 2024, this mission will be a crewed lunar landing. NASA has not yet determined whether Gateway, an outpost orbiting the Moon, will be used for the Artemis III mission.





ARTEMIS IV and beyond

This infographic shows all major NASA projects and programs supporting Artemis missions that we assessed in this report.

Source: GAO analysis of NASA documentation (data and images); elen31/stock.adobe.com (moon image); dimazel/stock.adobe.com (earth background). | GAO-21-306

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Gateway

The Gateway program aims to build a sustainable outpost in lunar orbit that will serve as a research platform, staging point for human and robotic exploration in deep space, and a technology test bed for Mars. The design will allow for the Orion crew capsule and the Human Landing System (HLS) vehicle to both dock with Gateway. Under this design, astronauts would board the Human Landing System vehicle from Gateway and HLS would transport the astronauts to the moon and back. The Gateway program is the first program NASA has designated as a tightly coupled program, which comprises multiple projects each with their own cost estimates and launch readiness dates.

Source: NASA. | GAO-21-306

PROGRAM INFORMATION

Gateway Initial Capability:

- **Deep Space Logistics (DSL)**
- **Habitation and Logistics Outpost (HALO)**
- **Power and Propulsion Element (PPE)**
- **Exploration Extravehicular Activity (xEVA)**

Gateway Sustained Capability (includes the initial capability modules):

- **International Habitat (i-Hab)**[1]
- **European System Providing Refueling, Infrastructure, and Telecommunications Refueler Module (ESPRIT-RM)**[1]
- **Multipurpose Module (MPM) / Airlock**[1,2]
- **Gateway External Robotic System (GERS)**[1]

[1]International contributions
[2]Not yet a confirmed contribution

PROJECT OFFICE COMMENTS

Gateway program officials provided technical comments on a draft of this summary, which were incorporated as appropriate.

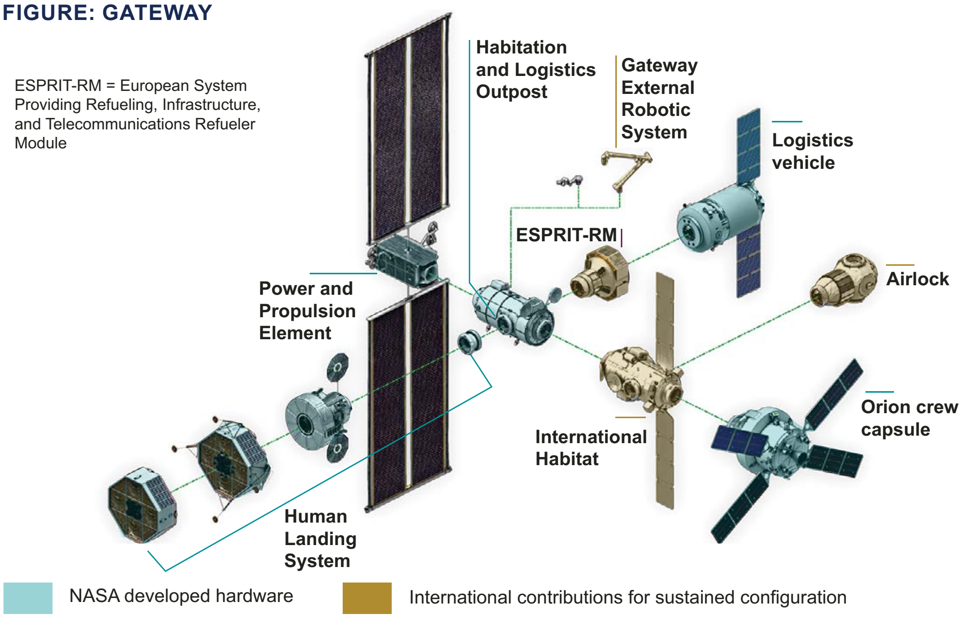
CURRENT STATUS

Gateway will have an initial capability comprised of the PPE and HALO elements, which will launch together. The PPE element will provide power and propulsion, and the HALO element will provide living space for the astronauts. It will also include the DSL element, which will execute resupply missions, and the xEVA project, which will provide space suits and tools for extravehicular exploration.

The sustained capability will also include an additional habitation element (i-Hab) provided by the European Space Agency (ESA) and the Japan Aerospace Exploration Agency, an external robotic system provided by the Canadian Space Agency, and the ESPRIT refueler module also provided by ESA.

NASA has not decided whether astronauts will dock with Gateway as part of the 2024 Artemis III lunar landing mission. Before White House direction to accelerate a lunar landing from 2028 to 2024, NASA previously planned that astronauts arriving on the Orion crew capsule would dock with Gateway before transferring to the HLS and continuing to the moon. However, to help meet the accelerated 2024 deadline, NASA is leaving open the option for the HLS providers to propose designs that dock directly with Orion. NASA plans to launch the co-manifested PPE and HALO modules together in January 2024 in time to support an Artemis III mission, but this schedule is aggressive.

FIGURE: GATEWAY



Source: NASA for image; GAO analysis of Gateway Program documentation. | GAO-21-306

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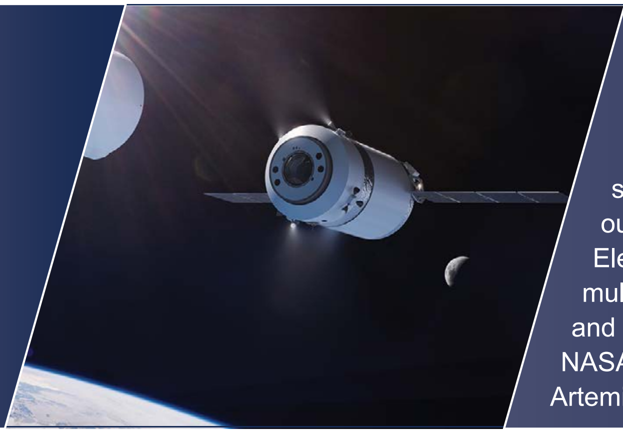


Source: SpaceX. | GAO-21-306

Gateway - Deep Space Logistics

The Deep Space Logistics (DSL) project is responsible for the execution of commercial end-to-end services that will provide Gateway with cargo and supplies prior to crew arrival. NASA plans for Gateway to be a sustainable outpost in lunar orbit that will initially include NASA's Power and Propulsion Element, Habitation and Logistics Outpost, and the DSL vehicle. NASA plans multiple missions for a logistics vehicle to dock with the Gateway's Habitation and Logistics Outpost to provide storage and, upon its departure, trash disposal. NASA may also use these logistics services to deliver other elements of the Artemis architecture.

FORMULATION
- **04/19** Formulation start
- **01/21** **GAO review**
- **TBD** Authority to proceed
- **TBD** SpaceX system requirements review
- **TBD** SpaceX preliminary design review
- **TBD** Project confirmation

IMPLEMENTATION
- **TBD** SpaceX critical design review
- **TBD** Target launch readiness date

TBD = Date to be determined

PROJECT INFORMATION

NASA Lead Center: **Kennedy Space Center**

International Partner: **None**

Launch Location: **Kennedy Space Center**

Launch Vehicle: **Commercial, Falcon Heavy (for SpaceX launches)**

Mission Duration: **Maximum of 1 year on-orbit**

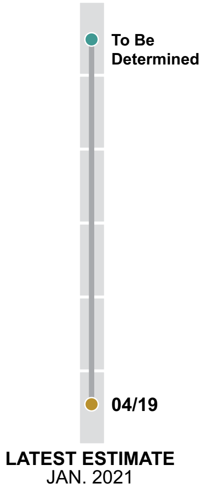
Requirement Derived from: **National Space Policy Directive 1 and NASA Strategic Plan 2018**

Budget Portfolio: **Exploration Research & Development**

PROJECT SUMMARY

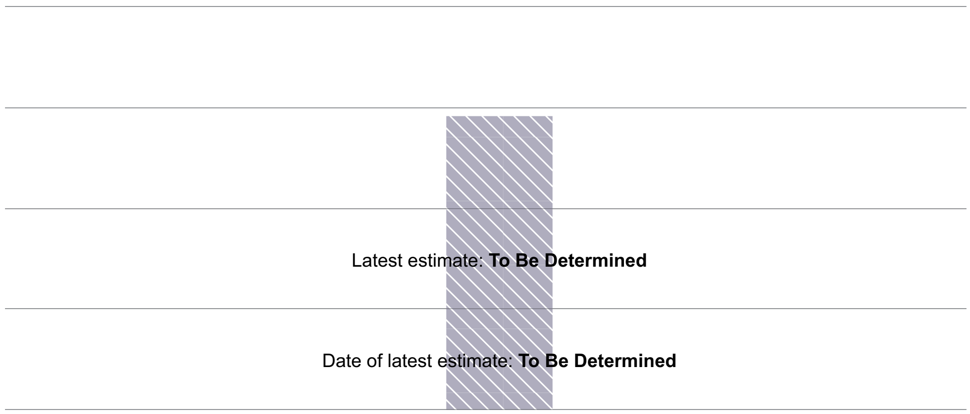
NASA plans to review the project's preliminary cost and schedule estimate at an upcoming Gateway program-level review planned for spring 2021. In March 2020, NASA awarded an initial firm-fixed price, indefinite delivery / indefinite quantity contract to SpaceX for the design and development, launch, transit, operation, and disposal of a logistics vehicle. The project's schedule and costs depend on when NASA provides SpaceX with authority to proceed with work on the task order. According to project officials, NASA did not provide SpaceX with authority to proceed in October 2020, as originally planned, due to funding constraints from operating under a continuing resolution and NASA having other funding priorities. As a result, there is a risk that the logistics mission may not be capable of supporting the Artemis III mission at the end of 2024. The project is currently assessing its schedule and performance requirements if the authority to proceed continues to be delayed.

PRELIMINARY SCHEDULE



PRELIMINARY COST

then-year dollars in millions



Cost and Schedule Status

The DSL project does not yet have a preliminary cost and schedule estimate. NASA plans to review the project's preliminary cost and schedule estimate at an upcoming Gateway program-level review planned for spring 2021. In March 2020, NASA awarded an initial firm-fixed price, indefinite delivery / indefinite quantity contract to SpaceX, which guarantees the company a minimum of two logistics missions. SpaceX is responsible for design and development, launch, transit, operating, and disposal of a logistics vehicle. NASA may make further indefinite delivery / indefinite quantity contract awards to additional logistics service providers, allowing them to compete for future missions with a total maximum value of $7 billion across all task orders.

The project's cost and schedule depends on the timing of NASA providing SpaceX with authority to proceed with work on the task order. According to project officials, NASA did not provide SpaceX with authority to proceed in October 2020, as originally planned, due to funding constraints from operating under a continuing resolution and NASA having other funding priorities. As a result, there is a risk that the logistics mission may not be capable of supporting the Artemis III mission at the end of 2024. If NASA had provided SpaceX with the authority to proceed in October 2020, SpaceX would have planned to develop the logistics vehicle and launch it in October 2024 to support the Artemis III mission. Project officials said they are evaluating whether using a fast transit capability, which increases the cost of SpaceX's task order, could help the project support the Artemis III mission time frames. This capability increases the speed that the logistics vehicle arrives in lunar orbit by using expendable rather than reusable first stages for all three cores of the Falcon Heavy to increase launch capability.

To try to mitigate this schedule risk, the project is also working with the Gateway program and the Advanced Exploration Systems division to obtain funding and with SpaceX on four special studies to prepare for the authority to proceed. For example, project officials said one study tasked SpaceX to develop an updated schedule to inform the launch readiness date for the initial mission. The project is also assessing whether it could tailor the current schedule and performance requirements if the authority to proceed continues to be delayed.

Design

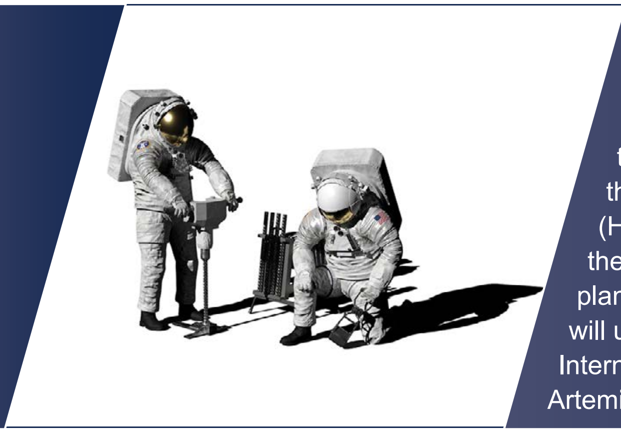
According to the project, the four special studies NASA tasked SpaceX with also aim to evaluate and improve capabilities in advance of the authority to proceed. For example, project officials said SpaceX is reviewing Gateway program requirements changes since NASA awarded the task order to identify any potential requirements gaps. Identifying requirements gaps could result in contract modifications that lead to cost and schedule adjustments. In addition, project officials said SpaceX is conducting ground-based radiation testing on select components to inform potential design trades NASA may need to make to extend mission duration.

Technology

SpaceX's vehicle heavily leverages its pre-existing systems and processes. SpaceX is using the heritage design of its Dragon vehicle, which is currently flying cargo missions to the International Space Station, for the Dragon XL logistics vehicle. In addition, SpaceX plans to launch the logistics vehicle on its Falcon Heavy launch vehicle, which is currently in production and operational.

PROJECT OFFICE COMMENTS

When commenting on a draft of this assessment, DSL project officials stated that they agree with this assessment and that it reflects the impacts and uncertainties on cost and schedule due to the funding constraints and priorities at NASA. They further stated that this assessment also reflects the work that the project is performing to mitigate risk in advance of the authority to proceed. Project officials also provided technical comments, which were incorporated as appropriate.



Source: NASA. | GAO-21-306

Gateway - Exploration Extravehicular Activity

The Exploration Extravehicular Activity (xEVA) project is developing three kinds of hardware to support NASA's return to the lunar surface: (1) tools the crew will use for lunar science and maintenance tasks; (2) interfaces that the crew will use to connect to other systems, like the Human Landing System (HLS); and (3) space suits, including the portable life-support backpack and the pressurized garment that wraps around the astronaut. The xEVA project plans to build five space suits before the planned Artemis III mission. The project will use two suits for qualification testing, one suit for a demonstration on the International Space Station, and two flight suits for lunar surface operations for the Artemis III mission.

TBD = Date to be determined

PROJECT INFORMATION

NASA Lead Center: **Johnson Space Center**

International Partner: **None**

Launch Location: **N/A**

Launch Vehicle: **N/A**

Service Life: **5 years**

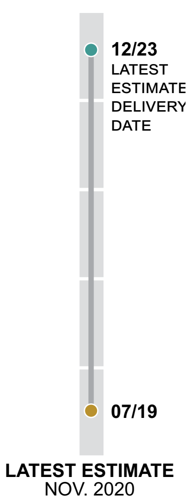
Requirement Derived from: **NASA Strategic Plan**

Budget Portfolio: **Deep Space Exploration Systems, Exploration Research & Development**

PROJECT SUMMARY

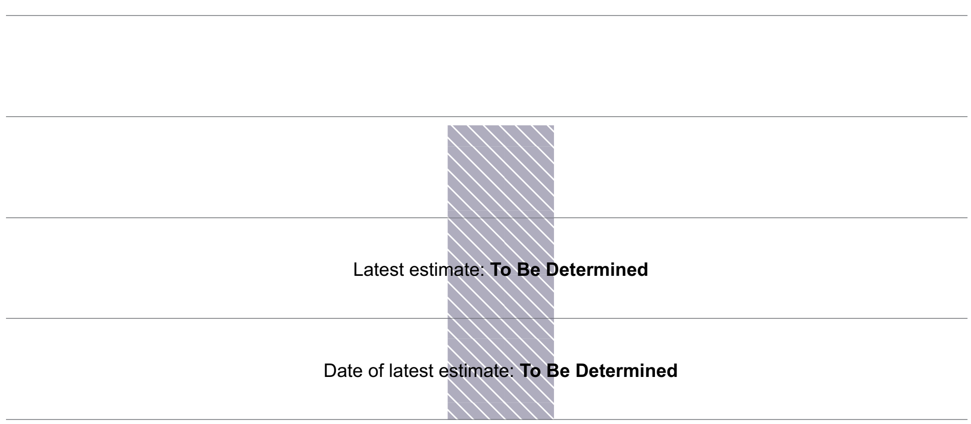
NASA plans to review the xEVA project's preliminary cost and schedule estimate at an upcoming Gateway program-level review planned for spring 2021. The project plans to deliver xEVA system hardware for the Artemis III mission in December 2023, but this schedule may change due to delays related to COVID-19 and the need date for the mission. The project does not plan to mature two of its three critical technologies prior to its planned October 2021 preliminary design review. Not maturing technologies by this review can present risks to systems entering product development. The project is also tracking risks related to potential design changes that may result from the HLS contractor selection.

PRELIMINARY SCHEDULE



PRELIMINARY COST

then-year dollars in millions



Cost and Schedule Status

NASA plans to review the xEVA project's preliminary cost and schedule estimates at an upcoming Gateway program-level review planned for spring 2021. NASA moved the xEVA project under the Gateway program starting in fiscal year 2020. The project previously received funding from multiple sources across the Human Exploration and Operations Mission Directorate. The project currently plans to deliver the two flight suits, interfaces, and tools in December 2023 for launch before the Artemis III mission. However, the project's delivery date may change depending on the need date for the mission, which has yet to be determined.

COVID-19 has affected the project's schedule, according to officials. The project delayed two major schedule milestones—including the project's confirmation review when NASA will establish a cost and schedule baseline. However, it is too soon to know the full extent of COVID-19 effects on the project's cost and schedule because the pandemic is ongoing and the project is still determining its official estimates.

Technology

The project does not plan to mature two of its three critical technologies by its preliminary design review, planned for October 2021. Our best practices work has shown that achieving a technology readiness level 6—or demonstrating a representative prototype of the technology in a relevant environment that simulates the harsh conditions of space—by this review can minimize risks for the systems entering product development. Officials noted that they continue to mature its critical technologies, but observed that not all risk reduction will be complete by the project's preliminary design review. As of November 2020, xEVA project officials anticipated that the project would be able to mature two of its critical technologies related to its suits—the portable life support system and the pressure garment system—to a technology readiness level 6 after the design verification assembly and testing in January 2022.

Officials also told us that they plan to mature the third technology, vehicle to suit interface equipment, to a technology readiness level 6 by the project's preliminary design review. They said that the vehicle to suit interface equipment subsystem will not incorporate any new or unproven space technologies, and noted that these technologies are in operation today in similar spacecraft environments including the International Space Station.

Design

The xEVA project is tracking a risk that the HLS design could affect the mass allocation and design of the suits, resulting in design changes and delays. Project officials stated that the current xEVA system design meets the mass allocation for the project. However, they are working to identify ways to further lower suit mass to avoid future challenges that may arise when the overall mass of the lander is known. For example, project officials told us they could reconfigure the suits for fewer space walks, which would reduce the amount of batteries and oxygen needed. In addition, the project is working with HLS on contingency scenarios to determine the safety features that it needs to include in the suit design versus into the landing system. For example, the project will need to determine how the suits would function in a contingency scenario if the lander experiences a loss of cabin pressure.

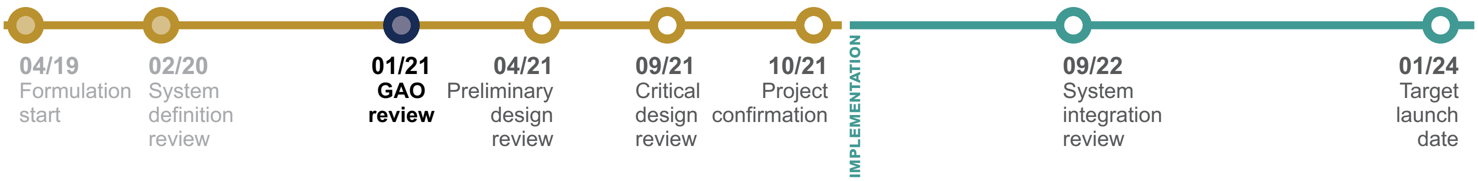
PROJECT OFFICE COMMENTS

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

Gateway - Habitation and Logistics Outpost

The Habitation and Logistics Outpost (HALO) will be the initial crew module for Gateway, which NASA plans to be a sustainable outpost in lunar orbit. It will provide living quarters and communication functions to the lunar surface and for visiting vehicles. The HALO will also augment life support systems in conjunction with NASA's Orion Multi-Purpose Crew Vehicle (Orion). It will have docking ports to connect with Orion, the Human Landing System, and other components of Gateway. NASA plans to integrate the HALO and the Power and Propulsion Element (PPE) on the ground and launch them together, known as co-manifesting.

Source: NASA. | GAO-21-306



PROJECT INFORMATION

NASA Lead Center: **Johnson Space Center**

International Partner: **European Space Agency, Japan Aerospace Exploration Agency, Canadian Space Agency**

Launch Location: **Kennedy Space Center**

Launch Vehicle: **Falcon Heavy**

Mission Duration: **15 years**

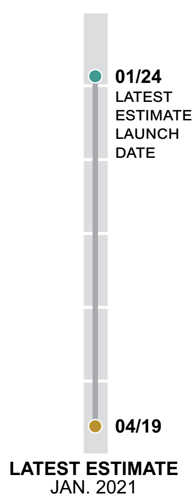
Requirement Derived from: **Space Policy Directive-1 and 2018 NASA Strategic Plan**

Budget Portfolio: **Exploration Research and Development**

PROJECT SUMMARY

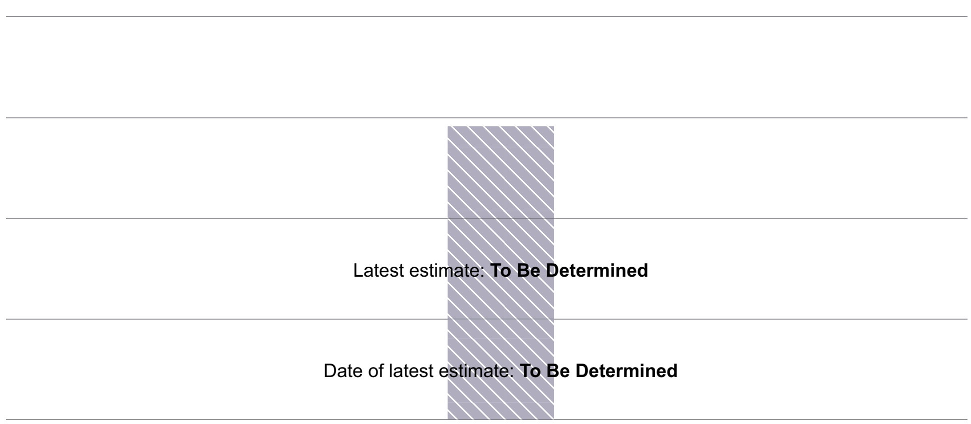
NASA plans to establish a combined preliminary cost estimate for the HALO and PPE projects at an upcoming Gateway program-level review planned for spring 2021. As a result of NASA's recent decision to launch the HALO and PPE together, the HALO project office's scope of work has increased to also oversee and track risks for the integration of both the HALO and PPE as a co-manifested vehicle. According to project officials, the most significant risk is that the combined mass of PPE and the HALO may limit the Gateway program's ability to achieve a timely and effective integrated mission design solution. Officials said the project plans to finalize mass allocations for the co-manifested vehicle after a 2021 review.

PRELIMINARY SCHEDULE



PRELIMINARY COST

then-year dollars in millions



Cost and Schedule Status

NASA is planning to launch PPE and the HALO on the same vehicle, known as a co-manifest, in January 2024. NASA expects to establish a preliminary cost estimate for this effort at an upcoming Gateway program-level review planned for spring 2021. NASA officials told us that this estimate will include Gateway program costs to certify, deliver, and launch the co-manifest. NASA expects to then establish a combined cost and schedule baseline for this effort in October 2021.

The HALO project office is also now responsible for managing the integration of PPE and the HALO as well as tracking joint technical risks associated with the co-manifested launch. As a result of this change, NASA reported extending its firm-fixed-price and cost-plus-incentive-fee contract for the HALO—valued at $187 million at the time of the definitization—from December 2020 to June 2021 to account for the co-manifested launch and resulting design changes. NASA plans for the contract that follows to also include work to integrate and test the HALO and PPE.

Design and Technology

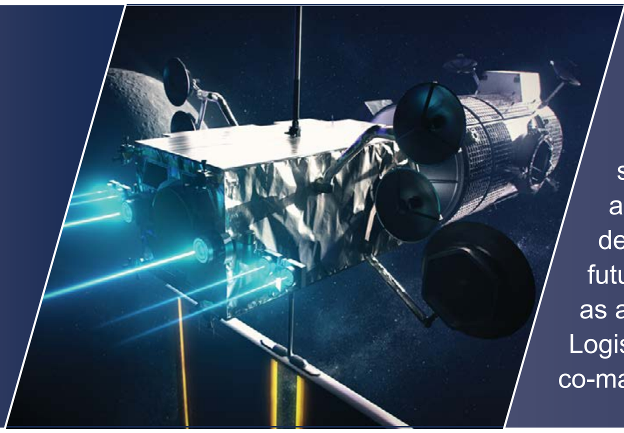
The February 2020 decision to co-manifest PPE and the HALO resulted in design changes to the HALO. NASA will integrate the two projects before launch, so some of the HALO hardware and capabilities were eliminated from the initial design. For example, the propulsion service element is no longer needed because PPE will provide all of the power. In addition to design reviews specific to the HALO, the project office plans to conduct a series of sync reviews with the PPE project to define the interfaces and make architectural decisions for the co-manifested vehicle. These decisions will focus on the integration of the HALO, the inter-element adapter, and PPE. They will also focus on how the vehicle interfaces with other mission components, including other components of Gateway and the Human Landing System. The project plans to hold its first sync review in early 2021.

Project officials said the co-manifested launch will enhance the likelihood of mission success by eliminating the need for both in-orbit docking between the two elements and testing them as an integrated vehicle before launch. However, the launch has also resulted in technical risks for the overall co-manifested vehicle. Project officials stated that the increased mass is the most significant technical risk. There is a risk that the mass of the co-manifest may limit the Gateway program's ability to achieve a timely and effective integrated mission design solution. According to officials, the project needs additional mission design information, including updated launch vehicle capabilities and solar electric propulsion performance data to finalize mass allocations for the co-manifested vehicle. Officials said the project plans to finalize mass allocations for the co-manifested vehicle after a design analysis cycle planned for July 2021.

The HALO project reported that it matured its six critical technologies ahead of its planned April 2021 preliminary design review but is tracking a potential delay related to the avionics technology. The avionics system is designed to use a combination of heritage and new technology. The new technology aims to improve communication across the components of Gateway, but the technology has not yet been able to communicate at the necessary data-rates. According to project officials, they have recently conducted several integrated demonstration activities with the technology to help ensure they have a good foundation for integration and reduce further risk.

PROJECT OFFICE COMMENTS

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



Gateway - Power and Propulsion Element

The Power and Propulsion Element (PPE) will provide the Gateway—a sustainable outpost planned for lunar orbit—with power, communications, and the ability to change orbits, among other things. The PPE also aims to demonstrate advanced Solar Electric Propulsion (SEP) technology to support future human space exploration. NASA is managing the development of SEP as a separate project. NASA plans to integrate the PPE and the Habitation and Logistics Outpost (HALO) on the ground and launch them together, known as a co-manifest.

Source: NASA. | GAO-21-306

PROJECT INFORMATION

NASA Lead Center: **Glenn Research Center**

International Partner: **Canadian Space Agency**

Launch Location: **Kennedy Space Center**

Launch Vehicle: **Falcon Heavy**

Mission Duration: **15 years**

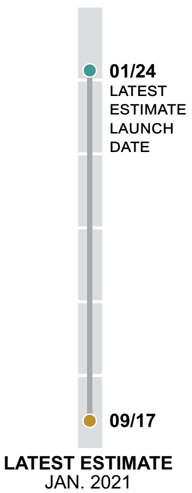
Requirement Derived from: **Space Policy Directive-1 and 2018 NASA Strategic Plan**

Budget Portfolio: **Exploration Research and Development**

PROJECT SUMMARY

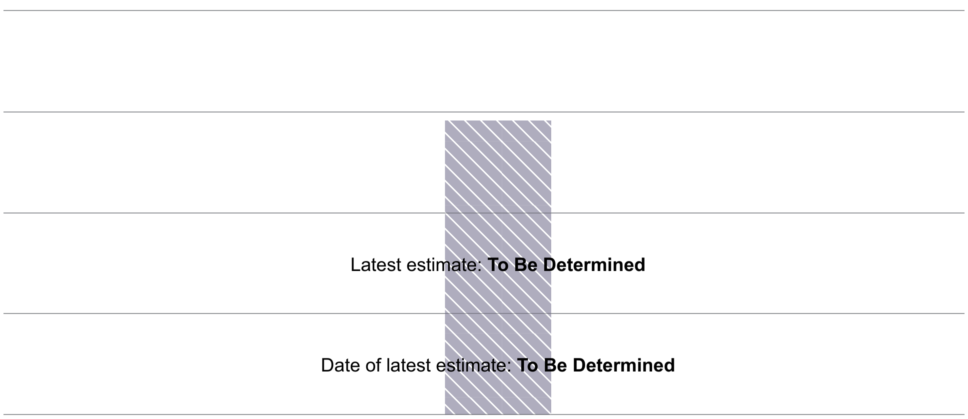
NASA plans to establish a combined preliminary cost estimate for the PPE and HALO projects at an upcoming Gateway program-level key decision point review planned for spring 2021. NASA's recent decision to launch the PPE and the HALO together has some benefits, but adds additional technical and schedule risk for the PPE. For example, the decision increased the need for a high-power solar electric propulsion system—which includes technologies that are not mature—to carry the greater mass of the co-manifested vehicle to lunar orbit and sustain the life of the Gateway. Contractor efforts to develop the propulsion technology are significantly behind schedule.

PRELIMINARY SCHEDULE



PRELIMINARY COST

then-year dollars in millions



Cost and Schedule Status

NASA is planning to launch PPE and the HALO on the same vehicle, known as a co-manifest, in January 2024. NASA expects to establish a preliminary cost estimate for this effort at an upcoming Gateway program-level key decision point review planned for spring 2021. NASA officials told us that this estimate will include Gateway program costs to certify, deliver and launch the co-manifest. NASA expects to then establish a combined cost and schedule baseline for this activity as part of another Gateway program key decision point review, which the program plans to hold no earlier than October 2021.

Design

Project officials said the February 2020 co-manifested launch decision will enhance the likelihood of mission success by eliminating the need for an in-orbit docking between the PPE and the HALO. However, the launch decision has also caused design changes for the PPE and contract cost increases and modifications. For example, the co-manifest requires PPE to be launched inverted when compared to original designs. As a result, the project had to redesign its bi-propellant tank—a dual chambered fuel system—that originally used a heritage design. The project finalized a contract modification in July 2020 for the redesign of this tank, which increased the value of the firm-fixed-price contract by approximately $3.7 million. The initial value of the contract was $375 million. NASA expects additional contract modifications for a range of requirements changes related to the co-manifest and changes to the propulsion system, among other things. The project also plans to modify the contract to remove the requirement to procure a launch vehicle specifically for the PPE.

The PPE project has also experienced contract cost growth due to PPE design changes to resolve requirements gaps. In December 2019, we identified that the PPE project finalized its requirements before the Gateway program finalized corresponding requirements at the program level, leading to requirements gaps between the PPE and the Gateway.[1] The two gaps related to the amount of power the PPE is expected to provide the Gateway and the PPE's ability to control the entire Gateway when in orbit. These gaps resulted in contract modifications to update the PPE design to increase the operating voltage of the PPE and add small chemical thrusters and larger wheels to aid control that increased the value of the contract by $30 million.

Technology

The PPE project is tracking several technologies that will need to mature before the project's preliminary design review, including the solar electric propulsion system thrusters. Our best practices work has shown that achieving a technology readiness level 6 by this review can minimize risks for projects moving forward. However, the PPE project does not expect the thruster technology to be mature until after this review. The PPE project will fund and provide three flight thrusters to the PPE contractor as government furnished equipment. The SEP project will manage the contract for the flight thrusters, but the SEP contractor efforts to develop the propulsion technology are significantly behind schedule. Project officials stated that receiving the SEP thrusters in time for integration and testing is one of the largest risks to the project's schedule.

In addition, the decision to co-manifest increased the need for a high-power solar electric propulsion system to carry the greater mass of the co-manifested vehicle to lunar orbit and sustain the Gateway. The PPE project previously stated that it could use an already developed lower-kilowatt system instead of the high-power SEP system if the development continued to lag, but that is no longer an option due to the mass of the co-manifested vehicle. The PPE project officials stated that, if the thrusters are not available, they would have to request relief from their technical requirements or reassess the schedule.

PROJECT OFFICE COMMENTS

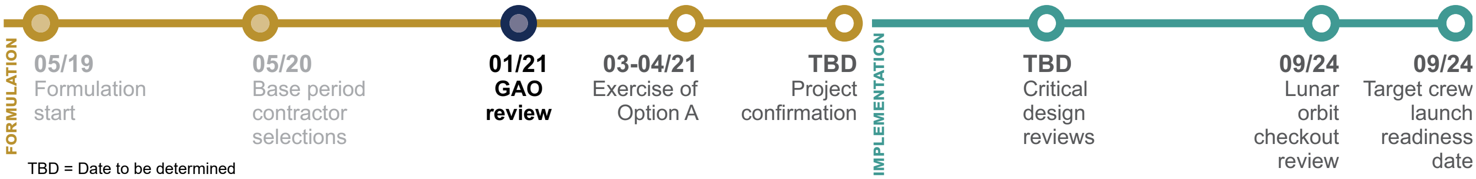
When commenting on a draft of this assessment, PPE project officials said they generally agreed with this assessment. They provided technical comments, which were incorporated as appropriate.

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

Human Landing System

The Human Landing System (HLS) will provide crew access to the lunar surface and demonstrate capabilities required for deep space missions. NASA plans to use HLS for the Artemis III mission to the moon—planned for 2024—and for later missions focused on developing a sustainable lunar presence. HLS is expected to be able to dock with either the Orion Multi-Purpose Crew Vehicle or Gateway, an outpost in lunar orbit.

Source: NASA. | GAO-21-306



PROJECT INFORMATION

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

International Partner: **None**

Launch Location: **To be determined**

Launch Vehicle: **To be determined**

Mission Duration: **To be determined**

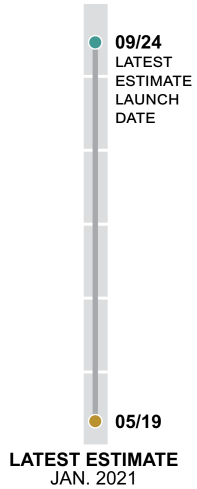
Requirement Derived from: **Space Policy Directive 1 and National Space Policy**

Budget Portfolio: **Exploration Research & Development**

PROJECT SUMMARY

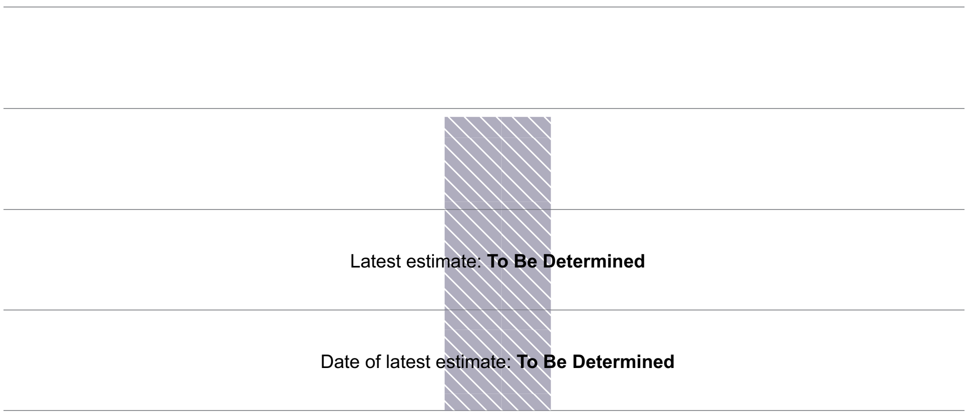
The HLS program plans to establish cost and schedule baselines approximately 8 months after exercising an option on its existing contracts—known as Option A—in spring 2021. NASA awarded contracts to three contractors in May 2020 for early design and risk reduction work. NASA plans to exercise Option A on one or more of these existing contracts for the development of the Artemis III lander. The program is early in development, and the program and contractors will likely have to make significant design trades because the companies' proposed designs included multiple immature technologies. For example, the program office is assessing trades for each of the contractor's power and propulsion system designs. According to program officials, NASA and the contractors may have to make a trade-off between using more mature technologies and/or developing new technologies.

PRELIMINARY SCHEDULE



PRELIMINARY COST[a]

then-year dollars in millions



[a]NASA did not require the HLS program to establish a preliminary cost estimate for the program.

Cost and Schedule Status

NASA did not require the HLS program to establish a preliminary cost estimate, but the program plans to establish cost and schedule baselines at its key decision point C review. The program was not required to establish preliminary estimates because NASA agreed to tailor a program management policy requirement. According to program officials, this approach allows for ongoing insight of the contractor's progress while streamlining the acquisition process. NASA's September 2020 Artemis Plan included a funding plan for the program between fiscal year 2021 and fiscal year 2025.

In May 2020, NASA awarded firm-fixed price contracts to design a lunar lander to three contractors—Blue Origin Federation, Dynetics, and SpaceX—totaling approximately $856 million for the base period, and which included options for future work. During the base period, the contractors will refine their designs and complete risk reduction work. In spring 2021, NASA plans to exercise Option A on one or more of these existing contracts for the design, development, test and evaluation, and flight demonstration of a lander for the 2024 lunar landing. The explanatory statement accompanying the Consolidated Appropriations Act, 2021 denoted $850 million of the $3.4 billion requested by NASA for HLS in its fiscal year 2021 budget request. If contractors are selected to continue work for the first lunar landing, they may also continue to compete to develop landers for later missions.

The program plans to hold its key decision point C review approximately 8 months from the time that NASA exercises Option A on the existing contract(s). NASA expects to have contractor data available to prepare for the review.

Technology

To help meet the 2024 schedule, NASA planned to avoid extensive technology development, but the companies' proposed designs for the base period contracts included multiple immature technologies, which could require trade-offs. For example, the proposed designs for the power and propulsion systems are comprised of complex, immature systems, which would require significant development work on an aggressive schedule. According to program officials, NASA and the contractors may have to make a trade-off between using more mature technologies and developing new technologies. In addition, HLS program officials expect the contractors to be at a preliminary design review-level of readiness at the time NASA exercises Option A. NASA asked the contractors to include plans for how they will mitigate the technical and schedule risks related to lower maturity technologies in their proposals.

Design

The three contractors proposed different designs and architectures for their lunar landers, and each is continuing to develop its design with NASA. For example, the Blue Origin Federation has a three-stage architecture with ascent, descent, and transfer stages. Dynetics has an architecture with combined ascent and descent stages, and SpaceX has a single-stage lander design. Program officials stated that all designs are still early concepts and a key aspect of the contractors' work within the base period is dedicated to refining design requirements. The base period contracts include a NASA review of each contractor's design relative to their initial proposals, which is intended to help the program understand design risks and the contractors' plans to effectively manage those risks within the available schedule.

PROJECT OFFICE COMMENTS

In commenting on a draft of this assessment, HLS project officials stated that the project prepared an independent cost estimate to inform the fiscal year 2022 budget cycle and plans to provide updates as part of the key decision point C review. HLS project officials stated that they concurred with the assessment and provided technical comments, which were incorporated as appropriate.

Mobile Launcher 2

Mobile Launcher 2 (ML2) is a project within the Exploration Ground Systems (EGS) program and will be the newly designed launch platform and tower for the Space Launch System (SLS) Block 1B vehicle with the upgraded Exploration Upper Stage. The platform and tower support the vehicle and capsule during stacking, transportation to the launch pad, and launch. In addition, ML2 provides all fuel, power, and environmental control connections to the vehicle up until launch.

Source: NASA. | GAO-21-306

FORMULATION

- **Continued from EGS program** Formulation start
- **03/20** System requirements review
- **01/21 GAO review**
- **03/21 and 07/21** Preliminary design review steps 1 and 2
- **09/21** Project confirmation

IMPLEMENTATION

- ***Under review*** Critical design review
- **01/24 – 01/25** Multi-Element Verification and Validation
- **Fiscal year 2026** Target launch readiness date

PROJECT INFORMATION

NASA Lead Center: **Kennedy Space Center**

Requirement Derived from: **Consolidated Appropriations Act, 2018**

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

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

PROJECT OFFICE COMMENTS

When commenting on a draft of this assessment, ML2 officials stated that NASA continues to make progress on ML2, and noted that NASA has committed to establishing an Agency Baseline Commitment for ML2 by September 30, 2021. They also provided technical comments, which were incorporated as appropriate.

CURRENT STATUS

Officials stated that the project delayed its preliminary design review (PDR) by 3 months to March 2021 due to a combination of the following: resources were reallocated to Mobile Launcher 1, COVID-19 created inefficiencies and disrupted collaboration, they experienced delays receiving data from the SLS program that the project needs to inform the design of ML2, and other related design development inefficiencies. Project officials stated that nearly all of the subsystem reviews were complete ahead of a pre-PDR held by the contractor. These subsystem reviews focused on interdependencies and integration between subsystems as well as other topics. The pre-PDR is intended to ensure that the interdependencies between subsystems were adequately addressed as part of the design process.

Officials said that the PDR will be held in two steps. The first will be a technical review planned for March 2021, and the second, planned for July 2021, will review programmatic content using technical data from the first step. This will inform a joint cost and schedule confidence level analysis.

While NASA did not establish preliminary cost and schedule estimates for the ML2 project, project officials told us that they plan to use the joint cost and schedule confidence level analysis to establish a cost and schedule baseline. In December 2020, we recommended that NASA establish a cost and schedule baseline for the ML2 project as soon as practicable in advance of critical design review.[1] NASA concurred with this recommendation and stated that the agency expects to establish the baseline by September 2021.

Project officials said the schedule's critical path includes upcoming long-lead structural steel procurements. They explained that the project has had to delay steel orders because it does not have the necessary information from SLS to ensure that the ML2 structure can both support the SLS vehicle and withstand the forces exerted on the structure prior to and during launch. Officials indicated that there may be delivery delays due to COVID-19-related restrictions at steel mills.

[1]GAO, *NASA Human Space Exploration: Significant Investments in Future Capabilities Require Strengthened Management Oversight*, GAO-21-105 (Washington, D.C.: Dec. 15, 2020).

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Space Launch System Block 1B

The Space Launch System (SLS) Block 1B is a planned evolution of the SLS. The SLS Block 1 is intended to be NASA's first human rated heavy-lift vehicle since the Saturn V and is intended to enable deep-space Artemis and Mars missions. The SLS Block 1B will retain the core stage and solid rocket boosters from Block 1, but replace the interim cryogenic propulsion stage (ICPS) with the Exploration Upper Stage (EUS). The Block 1 ICPS uses one RL-10 engine with 25,000 pounds of thrust, whereas the EUS on Block 1B will have four RL-10 engines with a total of 97,000 pounds of thrust, which will increase the amount of mass the SLS Block 1B can deliver to the moon and other destinations.

Source: NASA. | GAO-21-306

FORMULATION

- **Continued from SLS program** Formulation start
- **11/16** Preliminary design review
- **01/21 GAO review**
- **09/21** Project confirmation

IMPLEMENTATION

- **Summer 2022** Critical design review
- **TBD** System integration review
- **Fiscal year 2026** Target launch readiness date

TBD = Date to be determined

PROJECT INFORMATION

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

Mission Duration: **Varied based on destination**

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

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

Next Major Project Event: **Key decision point C (September 2021)**

CURRENT STATUS

The SLS Block 1B project completed its preliminary design review (PDR) in November 2016, and at that time, the design was based on a non-lunar mission, whereas the current design is for a lunar mission. According to program officials, the SLS program conducted a critical design review (CDR) for one component of the Block 1B—the Exploration Upper Stage (EUS)—in December 2020. At this EUS CDR, NASA reviewed design changes for the entire Block 1B vehicle including maturation of adapter designs and overall vehicle lift performance since the change to a lunar mission for the EUS. To satisfy the EUS CDR success criteria, the program must implement corrective actions to address discrepancies and comments documented during the review. These corrective actions are scheduled for completion through at least December 2021. NASA plans to complete a CDR in summer 2022.

NASA has not established preliminary cost and schedule estimates or a baseline for the SLS Block 1B project. Program officials stated it has been too difficult to complete a baseline with the uncertainty surrounding the schedule for the first launch of Block 1B and whether that flight would be crewed or uncrewed. For example, during a 10-month period from fall 2019 through summer 2020, NASA developed four different flight schedules. Each flight schedule contained different dates for Artemis missions and varying plans for the use of future SLS Block 1B capabilities. In June 2020, NASA released a new Artemis flight schedule that calls for the first SLS Block 1B mission to be a crewed mission in March 2026. However, in December 2020, the Consolidated Appropriations Act, 2021, stated that it provided not less than $400 million to support an SLS Block 1B mission available to launch in 2025.

The SLS program is actively working on maturing designs without agreements on the resources and time frames needed to complete the effort. In December 2020, we recommended that NASA establish a cost and schedule baseline for the SLS Block 1B as soon as practicable in advance of critical design review.[1] NASA concurred with this recommendation and stated that the agency expected to establish baselines for major capability upgrades over $250 million, including the SLS Block 1B, by September 2021.

PROJECT OFFICE COMMENTS

SLS Block 1B project officials said that despite dynamic requirements, mission objectives and dates, the SLS program is on target to submit a SLS Block 1B agency baseline commitment as planned by September 2021. Officials stated that the baseline will be informed by the planning, programming, budget, and execution process for fiscal year 2023, internal Center reviews, and the initial SLS Block 1B Joint Confidence Level assessment. They also provided technical comments, which were incorporated as appropriate.

[1]GAO, *NASA Human Space Exploration: Significant Investments in Future Capabilities Require Strengthened Management Oversight*, GAO-21-105 (Washington, D.C.: Dec. 15, 2020).

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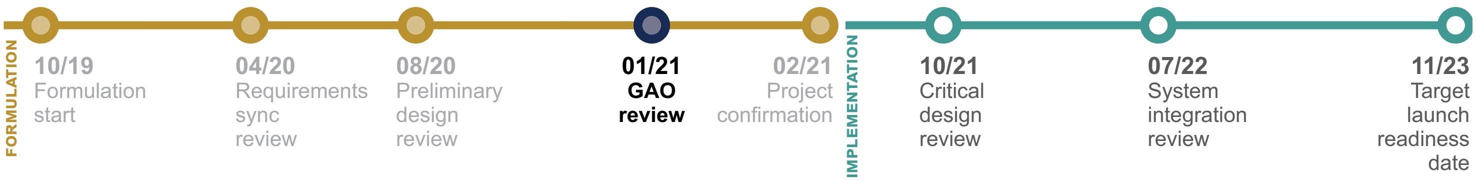
Volatiles Investigating Polar Exploration Rover

The Volatiles Investigating Polar Exploration Rover (VIPER) will be a rover that aims to understand how much water is on the moon and where it is located, among other things. The VIPER project plans to use the rover's three spectrometers and a 1-meter drill with temperature sensors to accomplish these goals. NASA plans for the scientific data that VIPER collects to inform the first global water resources map of the moon and to inform Artemis III lunar landing site decisions. The VIPER project is continuing to advance development of the rover started under the canceled Resource Prospector project, which was planned as a shorter mission to excavate volatiles such as hydrogen, oxygen, and water from the moon.

Source: NASA. | GAO-21-306



PROJECT INFORMATION

NASA Lead Center: **Ames Research Center**

International Partner: **N/A**

Launch Location: **To be determined**

Launch Vehicle: **Commercial Lunar Payload Services (CLPS) Provided – To be determined**

Mission Duration: **3 Earth Months (~100 days)**

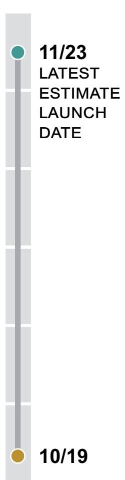
Requirement Derived from: **2013 Planetary Decadal Study**

Budget Portfolio: **Science, Planetary Science**

PROJECT SUMMARY

VIPER project officials told us that the project has a preliminary life cycle cost of $378.5 million as of the preliminary design review. However, project officials said this estimate does not include the cost to transport VIPER to the lunar surface or development work completed under a prior project. It also does not include any potential headquarters-held cost reserves that NASA may add in the future. NASA awarded a contract to Astrobotic—a Commercial Lunar Payload Services (CLPS) provider—to provide end-to-end commercial payload services, which will require both a lander and the launch vehicle for VIPER, between Earth and the lunar surface. The VIPER project faces a risk that it may have to redesign its rover if Astrobotic's lander cannot accommodate the rover as designed, which could result in cost overruns or schedule delays. Officials said it will become more difficult for the VIPER project to accommodate design changes after critical design review, which is planned for October 2021.

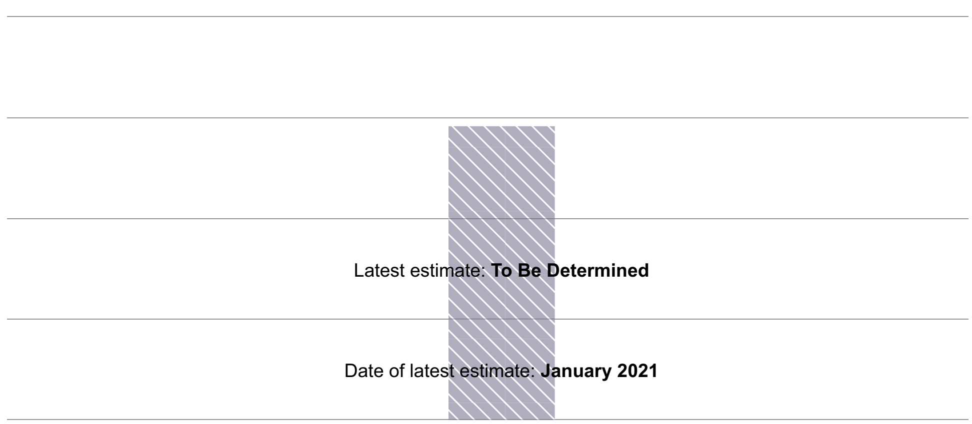
PRELIMINARY SCHEDULE



LATEST ESTIMATE
JAN. 2021

PRELIMINARY COST

then-year dollars in millions



Cost and Schedule Status

Project officials told us that the project has a preliminary life cycle cost of $378.5 million as of the preliminary design review, but the estimate was not documented at a key decision point B review. NASA's project management guidance does not require this review for research and technology projects. According to officials, this preliminary estimate does not include the following: $90.6 million in funding used for prior development work under the Resource Prospector project, any headquarters-held cost reserves that may be added in the future, and the costs for VIPER's landing and launch vehicles. Project officials stated that the prior development work costs are not included because the scope of the project has significantly changed from what was planned for Resource Prospector. In addition, the estimate does not include funding provided through CLPS, which is a partnership between NASA and the U.S. commercial space industry. In June 2020, NASA awarded a contract valued at $199.5 million to Astrobotic—a CLPS provider—to provide end-to-end commercial payload services between Earth and the lunar surface that will deliver VIPER to the moon's South Pole in late 2023. According to project officials, the mission directorate is accounting for these costs under CLPS.

According to officials, the project experienced schedule delays and cost effects due to COVID-19. The delays have not yet affected the project's overall schedule, but the project has experienced $10 million in cost effects. The schedule delays are due to COVID-19-related supply chain disruptions, which delayed deliveries of VIPER flight and engineering development unit cameras and command and data handling hardware. Project officials said that the cost effects stem from higher labor costs across the aerospace industry and due to NASA facility closures limiting the number of employees able to work onsite at a given time.

Design

The project is tracking a risk that it may have to redesign its rover if Astrobotic's lander cannot accommodate the rover as designed, which could result in cost overruns or schedule delays. Astrobotic is maturing its lander design independently from NASA maturing its VIPER rover design. Project officials said there are technical and programmatic challenges inherent in integrating the two different systems to execute a single mission. Officials said they will work with Astrobotic and the Science Mission Directorate to address this risk as the project continues to mature its design, but it will become more difficult to accommodate design changes after critical design review, planned for October 2021. The project is surveying its current rover design in preparation for the possibility of design changes.

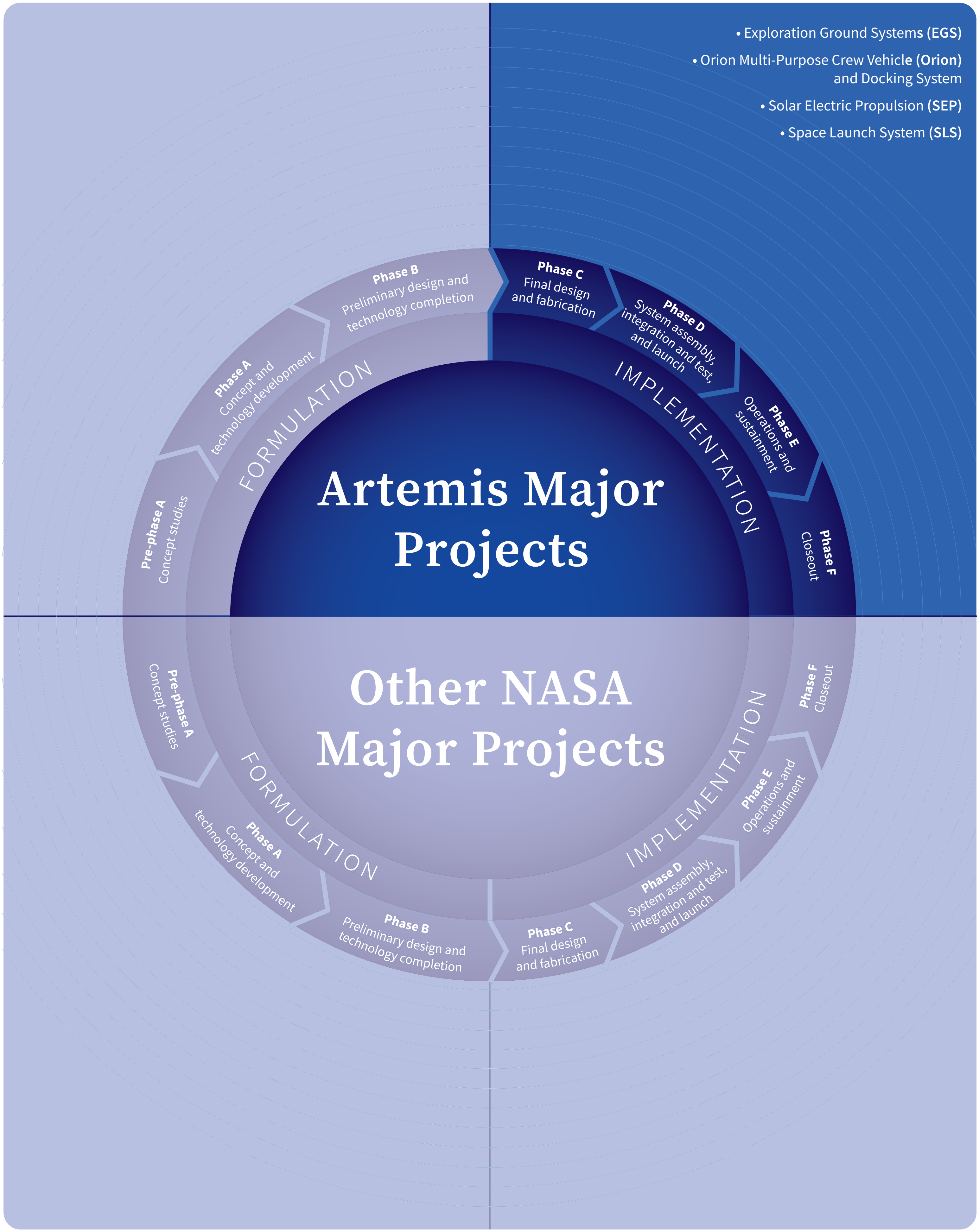
The VIPER project is also tracking a mass growth risk as it balances CLPS mass constraints with changes in mission requirements from Resource Prospector to VIPER. VIPER's requirements include ensuring the rover can survive a 100-plus-day mission and a lunar night, which according to project officials, will require a bigger battery system and chassis than what the project planned under Resource Prospector. There is a possibility that design changes driven by Astrobotic's lander design could result in future mass growth and schedule delays to accommodate redesigns. The VIPER project is currently pursuing mass reduction efforts.

Technology

The VIPER project matured its four critical technologies—which are the rover's instruments—to technology readiness level 6 by its preliminary design review in August 2020. Our best practices work has shown that maturing technologies by this review can minimize risks for the systems entering product development. Project officials noted that they would mature these technologies to technology readiness level 9 by launch because the instruments will fly on other missions to the lunar surface before VIPER's launch.

PROJECT OFFICE COMMENTS

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


• Exploration Ground Systems (EGS)
• Orion Multi-Purpose Crew Vehicle (Orion) and Docking System
• Solar Electric Propulsion (SEP)
• Space Launch System (SLS)
Artemis Major Projects
FORMULATION
IMPLEMENTATION
Pre-phase A Concept studies
Phase A Concept and technology development
Phase B Preliminary design and technology completion
Phase C Final design and fabrication
Phase D System assembly, integration and test, and launch
Phase E Operations and sustainment
Phase F Closeout
Other NASA Major Projects
FORMULATION
IMPLEMENTATION
Pre-phase A Concept studies
Phase A Concept and technology development
Phase B Preliminary design and technology completion
Phase C Final design and fabrication
Phase D System assembly, integration and test, and launch
Phase E Operations and sustainment
Phase F Closeout

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Exploration Ground Systems

The Exploration Ground Systems (EGS) program is modernizing and upgrading the 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). Additionally, EGS is responsible for recovering Orion. The EGS program consists of several major construction projects of facilities and ground support equipment including the Mobile Launcher, Crawler Transporter, Vehicle Assembly Building (pictured at left), and Launch Pad 39-B, all of which need to be completed before the first uncrewed exploration mission, Artemis I.

Source: NASA. | GAO-21-306

PROJECT INFORMATION

NASA Lead Center: **Kennedy Space Center**

International Partner: **None**

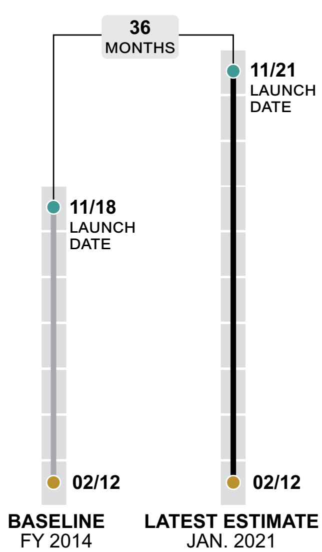
Requirement Derived from: **NASA Authorization Act of 2010**

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

PROJECT SUMMARY

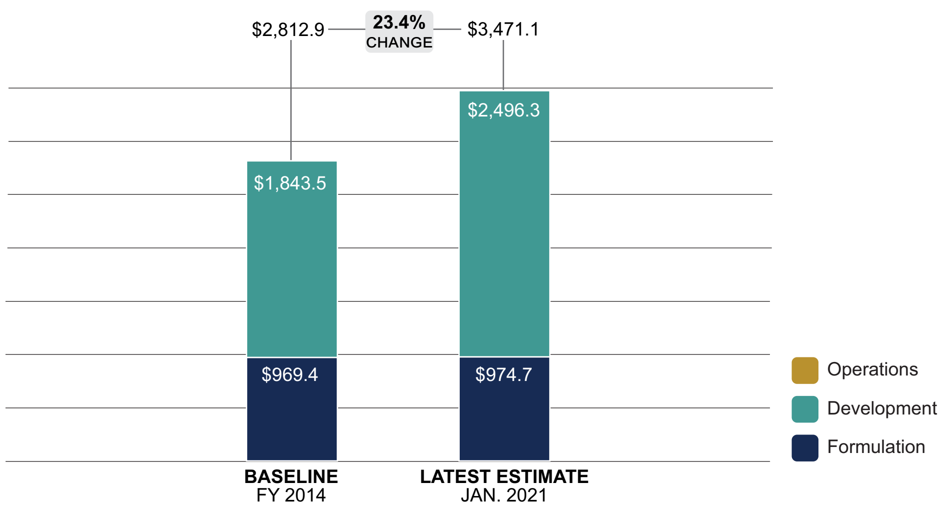
In June 2020, NASA established new cost and schedule estimates for the EGS program, but costs have increased since that rebaseline and the new launch date is at risk. The new baseline increased the program's life-cycle cost 21.3 percent to about $3.4 billion and commits to a launch date in November 2021, but development costs have increased an additional $58 million due to COVID-19 and additional repairs to the Mobile Launcher. This is the second time NASA notified Congress of a change to the Artemis I launch date, for a cumulative delay of 36 months. However, due in part to COVID-19, manufacturing delays, and remaining risks, the program is at risk of not meeting this new launch date. The program has identified the learning curve related to first time assembly and processing of the Artemis I vehicles during integrated operations as its top remaining risk.

SCHEDULE PERFORMANCE



COST PERFORMANCE

then-year dollars in millions



Cost and Schedule Status

In June 2020, NASA rebaselined the EGS program; however, development costs have increased further, and the new schedule is already at risk. The revised baseline increased the program's life cycle cost 21.3 percent to $3.4 billion and commits to a launch readiness date in November 2021. NASA completed the analysis to inform the new launch date and associated cost estimates during the initial stages of COVID-19, and, as a result, the new commitments did not reflect any cost or schedule effects experienced to date from COVID-19. Since the June 2020 rebaselining, the EGS program has reported a $58 million cost increase, for a total of 23.4 percent cost growth over the project's baseline. The more recent cost increase is associated with software delays, reinforcing portions of the Mobile Launcher 1, and COVID-19 effects that were not anticipated at the time of the rebaselining.

This is the second time NASA notified Congress of a change to the Artemis I launch date for a cumulative 36 months of delays. While the SLS core stage manufacturing challenges and testing delays remain the critical path to the Artemis I date, the EGS program also experienced delays during this time developing facilities, ground support equipment, and software.

Due to COVID-19 and delays in core stage testing including technical issues that affected hardware deliveries, the November 2021 launch date is at risk. According to EGS officials, the program completed a schedule analysis that, when accounting for risks, indicated the program will need 10 months to prepare for launch once the SLS core stage arrives at Kennedy Space Center. For example, at the time of our review, the EGS program's risk-informed estimates indicated Artemis I could launch in late 2021 to early 2022. The actual launch date, however, may be sooner or later depending on the extent to which the risks in the schedule analysis are realized. In addition, EGS program officials stated that the time line could lengthen if the SLS program transfers additional core stage work for completion at Kennedy Space Center.

Integration and Test

According to program officials, the EGS program has one System Acceptance Review/Operational Readiness Review remaining, which is intended to ensure the ground systems, hardware, software, procedures, and processes are in place to support integrated testing, pad, and landing and recovery operations. The program had planned to conduct this review in December 2020, but delayed the date of the review to spring 2021 to better align with the new anticipated delivery date of the core stage to Kennedy Space Center.

The program is also working to mitigate schedule risk associated with the learning curve related to first time assembly and processing of the Artemis I vehicles during integrated operations. The program plans to mitigate this risk by providing opportunities for EGS personnel to become familiar with the operation of support systems and simulated flight hardware interfaces. The program considers this its top remaining risk.

Software

COVID-19 related software development delays are responsible for $25 million of the EGS program's $58 million cost growth since the program was rebaselined in June 2020. According to program officials, the pace of software testing was slowed because several software testing facilities were closed due to COVID-19 and social distancing restrictions were implemented to ensure a safe working environment. Nevertheless, in spring 2020, the EGS program completed development of the Ground Flight Application Software, which will interface with flight and ground systems. In addition, according to EGS officials, the program completed the last design certification review in February 2021, which certifies that the software meets Artemis I requirements of the Spaceport Command and Control System, which will operate and monitor ground equipment.

PROJECT OFFICE COMMENTS

EGS project officials said that the project is making excellent progress towards the launch of Artemis I. They said that EGS is preparing the Orion space capsule for flight, that all 10 segments of the two SLS solid rocket boosters are fully stacked on the mobile launcher and ready for further integration and testing with other flight components, and the team is preparing to receive the SLS core stage. Officials also provided technical comments on a draft of this assessment, which were incorporated as appropriate.

Orion Multi-Purpose Crew Vehicle

The Orion Multi-Purpose Crew Vehicle (Orion) is being developed to transport and support astronauts beyond low-Earth orbit and will launch atop NASA's Space Launch System (SLS). 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-21-306

- 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
- **01/21 GAO review**
- 11/21 First uncrewed flight launch readiness date
- 08/23 First crewed flight committed launch readiness date

PROJECT INFORMATION

NASA Lead Center: **Johnson Space Center**

International Partner: **European Space Agency**

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

Launch Vehicle: **Space Launch System**

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

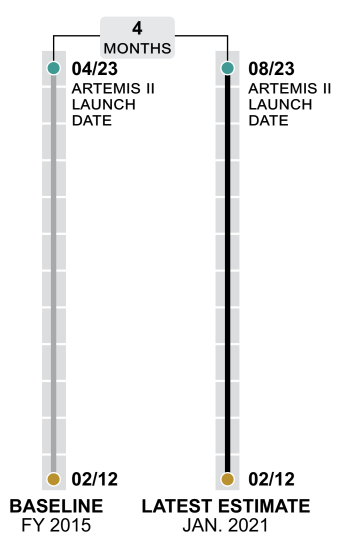
Requirement Derived from: **NASA Authorization Act of 2010**

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

PROJECT SUMMARY

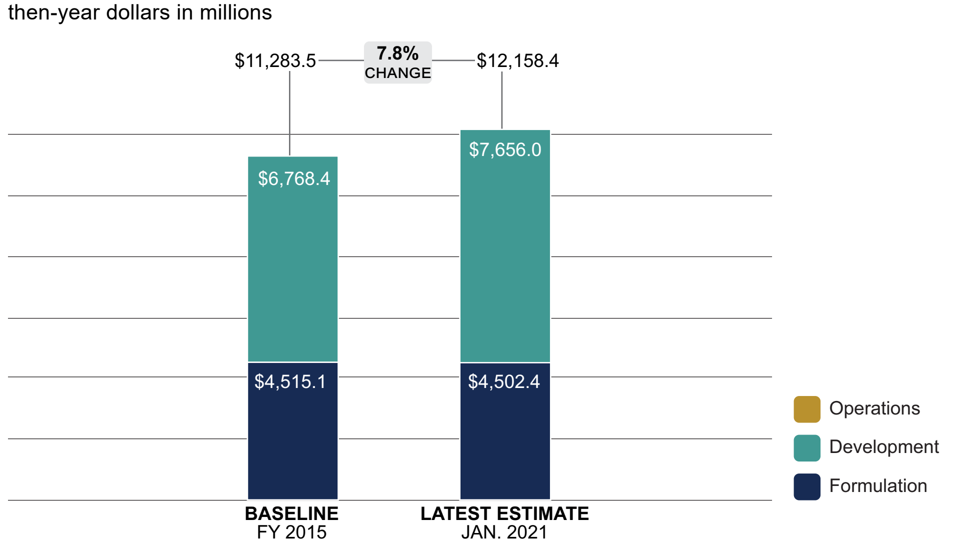
The Orion program exceeded its cost baseline and is now projected to slip past its schedule baseline. The program's development costs have increased by approximately $888 million or 13.1 percent. Due to continued delays to the Artemis I mission and production issues with the Artemis II spacecraft, the Orion program now projects that it cannot support an Artemis II launch until August 2023—4 months after the committed baseline Artemis II launch date of April 2023. In November 2020, NASA discovered a malfunctioning power and data unit on the Artemis I spacecraft, and officials said that further investigation revealed that a capacitor on the failed communications card in the malfunctioning power and data unit was installed backwards. Officials told us the program has decided it can proceed without replacing the unit because it is part of a redundant system and does not affect flight operations.

SCHEDULE PERFORMANCE



COST PERFORMANCE

then-year dollars in millions



Cost and Schedule Status

The Orion program's development costs have increased by approximately $888 million or 13.1 percent. According to the program, the increase was due in large part to European Service Module (ESM) delays and contractor performance. For example, the Orion program experienced delays resulting from issues encountered during the ESM propulsion system testing, the need to redesign the ESM power system components, and component design issues with the Crew Module avionics systems. In addition, program officials told us that they have had supply chain issues with valves required for both the crew and service modules.

Orion is now projecting that it will launch 4 months later than its schedule baseline and has no schedule margin to meet the new August 2023 launch date for Artemis II. Continued delays to the Artemis I mission and production issues for the Artemis II spacecraft are driving this delay. NASA plans to reuse some avionics from the Artemis I crew module, including GPS receivers and antennas, on the Artemis II crew module. In June 2020, NASA postponed the Artemis I mission 17 months to November 2021, primarily due to program delays and remaining schedule risk to integration and testing of the three systems—SLS, Exploration Ground Systems (EGS), and Orion. According to program officials, NASA will require a minimum of 20 months to refurbish and install the reused components, complete the crew and service module, and complete the EGS prelaunch processing activities.

Program officials stated that COVID-19 has led to further delays as the production of the ESM for Artemis II has been hampered by late deliveries of redesigned pressure control valves. Since the Orion program has no schedule margin to the new launch date, any further production or testing delays will likely result in additional schedule delays to the Artemis II mission.

Since the program's development costs increased by more than 5 percent, the program will complete an updated joint cost and schedule confidence level analysis at its key decision point D review—which initiates the system assembly, integration and test, and launch phase—scheduled for fall 2021.[1] This analysis will help inform the extent to which the Artemis II mission is delayed and the associated costs of those delays.

Integration and Test

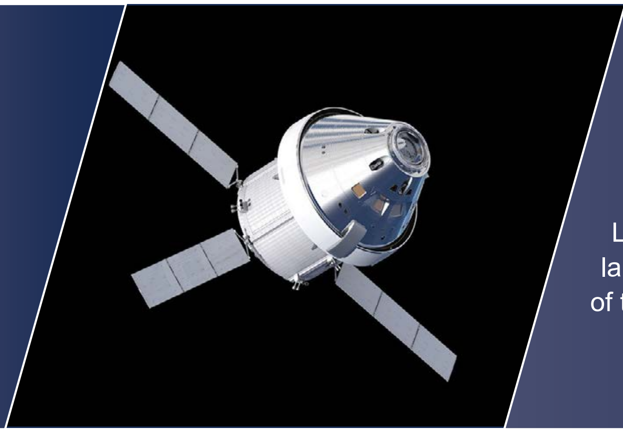
In November 2020, the Orion program identified an issue with a power and data unit on the Artemis I spacecraft, and officials said that further investigation revealed that a capacitor on the failed communications card in the malfunctioning power and data unit had been installed backwards. However, according to program officials, the program has decided to fly Artemis I with the malfunctioning unit and delivered the spacecraft to the EGS program in January 2021 for ground processing and integration. Program officials said that this unit is part of a redundant system and does not affect flight operations. Further, their investigations found that replacing the malfunctioning unit was actually riskier than flying the spacecraft with it due to the work required to access the unit.

Final integrated testing with SLS and EGS is the remaining testing for the Orion vehicle prior to the Artemis I launch. Our prior work has shown this phase of the acquisition process often reveals unforeseen challenges leading to cost growth and schedule delays.

PROJECT OFFICE COMMENTS

When commenting on a draft of this assessment, Orion project officials said that they continue to make excellent progress on delivering Orion spacecraft to support the Artemis missions despite the challenging COVID-19 situation over the last year. They said that the Artemis I spacecraft has been successfully turned over for ground processing. They also said the Artemis II spacecraft assembly is underway, and they anticipate the arrival of the European Service Module-2 this summer.

[1]National Aeronautics and Space Administration, NASA Interim Directive 7120.122, *Joint Cost and Schedule Confidence Level (JCL) Requirements Updates* requires another JCL at Knowledge Point D for programs with a life cycle cost of $1 billion or more that exceed their developmental cost baseline by 5 percent.



Orion Docking System

The Orion Docking System will enable the Orion Multi-Purpose Crew Vehicle (Orion) to dock with future lunar capabilities such as Gateway and the Human Landing System. This system will support Artemis III, NASA's crewed lunar landing planned for 2024. The Orion program plans to use a modified version of the existing NASA docking system used for the International Space Station.

Source:NASA. | GAO-21-306

FORMULATION

Continued from Orion program
Formulation start
System requirements/ mission definition review

04/20 Preliminary design review

01/21 GAO review

IMPLEMENTATION

Summer 2021 Critical design review

09/24 Target launch readiness date

PROJECT INFORMATION

See Orion Multi-Purpose Crew Vehicle assessment for project information.

CURRENT STATUS

NASA has not established a cost or schedule commitment for the Orion Docking System but plans to incorporate estimates as part of an upcoming update to the Orion program baseline. In December 2020, we recommended that NASA establish a cost and schedule baseline for the Docking System as soon as practicable in advance of critical design review.[1] NASA concurred with this recommendation. In January 2021, NASA told us that rather than establish separate cost and schedule baselines for the Orion Docking System, NASA will add the Docking System to the Orion program's baseline as part of that program's ongoing key decision point D review. NASA expects to complete that review in the fall of 2021. Officials further stated that the Docking System is a critical subsystem, and an evolution of existing technologies and capabilities that is being managed and integrated as part of the overall vehicle like all other subsystems. The Docking System was not part of the original Orion baseline established through the Artemis II mission and will not be used for docking operations until the Artemis III mission.

The Orion Docking System uses heritage components and software, including the docking mechanism, developed for the International Space Station. The Docking System's preliminary design review was in April 2020. At the time, the program was tracking one risk that the Docking System would possibly exceed mass restrictions by about 500 pounds, potentially affecting the ability to support all mission objectives. The Orion program is exploring ways to mitigate this risk.

According to program officials, to reduce risk for Artemis III, NASA intends to demonstrate proximity operations on the Artemis II crewed test flight. This demonstration will not include the full Docking System and will use the expended Interim Cryogenic Propulsion Stage (ICPS) as a target. The astronauts will pilot Orion to line up with the ICPS and assess Orion's handling characteristics. The demonstration will provide performance data and operational experience that cannot be readily gained on the ground in preparation for Artemis III.

PROJECT OFFICE COMMENTS

When commenting on a draft of this assessment, Orion program officials said that NASA is making excellent progress on the development and build of the Orion Docking System. They also provided technical comments, which were incorporated as appropriate.

[1]GAO, *NASA Human Space Exploration: Significant Investments in Future Capabilities Require Strengthened Management Oversight*, GAO-21-105 (Washington, D.C.: Dec. 15, 2020).

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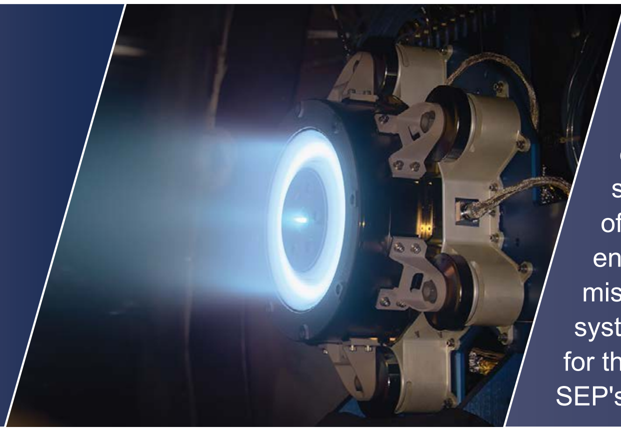
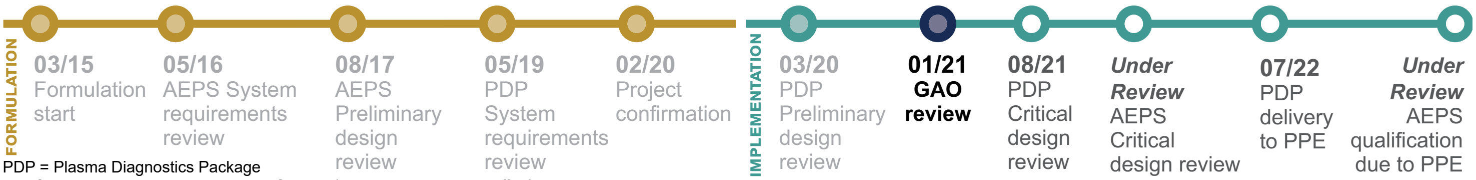


Solar Electric Propulsion

The Solar Electric Propulsion (SEP) project aims to develop high power electric propulsion technologies for NASA exploration and empower the U.S. space industry. By augmenting propellant with energy from the Sun, the mass of the propulsion system and amount of propellant can be reduced. This can enable spacecraft weight reduction and enable high-fuel-efficient spaceflight missions beyond low-Earth orbit compared to conventional chemical propulsion systems. SEP's advanced electric propulsion thruster is a critical technology for the Power and Propulsion Element (PPE). NASA also plans to demonstrate SEP's plasma diagnostics package on PPE.

Source: NASA. | GAO-21-306



PDP = Plasma Diagnostics Package
AEPS = Advanced Electric Propulsion System (now the thruster-only effort) PPE = Power and Propulsion Element

PROJECT INFORMATION

NASA Lead Center: **Glenn Research Center**

International Partner: **None**

Launch Location: **Kennedy Space Center, FL (with PPE)**

Launch Vehicle: **Falcon Heavy (with PPE)**

Mission Duration: **15 years (with PPE)**

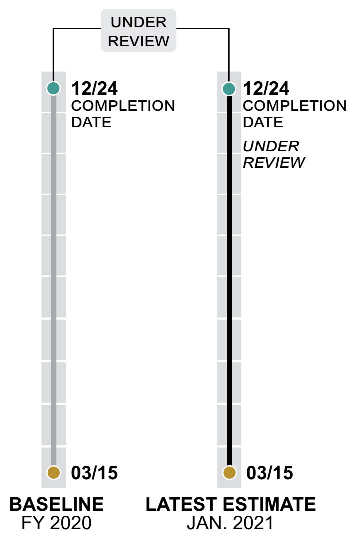
Requirement Derived from: **2018 Strategic Objectives 2.2, 3.1, 4.2**

Budget Portfolio: **Exploration Technology, Technology Demonstration, Exploration Research and Development**

PROJECT SUMMARY

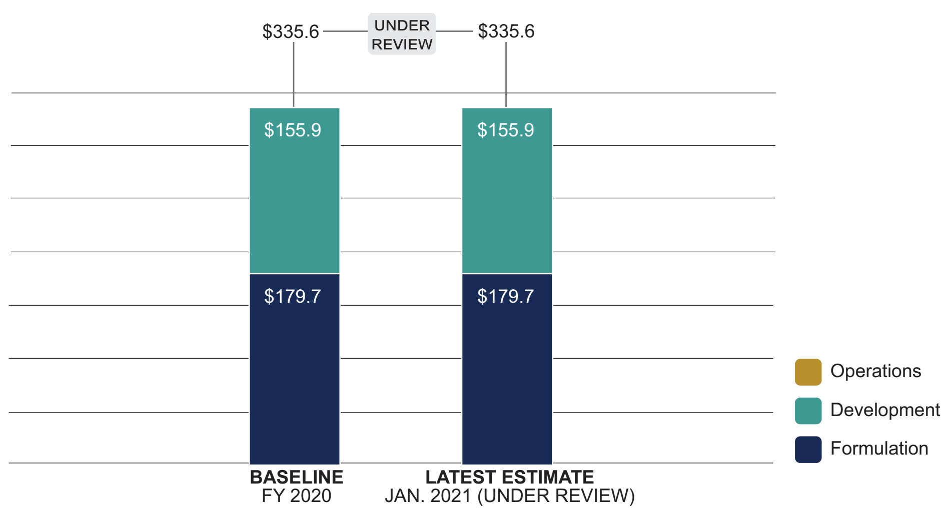
The SEP project is revising its cost and schedule baselines due to project changes related to NASA's decision to launch PPE and the Habitation and Logistics Outpost (HALO) on the same launch vehicle, known as a co-manifested launch. Instead of developing and qualifying the advanced electric propulsion system for this launch, the project will only develop and qualify the thrusters. Additionally, the PPE project will provide three flight thrusters of this design to the PPE contractor as government furnished equipment, according to project officials. According to NASA, SEP's top risk is that the PPE project may add requirements for the thrusters that are beyond SEP's revised baselines and may result in significant schedule delays or cost increases.

SCHEDULE PERFORMANCE



COST PERFORMANCE

then-year dollars in millions



Cost and Schedule Status

The SEP project is revising its cost and schedule baselines due to project changes related to NASA's decision to launch PPE and the HALO—the Gateway's crew module—as a co-manifested launch. Instead of developing and qualifying the advanced electric propulsion system, the project will only develop and qualify the thrusters. NASA officials said that the electric propulsion system was rescoped to a thruster-only effort because of continued poor contractor performance and because PPE only needed the thrusters. For example, NASA officials said they determined to descope the power processing unit subsystem because it was too high risk to continue its development. Further, as part of a risk mitigation activity, NASA officials stated they had another contractor developing a simpler, lower-risk unit that would meet PPE's needs. The SEP project expects to revise its baselines in spring 2021 after it awards the contract for the thruster-only development effort. The revised baselines will also include delivering a plasma diagnostics package to PPE as government furnished equipment, which will characterize high power electric propulsion system performance in space.

NASA officials said that the co-manifested vehicle is nearly double the mass of PPE alone, which increases the performance requirements for the thrusters. As a result, PPE officials said that there are no alternative thrusters available to the ones that will be provided by SEP, and a third thruster was needed. The project plans to baseline the flight thrusters no earlier than fall 2021. Project officials said that they plan to qualify the thruster under the development contract and build the flight units concurrently. Officials further explained that the PPE project is responsible for providing the three flight thrusters to the PPE contractor as government furnished equipment. This effort will be funded by the Human Exploration and Operations Mission Directorate.

The project reported that upcoming milestones are at risk of being delayed due to increased workload related to the project's rescope. These milestones include the upcoming review to revise project baselines and awarding the flight thruster effort. SEP has hired additional project management and acquisition staff to mitigate this risk.

Technology and Design

The project continues to develop the thrusters, but the critical design review date is in flux until the project revises its baselines and technical requirements. NASA has reduced the SEP project's requirements by half as a result of the project changes, including new PPE requirements. Project officials said that the thruster's technical complexity remains about the same, but the new PPE requirements have significant schedule effects. For example, project officials said that they will have to revisit testing and analyses that they have already completed. SEP's top risk is that the PPE project may add requirements for the thrusters that are beyond SEP's revised baselines and may result in significant schedule delays or cost increases.

The project is tracking an issue regarding a requirement to reduce the mass of the plasma diagnostics package due to the co-manifested launch, which could affect the reliability of the system. While project officials said that they were evaluating opportunities to reduce mass, these efforts were complicated by one of the package's subsystems being relocated on the PPE spacecraft due to mission needs. In December 2020, the project reported that it is pursuing an alternative design of this subsystem, which meets all PDP science and mass requirements, but will slightly lower the reliability of the system and increase the amount of ground data post-processing.

Other Issues to Be Monitored

In August 2020, the two NASA directorates that manage the SEP and PPE projects agreed to a governance structure that formally aligns the SEP project with the PPE mission. It states that, while SEP is responsible for implementing and verifying all thruster requirements, the PPE project must concur with the verification methods and data. It also outlines how the SEP project is to handle issues that affect its cost, schedule, or technical baselines, including which issues are to be elevated to the PPE project.

PROJECT OFFICE COMMENTS

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

Space Launch System

The Space Launch System (SLS) is intended to be NASA's first human rated heavy-lift vehicle designed for deep space operations. NASA plans to launch its Orion Multi-Purpose Crew Vehicle (Orion) spacecraft and other systems on SLS on missions between the Earth and moon and to enable deep-space missions, including to Mars. NASA is designing SLS to provide an initial lift capability of 95 metric tons to low-Earth orbit and be evolvable to accommodate heaver payloads up to 130 metric tons for deep space missions. The 95-metric ton capability will include a core stage powered by four RS-25 engines and two boosters. The 130-metric ton capability will include the new Exploration Upper Stage and evolved boosters.

Source: NASA. | GAO-21-306

FORMULATION
- 11/11 Formulation start
- 05/12 System Requirements Review / System Defnition Review
- 07/13 Preliminary design review
- 08/14 Project confirmation

IMPLEMENTATION
- 07/15 Critical design review
- 06/17 System integration review
- **01/21 GAO review**
- 11/21 Committed launch readiness date

INFORMATION

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

International Partner: **None**

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

Launch Vehicle: **N/A**

Mission Duration: **Varied based on destination**

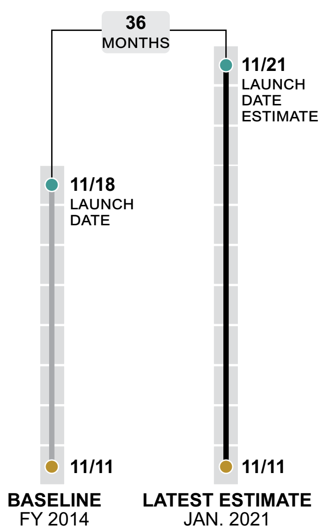
Requirement Derived from: **NASA Authorization Act of 2010**

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

PROJECT SUMMARY

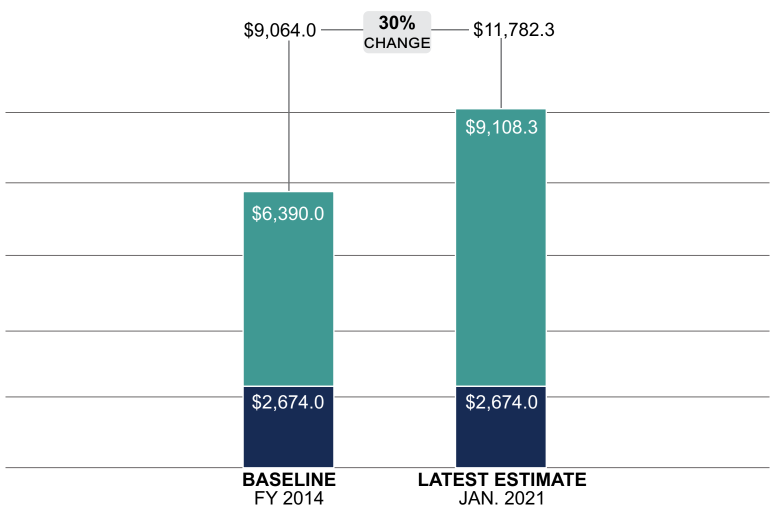
In June 2020, NASA rebaselined the SLS program, but the new schedule is already at risk. The new baseline increases the program's life cycle cost by 30 percent from $9,064 million to $11,782 million and commits to a launch readiness date in November 2021. NASA attributes the most recent increased development costs for the SLS program to the longer time frames caused by the delayed launch readiness date. In addition, the revised estimate reflects increased costs from a recent contract renegotiation with the SLS core stage contractor. In January 2021, the program attempted the first hot fire test of the SLS core stage—a test intended to validate the performance of the integrated core stage—but software halted the test early when the pressure on the system used to pivot one of the engines dropped just below the test parameters. The SLS program and Boeing analyzed the test results and determined that a second hot fire test should be conducted. The second hot fire test was scheduled for late February 2021 but was delayed to March 2021 because the program had to repair a valve. According to NASA officials, the second attempt was successful.

SCHEDULE PERFORMANCE



COST PERFORMANCE[a]

then-year dollars in millions



[a]When NASA rebaselined the SLS program in June 2020, it reduced the cost baseline by $631 million to account for development work that was moved to flights beyond Artemis I.

Cost and Schedule Status

In June 2020, NASA rebaselined the SLS program, but the new schedule is already at risk. The new baseline increases the program's life cycle cost by 30 percent from $9,064 million to $11,782 million and commits to a launch readiness date in November 2021. This is the second time NASA notified Congress of a change to the Artemis I launch date for a cumulative delay of 36 months from the original launch date. NASA attributed the initial delay to the complexity of first-time manufacturing, assembly of the core stage, and unforeseen technical issues.

NASA attributes the most recent increased development costs for the SLS program to the longer time frames caused by the delayed launch readiness date. In addition, in January 2020, NASA completed a contract renegotiation with the SLS core stage contractor, Boeing, after both determined Boeing was going to exceed the cost-reimbursement contract's not-to-exceed estimated total cost. The increased costs are also reflected in this new SLS cost estimate. Finally, as part of this rebaseline, NASA removed $631 million from the original SLS baseline to adjust for scope that was moved from the Artemis I mission to later missions and in response to a recommendation we made in 2019.[1]

However, NASA completed the analysis to inform the new launch date and associated cost estimates during the initial stages of COVID-19. As a result, the new commitments do not reflect any cost or schedule effects experienced to date from COVID-19. Subsequently, the program has also experienced testing delays related to weather and technical issues that have increased risk on the new launch date.

Integration and Test

In January 2021, the program attempted the first hot fire test of the SLS core stage—a test intended to validate the performance of the integrated core stage—but software halted the test about 67 seconds into the planned 500-second duration. Program officials indicated that the hardware and software worked well through cryogenic loading, ignition, and the first portion of the test. As part of the test, however, the SLS program intended to pivot the engines at a rate higher than they will encounter during actual flight—program officials indicated they were pivoting the engines at a rate of 10 degrees per second versus the in-flight maximum of 6 degrees per second. During this exercise, the pressure on the system used to pivot one of the engines dropped just below the test parameters, which triggered a shutdown of the test.

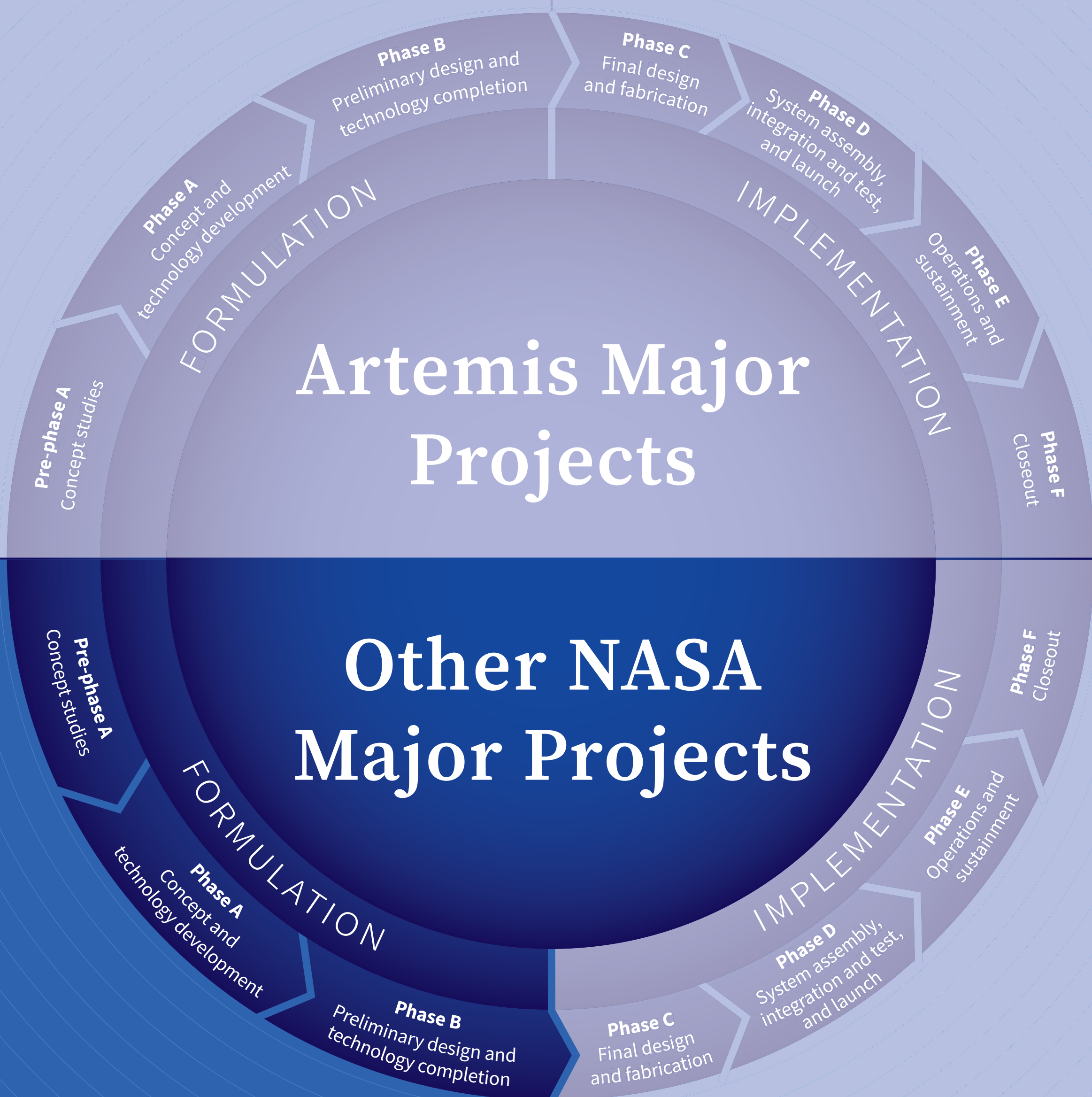
The SLS program and Boeing analyzed the test results and determined that a second hot fire test should be conducted to verify that the core stage is ready for flight. Officials stated that the second test in March 2021 was a success after being delayed from late February, because the program had to repair a valve in the propulsion system. Officials said that during the test, all planned timeline objectives were completed.

These delays are likely to further affect the Artemis I launch date. Exploration Ground Systems (EGS) officials indicated that delivery of the SLS core stage past January 2021 could affect the Artemis I launch date. This is because it would reduce the schedule margin available to the EGS program to address risks associated with first time integration of SLS, Orion, and the ground systems.

PROJECT OFFICE COMMENTS

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

[1]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).



- Dragonfly
- Electrified Powertrain Flight Demonstration **(EPFD)**
- Interstellar Mapping and Acceleration Probe **(IMAP)**
- Near Earth Object Surveyor **(NEO Surveyor)**
- Polarimeter to Unify the Corona and Heliosphere **(PUNCH)**

Source: GAO analysis of National Aeronautics and Space Administration (NASA) data. | GAO-21-306

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Dragonfly

Dragonfly will explore the 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. It will study chemical components and prebiotic processes needed for the development of life—and what conditions can make a planet or moon habitable—as well as search for evidence of life. This mission is the first time that NASA will fly a multi-rotor vehicle for science on another planet and fly its entire science payload to new places for repeatable and targeted access to surface materials.

Source: Johns Hopkins University Applied Physics Laboratory. | GAO-21-306

FORMULATION
- **06/19** Formulation start
- **08/20** Internal system requirements review
- **01/21 GAO review**
- **TBD** Preliminary design review
- **TBD** Project confirmation

IMPLEMENTATION
- **TBD** Critical design review
- **TBD** System integration review
- **TBD** Target launch readiness date
- **2027** Preliminary launch readiness date

TBD = Date to be determined

PROJECT INFORMATION

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

International Partners: **Centre National d'Etudes Spatiales, Japan Aerospace Exploration Agency, German Space Agency**

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

Launch Vehicle: **To be determined**

Mission Duration: **13 years**

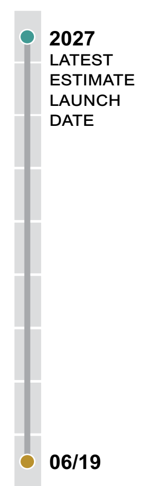
Requirement Derived from: **2011 Planetary Science Decadal Survey**

Budget Portfolio: **Planetary Science**

PROJECT SUMMARY

NASA has not yet approved a preliminary cost and schedule estimate for Dragonfly. In September 2020, NASA directed Dragonfly to start planning for a launch readiness date in 2027 because NASA said it was not possible to fund the project's plan for an earlier launch date due to competing budget priorities. This will require replanning development efforts. Dragonfly is continuing to finalize the designs of its science payload and develop its critical technologies before its preliminary design review. The project is tracking a risk that it may experience delays acquiring Domestic Phenolic-Impregnated Carbon Ablator (PICA-D) material used for its spacecraft thermal protection system. Further, the delayed launch readiness date now means the project may benefit from a heavy-lift class launch vehicle that would allow it to arrive at Titan sooner than the medium-class launch vehicle included in the original design proposal. Such a change would affect the design, and the project is currently evaluating its launch vehicle options.

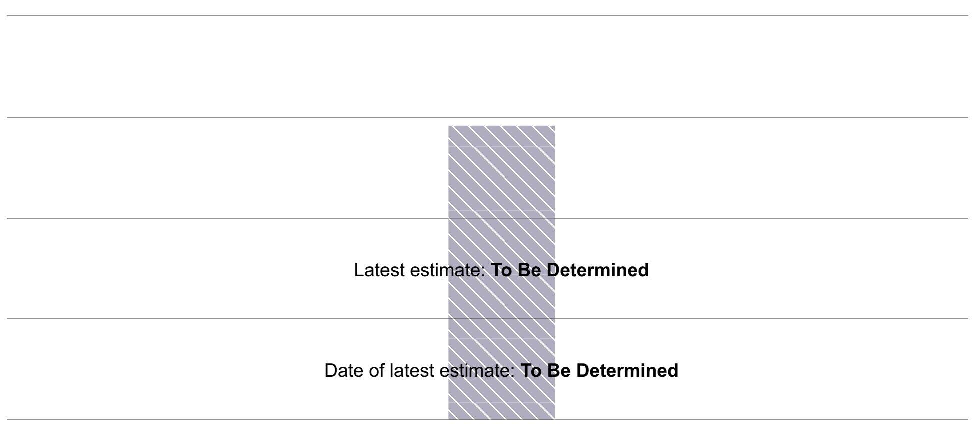
PRELIMINARY SCHEDULE



LATEST ESTIMATE
JAN. 2021

PRELIMINARY COST

then-year dollars in millions



Cost and Schedule Status

Dragonfly entered the preliminary design and technology completion phase in June 2019, but NASA has yet to approve a preliminary cost and schedule estimate for the project. In September 2020, NASA directed Dragonfly to change its launch readiness date from 2026 to 2027 due to an inability to fully fund the project's plan to achieve the earlier launch date. NASA officials noted that the decision to change the launch date was due to a number of factors external to the project including but not limited to the increased pressure on the entire planetary science budget to address cost effects from COVID-19. NASA officials requested that the project submit a revised cost and schedule plan to support a 2027 launch date, which would allow NASA to approve its preliminary cost and schedule estimate. Although the development cost of Dragonfly is cost-capped at $850 million (in 2015 dollars), NASA officials stated they anticipate having to increase the cost cap because NASA directed the project to work toward a later launch date.

Technology and Design

In June 2020, Dragonfly passed its payload system requirements review and is working to mature its critical technologies before its preliminary design review. For example, the project is working to determine if the laser and scroll pump for the Dragonfly Mass Spectrometer (DraMS)—an instrument that will study the chemical complexity and diversity of Titan's solid surface—and the blower motor for the Drill for Acquisition of Complex Organics (DrACO)—an instrument that will deliver surface materials to DraMS for analysis—will work in the Titan environment.

Dragonfly is also tracking several risks that if realized could affect mission success. For example, there is concern that downwash from the lander's rotors and wind on Titan could throw debris on the cameras, obscuring the images on land and in flight. The project is conducting trade studies to improve understanding of the probability of dust collection and to explore possible accommodations.

In addition, the project is tracking the procurement of PICA-D material as one of its top risks. Dragonfly uses PICA-D material in its spacecraft thermal protection system to protect the heatshield from intense heat as it enters into Titan's thick atmosphere. Since there is only a single supplier of PICA-D material, if Dragonfly's PICA-D procurement falls in conflict with another project, it will need to fund early procurement or suffer schedule effects due to late delivery. NASA is working to understand and resolve any conflicts with other projects.

Launch

Uncertainty surrounding the project's launch vehicle could affect the project's design. According to NASA officials, the project could benefit from using a heavy-lift class launch vehicle as it would allow Dragonfly to arrive at Titan almost 3 years earlier, even with a delayed launch. However, in accordance with its original proposal, the project is baselining its design to a medium-lift vehicle, which would allow Dragonfly to arrive at Titan in 2036. In addition, the launch vehicle will need to be nuclear-certified because Dragonfly will use a Multi-Mission Radioisotope Thermoelectric Generator for power. However, of the five candidate launch vehicles, only one is nuclear certified as of August 2020. The project would prefer to have the vehicle selected early in case changes are needed to the design based on the selection. Currently, the project is evaluating its launch vehicle options, which will inform NASA's selection.

PROJECT OFFICE COMMENTS

Dragonfly officials noted that the announcement of opportunity established a cost cap of $850 million in fiscal year 2015 dollars for the project's development and was based on a 2025 launch date. They said that this amount does not include all costs such as international contributions, the launch vehicle, headquarters cost reserves, or other potential science and engineering work. They noted that the revised cost for the 2027 launch date has not yet been formalized, and provided technical comments on a draft of this assessment, which were incorporated as appropriate.

Electrified Powertrain Flight Demonstration

The Electrified Powertrain Flight Demonstration (EPFD) project is a technology demonstration project that will demonstrate through flight and evaluate the performance of high-power hybrid electric propulsion system technologies for commercial aircraft. Incorporating these technologies could lead to lower operating costs, higher fuel efficiency, and reduced noise and emissions for commercial aircraft, among other benefits. The EPFD project intends to reduce risks for key critical technologies as well as address specific gaps in regulations and standards associated with introducing electrified propulsion into commercial aircraft.

Source: NASA. | GAO-21-306

FORMULATION

- **06/20** Formulation start
- **09/20** System requirements review
- **01/21** **GAO review**
- **FY22** Preliminary design review
- **03/22** Project confirmation

IMPLEMENTATION

- **FY22 – FY23** Critical design review
- **06/23** System integration review
- **12/23 – 08/24** Target First Flight for Concept 1 and 2

PROJECT INFORMATION

NASA Lead Center: **Virtual Project Office**

International Partner: **None**

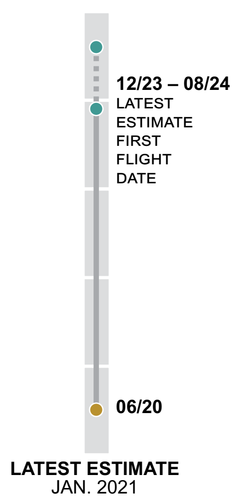
Requirement Derived from: **Aeronautics Research Mission Directorate Strategic Implementation Plan**

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

PROJECT SUMMARY

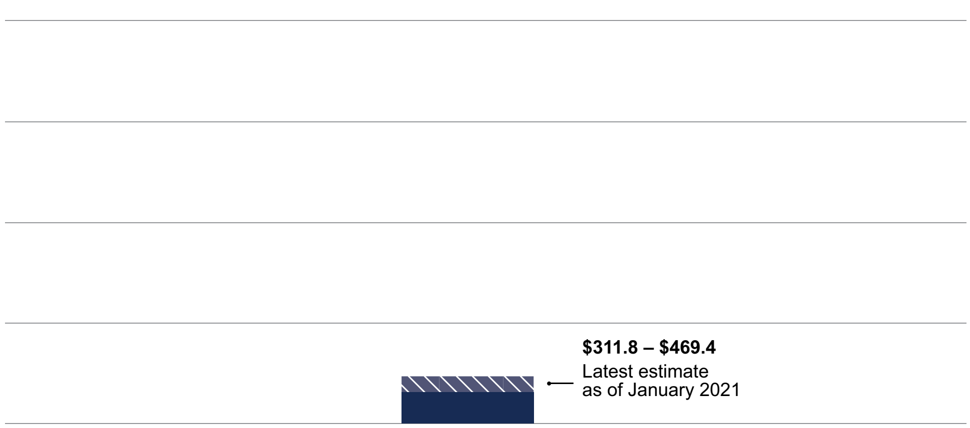
In November 2020, EPFD established a preliminary life-cycle cost estimate range of $311.8 million to $469.4 million and an estimated first flight date range between December 2023 and August 2024. The project expects to award multiple contracts to aviation industry partners in the fourth quarter of fiscal year 2021 and, ultimately, to select at least two partners to conduct two concept flight demonstrations. Following an economic downturn related to COVID-19, the aviation industry reported it lacked sufficient funding for early designs. As a result, project officials said they changed their initial strategy of sharing half of the total contract costs beginning at contract start in favor of waiting for industry's contribution of half the total cost until after critical design reviews. In addition, the project delayed planned dates for the project's preliminary design reviews. Among the project's top risks are future effects of COVID-19 on cost and schedule. The project is also focused on reducing technical risks for key critical technologies—including a battery system that exceeds the performance of any existing battery technologies.

PRELIMINARY SCHEDULE



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.*

Cost and Schedule Status

The EPFD project entered the preliminary design and technology completion phase in November 2020. The project established a preliminary life-cycle cost estimate range of $311.8 million to $469.4 million and an estimated first flight date range between December 2023 and August 2024. The project expects to competitively award multiple contracts for flight demonstrations in the fourth quarter of fiscal year 2021. Officials said the initial number of contracts awarded will be based on the cost of the selected proposals and funding available. EPFD plans to select at least two partners to conduct two separate flight demonstrations.

COVID-19 Effects

The project delayed some milestone events—including preliminary design reviews—by one year to fiscal year 2022, and adjusted its strategy of cost sharing with industry because of effects from COVID-19. EPFD originally planned to share half of the total contract costs with industry beginning at contract award through the period of performance of the contract. However, following an economic downturn related to COVID-19, the aviation industry reported it had little to no funding available for early EPFD design work. As a result, the project changed its acquisition strategy. NASA still plans to share half of the total costs, but it will fully fund early design work and delay industry's half of the cost contributions until after the partners' critical design review.

The EPFD project is tracking among its top risks that COVID-19 could have unknown future effects on cost and schedule. For example, the project is tracking a risk of potential vendor layoffs or work stoppages that could affect the project's costs and the schedule to first flight. Officials plan to mitigate this risk by continuing to exchange information with industry to assess its capabilities.

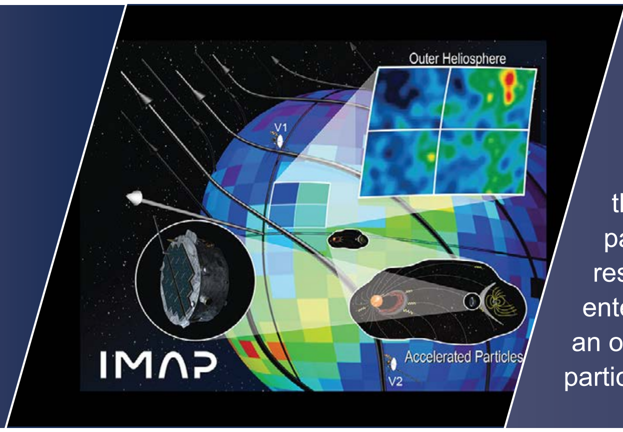
Technology

In 2020, the EPFD project reduced its minimum success criteria for total power by half from 1 megawatt to 500 kilowatts to maximize its benefit across aircraft markets. As part of its top-level goals, the project focused its technologies to be applicable to three classes of aircrafts: single aisle (150 to 200 seats), regional jets (20 to 149 seats), and thin haul (i.e. tourism jets with fewer than 19 seats). Officials said this change will make technologies more applicable to thin haul transports that most likely will not require a full megawatt of power. Officials said they made this change based on data from early concepts that indicated engines producing less than 1 megawatt of power were capable of providing the same intended benefits of reducing mission fuel burn and energy use by 4 percent.

To mature key technologies in the formulation phase, the EPFD project reported executing risk reduction contracts with numerous industry partners to mitigate a number of technical risks. For example, one risk reduction effort includes a focus on developing a battery system capable of providing high power at high voltage. The battery stores electricity for the hybrid propulsion system that, similar to hybrid automobiles, would be powered by both fuel and electricity. The project is tracking a risk that the battery system might not meet the needed requirements, which exceed the performance of any existing battery technologies. If this risk is realized, it could decrease the flight time of the aircraft, increase the total number of required flight tests, and add cost and schedule to the project. The project will get further insight into the maturity of each selected industry partner's concept for risk reduction during their individual preliminary design reviews expected in fiscal year 2022.

PROJECT OFFICE COMMENTS

EPFD project officials stated they agreed with a draft of this assessment and provided technical comments, which were incorporated as appropriate.



Source: Princeton University, JHU/APL, SwRI. | GAO-21-306

Interstellar Mapping and Acceleration Probe

The Interstellar Mapping and Acceleration Probe (IMAP) is a spinning spacecraft that 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. IMAP includes 10 instruments and will reside in an orbit almost 1 million miles from the Earth, where it will collect and analyze particles that make it through the boundary.

FORMULATION
- 05/18 Formulation start
- 12/19 System requirements/ mission definition review
- **01/21 GAO review**
- 05/21 Preliminary design review
- 07/21 Project confirmation

IMPLEMENTATION
- 07/22 Critical design review
- 04/23 System integration review
- 02/25 Target launch readiness date

PROJECT INFORMATION

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

International Partner: **Polish Academy of Sciences (Poland), University of Bern (Switzerland), Imperial College London (UK Space Agency)**

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

Launch Vehicle: **Falcon 9**

Mission Duration: **2 years**

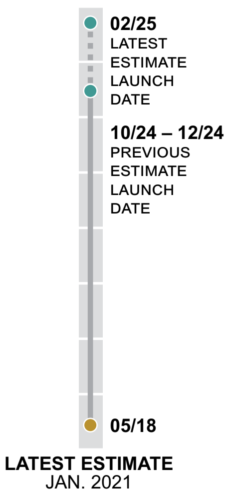
Requirement Derived from: **2013 Heliophysics Decadal Survey**

Budget Portfolio: **Science, Heliophysics**

PROJECT SUMMARY

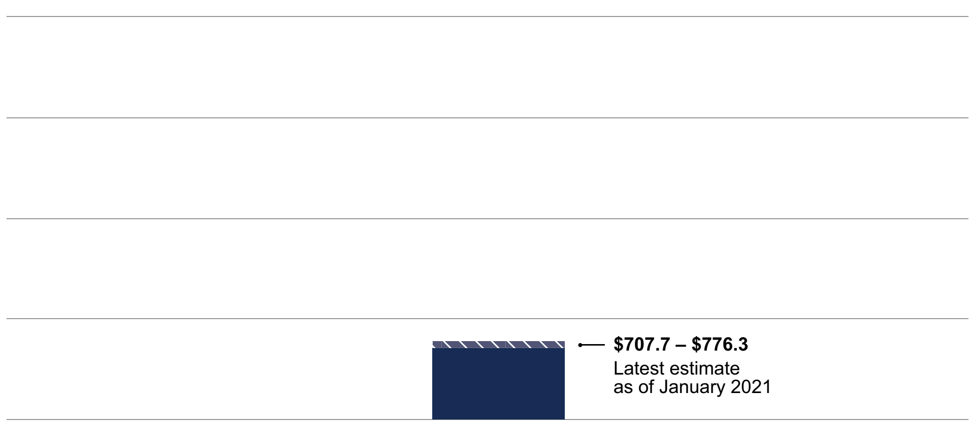
COVID-19 has slowed the project's progress resulting in a delay to the project's preliminary launch readiness date to February 2025, instead of fall 2024. NASA will not approve a cost and schedule baseline until the project's key decision point C review, now planned for July 2021. One of the top challenges for the project will be developing, testing, and integrating 10 instruments. All of the instruments are based on previously flown instruments, but will need some modification. For example, the project is planning to add a pivot platform to increase the measurements taken by one of the instruments, but it also adds complexity to the design. Project officials told us their current budget and estimate at completion now includes funds to replace and upgrade legacy equipment, which resolves a risk regarding obsolescence issues as some of the instruments are based on decade-old designs.

PRELIMINARY SCHEDULE



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.

Cost and Schedule Status

COVID-19 has slowed the project's progress resulting in a delay to the project's preliminary launch readiness date. The project is now planning for a launch readiness date of February 2025, instead of fall 2024. NASA will not approve a cost and schedule baseline until the project's key decision point C review, now planned for July 2021. These delays from COVID-19 are largely the result of inefficiencies across the project. For example, COVID-19 has resulted in facilities and personnel not being available and has slowed the project's ability to build and test models or emulators.

The project is underrunning its cost plan as a result of these delays, including lower than expected staffing levels. Similarly, officials told us that they had planned to increase purchasing for parts in spring 2020, but that was delayed due to COVID-19. As a result, the project's expenditures are less than expected.

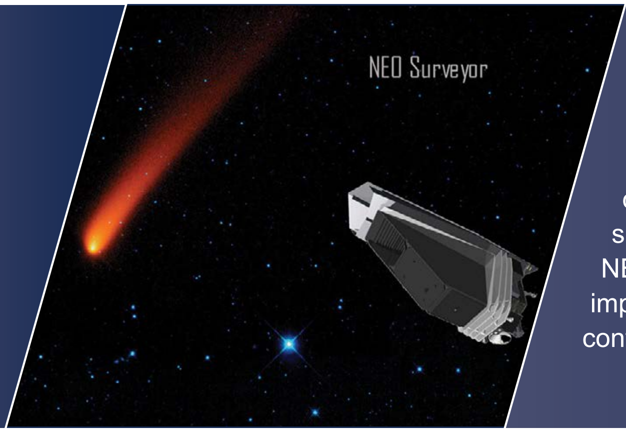
Technology

One of the top challenges facing the project will be developing, testing, and integrating 10 instruments. The project manager explained that while these instruments are all based on previously flown instruments, it will be a challenge to ensure that all 10 of them proceed on schedule. While the project did not report any critical technologies, officials told us that most of the instruments will need to be updated in some fashion, such as to update software. However, updates to the instruments may not be easy. For example, the IMAP-Lo instrument—which will measure interstellar atoms to improve understanding of the composition and properties of interstellar medium and which is required to perform for the mission to be considered a success—is being modified to add a pivot platform. That pivot platform is one of the main differences from the heritage instrument IMAP-Lo is based on and is expected to increase the measurements taken by the instrument. Project officials stated that the functioning of the pivot platform is not required for IMAP to meet requirements. According to project documentation, the instrument is already considered complicated and adding this pivot platform increases the complexity.

Additionally, given the heritage nature of the instruments, project officials told us that they recently resolved a risk to manage and address obsolescent parts. For example, one of the project's top risks was related to the age of its power distribution unit and power system electronic ground support equipment. Officials told us the equipment was originally built to support the Van Allen Probes mission, which launched in 2012. The IMAP project has no spare computers, simulators, or semiconductors to replace the legacy hardware if it were to fail, which the project considers highly likely. Project officials told us that their current budget and estimate at completion now includes funds to replace and upgrade the legacy equipment.

PROJECT OFFICE COMMENTS

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



Source: University of Arizona. | GAO-21-306

Near Earth Object Surveyor

The Near Earth Object (NEO) Surveyor is a space-based telescope designed to search for NEOs and accomplish the survey to at least objects as small as 140 meters across. It will detect, track, catalogue, and characterize NEOs—such as asteroids and comets—to identify objects that could potentially impact the Earth and pose a danger to life and property. The NEO Surveyor continues work previously done under the NEO Camera (NEOCam) project.

PROJECT INFORMATION

NASA Lead Center: **Jet Propulsion Laboratory**

Mission Duration: **5 years**

Requirement Derived from: **The George E. Brown, Jr. Near Earth Object Survey Act, Pub. L. No. 109-155, § 321 (2005)**

Budget Portfolio: **Planetary Science, Planetary Defense**

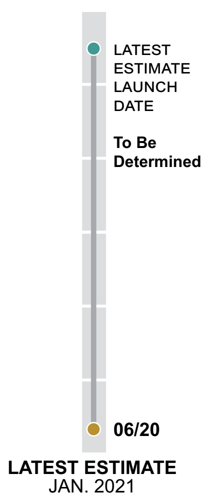
Next Major Project Event: **Key decision point B (Spring 2021)**

CURRENT STATUS

NASA delayed the NEO Surveyor project's key decision point B review—when it sets preliminary cost and schedule estimates and enters the preliminary design and technology completion phase—from December 2020 to spring 2021. The review was delayed because NASA needs more time to assess COVID-19 effects across the Planetary Science Division budget. In addition, officials said that the funding profile they received from NASA was less than half of what they planned for fiscal year 2021, which will require them to reassess their planned funding profile. They noted that the difference in funding levels will cause the project to delay its planned April 2025 launch date.

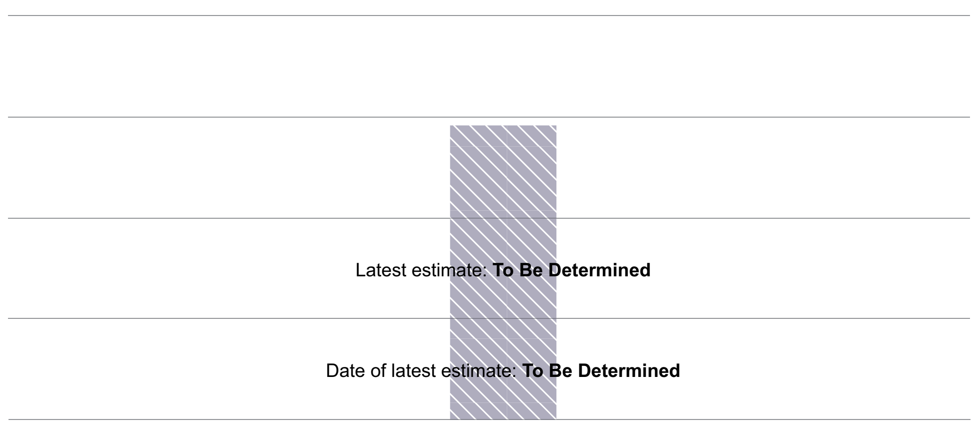
The project held its system requirements review in October 2020 and is preparing for its preliminary design review. As part of the systems requirements review, the project's standing review board's independent assessment found that the project's estimated life cycle cost and schedule may be underestimated. The project assessed that all of its technologies are mature and heritage. The NEO Surveyor completed an extended concept and technology development phase under the NEOCam project and, as a result, already completed some technical risk reduction activities.

PRELIMINARY SCHEDULE



PRELIMINARY COST

then-year dollars in millions



PROJECT OFFICE COMMENTS

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

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Source: Southwest Research Institute (SwRI) | GAO-21-306

Polarimeter to Unify the Corona and Heliosphere

The Polarimeter to Unify the Corona and Heliosphere (PUNCH) project will explore the Sun's outer atmosphere, known as the corona. It will deploy four suitcase-sized satellites to image and track the constant flow of particles, known as the solar wind, that leave the Sun. The spacecraft will also track large eruptions of charged particles and magnetic fields from the Sun, known as coronal mass ejections. These eruptions can drive large space weather events that disrupt space and ground equipment, including power grids, GPS navigation, and on-orbit spacecraft. PUNCH will provide information on the evolution of these eruptions and develop techniques to predict future eruptions.

PROJECT INFORMATION

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

International Partner: **None**

Launch Location: **To be determined**

Launch Vehicle: **To be determined**

Mission Duration: **2 years**

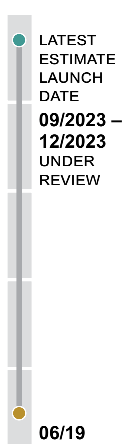
Requirement Derived from: **Heliophysics Roadmap; 2013 Heliophysics Decadal Survey**

Budget Portfolio: **Science, Heliophysics**

PROJECT SUMMARY

Shutdowns at a key vendor facility and reduced efficiency due to COVID-19 have caused the project to delay its preliminary launch readiness date from February 2023 to between September and December 2023. The project will continue to evaluate its preliminary life cycle cost and launch readiness date as COVID-19 effects continue. As part of the reevaluation, NASA will determine if the project will increase its total life cycle costs or use reserves early in the project, which officials say could put the project at risk for cost overruns later. Because officials needed additional time to determine COVID-19's effects on cost and schedule prior to setting baselines, the PUNCH project extended its preliminary design phase and delayed its preliminary design and confirmation reviews by 8 and 10 months, respectively. The project is tracking a number of risks it categorizes as low criticality, including a staffing risk it has been mitigating with outsourcing until new staff can be hired.

PRELIMINARY SCHEDULE



LATEST ESTIMATE
FEB. 2021

PRELIMINARY COST[a]

then-year dollars in millions

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

Cost and Schedule Status

As a result of COVID-19, the PUNCH project is reevaluating its preliminary cost and schedule estimates, and has delayed its key decision point C review 10 months—when it will set its cost and schedule baselines—to July 2021. Project officials expect this delay will provide additional time to more completely determine COVID-19's effects on cost and schedule. The project was working toward a preliminary life cycle cost and schedule estimate of $270.1 million and February 2023 launch readiness date. However, because of COVID-19, the project delayed its preliminary launch readiness date to between September and December 2023. It also provided a lower range of $170 million for its preliminary life-cycle cost estimate due to ongoing launch vehicle selection decisions, which could result in a rideshare option with lower total life cycle costs. However, officials noted that, because of potential future COVID-related effects, there could be additional costs or delays to the project.

According to officials, as part of the reevaluation, NASA will determine if the project will increase its total life cycle costs to incorporate COVID-19-related costs and exceed the $129.5 million development cost cap managed by the project, or if the project will use its reserves to stay within this cap. Officials stated that using reserves this early in the project's life cycle could put the project at risk for cost overruns later. Officials said the revised estimates will assume COVID-19 effects will continue through June 2021.

A main driver of the project's expected cost and schedule changes is that the vendor developing the camera assemblies on the project's critical path had to shut down for more than 4 months in 2020 due to COVID-19. Prior to the shutdown, the camera assembly was further along in development than other pieces of hardware, and the vendor set up its facilities to begin lab work in the spring of 2020. As a result, officials said this vendor's progress was affected by COVID-19 more than other vendors that were able to start their lab work as planned when facilities began to reopen in late summer or fall 2020 under revised safety protocols. Officials noted that all of its vendors are experiencing some reduced efficiency under remote working conditions and other COVID-19 safety protocols.

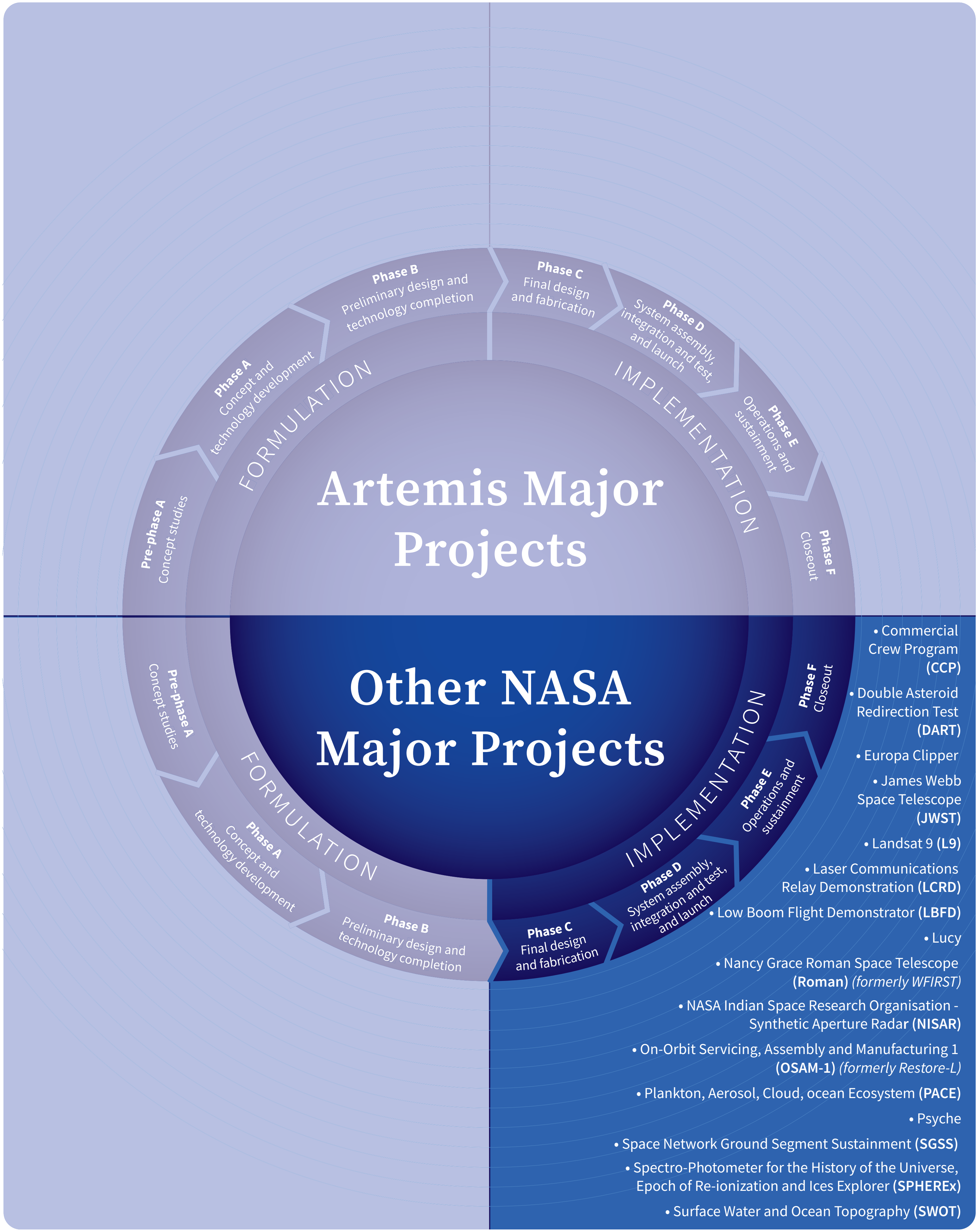
Technology and Design

While officials said the project has also delayed its preliminary design review 8 months primarily due to COVID-19 cost and schedule uncertainties, its technologies are mature. The project's main technologies are imagers that will be mounted on the project's four satellites. Three of the satellites will each carry a wide-field imager and one will carry a near-field imager along with a student-built spectrometer. Officials said the near-field imager was deemed mature based on its use in prior projects while the wide-field imager required some additional development to achieve maturity. As of October 2020, officials said both technologies are at a technology readiness level of 7 or above.

The PUNCH project is tracking a number of risks it categorizes as low criticality. One of these risks is that the project may experience a backlog of work once work-at-home restrictions under COVID-19 are lifted, which could lead to additional staffing challenges and subsequent schedule delays. The project has worked to mitigate this risk by outsourcing some tasks until new staff can be hired.

PROJECT OFFICE COMMENTS

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



Source: GAO analysis of National Aeronautics and Space Administration (NASA) data. | GAO-21-306

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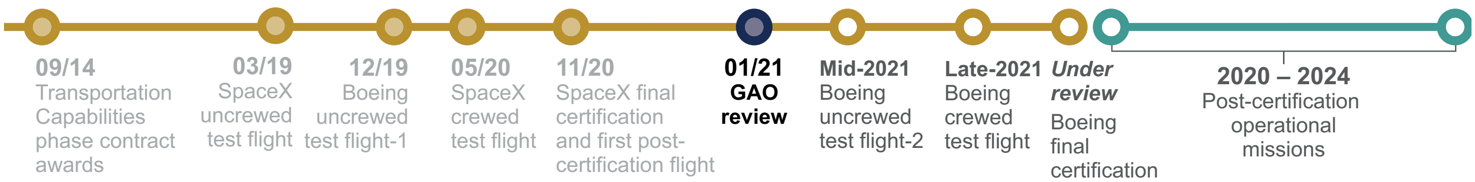
Commercial Crew Program

The Commercial Crew Program (CCP) 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). This 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.

Source: NASA. | GAO-21-306



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**

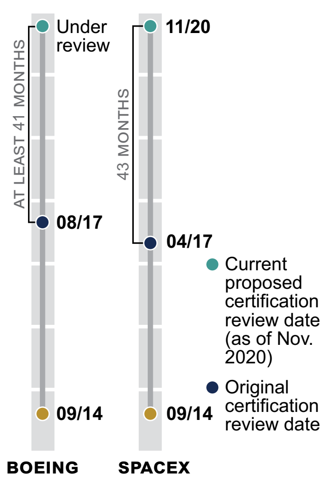
Budget Portfolio: **Low Earth Orbit and Spaceflight Operations, Space Transportation**

[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

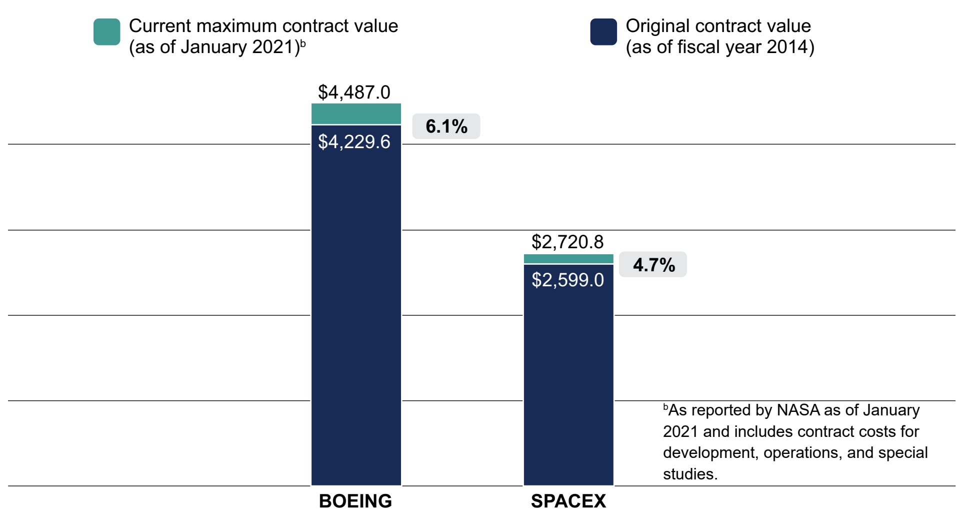
The Commercial Crew Program has transitioned to supporting SpaceX's operational missions while Boeing completes development of its crew transportation system. In November 2020, the Commercial Crew Program achieved a significant milestone when it certified SpaceX for operational crewed missions to the ISS. Shortly after certification, SpaceX launched its first post-certification mission, Crew-1, to the space station. Boeing is planning to conduct a second uncrewed test flight in mid-2021, based on launch availability and the ISS's ability to accommodate, followed by a crewed test flight late in 2021. In addition, in January 2021, Boeing reported completing the requalification of its crew capsule software following issues identified during the first uncrewed test flight.

SCHEDULE PERFORMANCE



COST PERFORMANCE

dollars in millions



[b]As reported by NASA as of January 2021 and includes contract costs for development, operations, and special studies.

Cost and Schedule Status

In November 2020, the Commercial Crew Program achieved a significant milestone when it certified SpaceX for operational missions to the ISS. Shortly after SpaceX was certified, the contractor launched its first post-certification mission, Crew-1, to the ISS. NASA already ordered the remaining five post-certification missions from SpaceX, the first of which will be launched in spring of 2021. The dates of the remaining missions have not yet been determined.

Following its first uncrewed test flight, during which the spacecraft did not reach the planned orbit and did not dock with the ISS, Boeing is planning to conduct a second uncrewed test flight in mid-2021, based on launch availability and the ISS's ability to accommodate. Boeing will conduct this additional test flight at no additional cost to the government. A crewed test flight is planned for later in 2021, and the date of Boeing's final certification review remains under review.

Integration and Test

In January 2021, Boeing reported that it had completed a formal requalification of its crew capsule software. This caps a year-long effort by the contractor to address the software issues identified during the first uncrewed test flight. Boeing officials told us that they are conducting three times as much testing for the second uncrewed test flight. In addition, the NASA program office told us that it has augmented its software team, more than doubling the number of people responsible for reviewing the contractor's software.

According to program documentation, Boeing has completed its software qualification test campaign, and the program is reviewing all hazard reports in detail. Hazard reports are generated by the contractors to document hazards, or conditions that could cause harm, and the controls put in place to mitigate them. We have previously found that these are part of the program's quality assurance activities to address safety issues prior to the contractor's first crewed test flight.[1]

Other Issues to Be Monitored

According to program officials, COVID-19 did not generally affect the program office. Officials said that, although the program was deemed mission critical to enable on-site work, they were able to conduct up to 95 percent of the work remotely and this allowed them to support SpaceX's crewed test flight, among other things.

Boeing's progress on its second uncrewed test flight was affected by COVID-19. Boeing officials told us that they have worked continuously throughout the pandemic and rearranged the build schedule as needed when staff members were required to quarantine, but COVID-19 was a major contributor for the second uncrewed test flight not occurring before spring 2021. For example, officials explained that there were delays in receiving hardware from their suppliers, who had to adjust their operations because of COVID-19. However, NASA officials told us that Boeing has not submitted official effects to NASA.

PROJECT OFFICE COMMENTS

Commercial Crew Program officials provided technical comments on a draft of this assessment, which were incorporated as appropriate.

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

Double Asteroid Redirection Test

The Double Asteroid Redirection Test (DART) project plans to travel to the near-Earth asteroid Didymos 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. The project's purpose is to better understand impact mitigation posture and to respond to a recommendation by the National Research Council Committee to test a kinetic impactor. The DART mission is part of the Asteroid Impact and Deflection Assessment, a collaboration with the European Space Agency and the Italian Space Agency.

Source: NASA/Johns Hopkins University/Applied Physics Lab/Steve Gribben. | GAO-21-306

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
- 03/20 Integration and test readiness review
- **01/21 GAO review**
- 11/21 Target launch readiness date
- 02/22 Committed launch readiness date

PROJECT INFORMATION

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

International Partners: **Italian Space Agency**

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

Launch Vehicle: **Falcon 9**

Mission Duration: **7–10 months (launch dependent)**

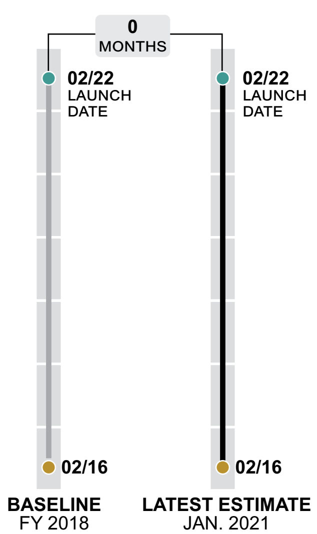
Requirement Derived from: **NASA Authorization Act of 2008 and implementing guidance**

Budget Portfolio: **Science, Planetary Science**

PROJECT SUMMARY

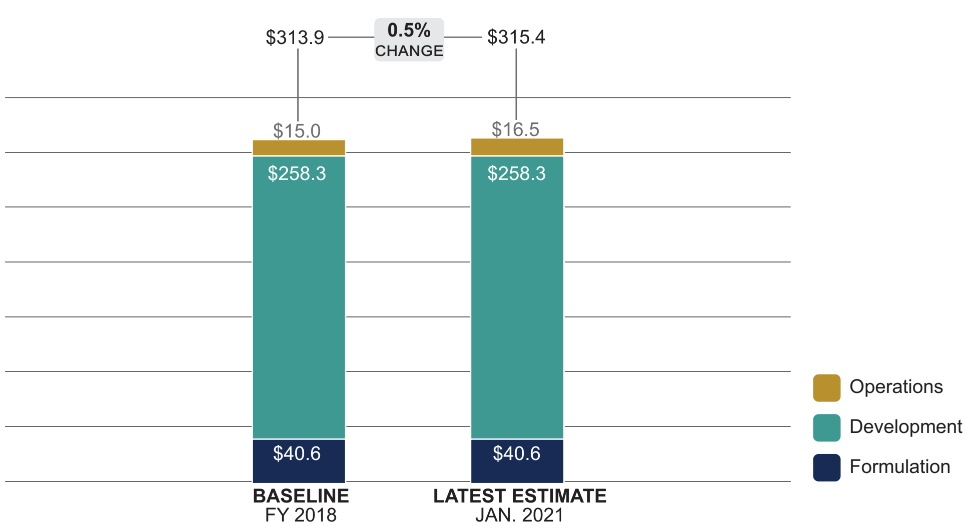
The DART project continues to operate within its development cost and schedule baselines but is exceeding its operations cost estimate. Delays related to the development and delivery of its solar arrays, imager sensor, and COVID-19 effects are using cost and schedule reserves. The project is no longer working to its target launch readiness date of July 2021—7 months earlier than the project's baseline schedule—because late delivery of the solar arrays and an issue with the navigation instrument made the target date no longer viable. The next available launch window does not start until November 2021. The project estimates the delay will cause it to exceed its cost baseline. The project had reported concerns regarding the NASA Evolutionary Xenon Thruster-Commercial (NEXT-C) in the past; however, NEXT-C has successfully been delivered to the project. The project reported that integration and test is proceeding well, but the project is tracking several risks related to delayed components that could affect the integration and test schedule.

SCHEDULE PERFORMANCE



COST PERFORMANCE

then-year dollars in millions



Cost and Schedule Status

The DART project continues to operate within its development cost and schedule baselines but is exceeding its operations cost baseline. The project is using cost and schedule reserves to address delays resulting from the development and delivery of its solar arrays, technical issues with its imager sensor discovered in testing, and COVID-19 effects. DART has struggled with the development of its solar array, primarily due to COVID-19 effects on efficiency and safety precautions, and engineering issues that required design changes and more rigorous testing. The project has rearranged the integration and testing schedule to accommodate delays in the delivery of the solar arrays and its imager sensor.

Including late delivery of the solar arrays, the project is tracking two risks that have caused it to miss its internal launch date, and the project estimates the delay will cause it to exceed its cost baseline. The project is experiencing delays to the navigation imaging instrument—Didymos Reconnaissance and Asteroid Camera for OpNav (DRACO)—after a primary mirror bond failed on the spare during testing. DRACO is now on the project's primary critical path, and a failure review board concluded that the mirror mount attaching DRACO to the spacecraft will need to be redesigned. The delays from the solar arrays and DRACO caused the project to miss its target launch readiness window. A new window opens between November 2021 and February 2022, which aligns with the project's baseline schedule. The latter launch window carries a cost effect that the project estimates to be about $10 million and will reduce operations time by four to seven months since the end date of the mission is still tied to the date of impacting the asteroid.

NASA released $12.5 million of the project's headquarters-held reserves to help address the cost growth from solar array development and to ensure the project has necessary funding and reserves to meet its target launch readiness date. As of January 2021, the project is estimating that it will require $3 million more from its remaining headquarters-held reserves to mitigate COVID-19 costs and solar array delays, among other things. The project is also tracking risks that could affect costs over and above available cost reserves. For example, the project estimates that solar array cost growth could increase another $1 million.

Integration and Testing

In July 2020, the project entered the assembly, integration and test, and launch phase, and the project reports that spacecraft integration and test is performing well. For example, the project had previously reported concerns about the on-time delivery of the NEXT-C—an electric propulsion technology demonstration project—due to development issues. The project previously reported in June 2020 that NEXT-C was successfully qualified and delivered to the project. As of November 2020, the NEXT-C thruster was installed and testing began in December 2020.

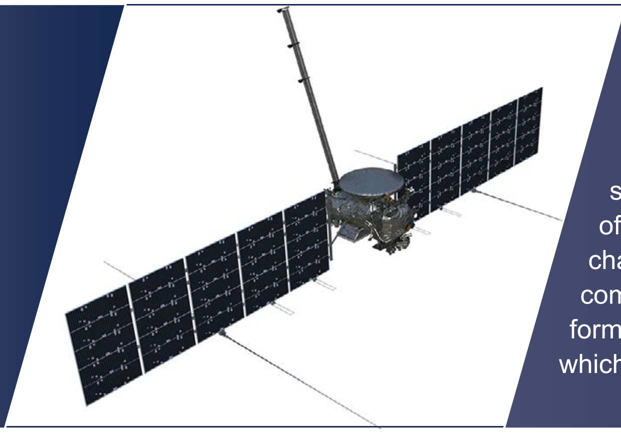
International Partner

Due to COVID-19, subject matter experts from the Italian Space Agency and its technical implementer cannot travel to the United States to assist in testing the Light Italian CubeSat for Imaging of Asteroids (LICIACube)—a CubeSat funded by the Italian Space Agency and hosted by DART that will image the asteroid before, during, and after the impact. In light of the restrictions, project officials developed a modified testing plan for the LICIACube radio. For example, the radio was tested by a contractor with project personnel on site.

PROJECT OFFICE COMMENTS

DART project officials stated that they agreed with a draft of this assessment and provided technical comments, 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 atmosphere, 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: NASA/JPL-Caltech. | GAO-21-306

PROJECT INFORMATION

NASA Lead Center: **Jet Propulsion Laboratory**

International Partner: **None**

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

Launch Vehicle: **To be determined (Heavy class)**

Mission Duration: **3-year science mission**

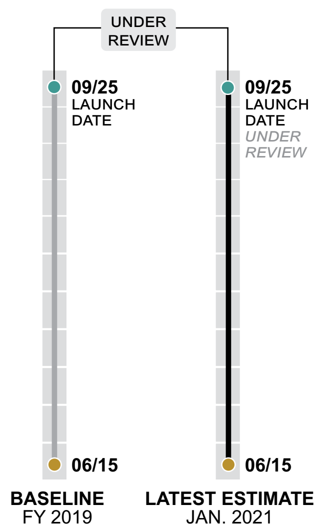
Requirement Derived from: **2011 Planetary Science Decadal Survey**

Budget Portfolio: **Science, Planetary Science**

PROJECT SUMMARY

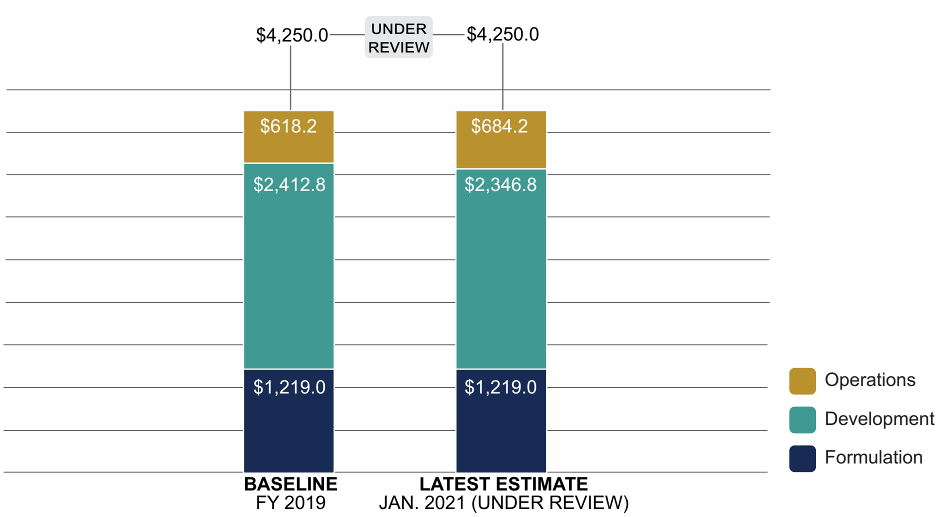
The Europa Clipper project is reviewing its cost and schedule baselines, following NASA's decision in January 2021 to launch the spacecraft on a commercial launch vehicle. The Consolidated Appropriations Act, 2021 stated that Europa Clipper shall launch on a Space Launch System (SLS) if an SLS is available and if torsional loads analysis—analysis that predicts Europa Clipper's ability to withstand the launch environment—confirmed Europa Clipper's appropriateness for SLS. In January 2021, the NASA administrator concluded that neither condition stipulated in the act could be met and directed the Launch Services Program to procure a commercial launch vehicle for the project. The project passed its critical design review in December 2020 with 81.5 percent of its design drawings released, which did not fully meet the best practice of releasing 90 percent of design drawings by this review.

SCHEDULE PERFORMANCE



COST PERFORMANCE

then-year dollars in millions



Cost and Schedule Status

According to officials, the Europa Clipper project is reviewing its cost and schedule baselines, following NASA's decision in January 2021 to launch the spacecraft on a commercial launch vehicle. Project officials explained that the review will include assessing cost and schedule effects, resulting from the project carrying designs for both a commercial launch vehicle and the SLS for 12 months longer than planned in the baseline, as well as effects from COVID-19.

In addition, the project will assess whether additional cost reserves are needed. The project has struggled to maintain its cost reserves at planned levels. The project received two headquarters-held cost reserve transfers in 2020 for a total of $385 million—or 77 percent—of its development cost headquarters-held reserves. The first transfer was to replenish low project-held reserve levels that had been consumed due to development challenges from certain flight subsystems and instruments. The second transfer was to accommodate a launch date change caused by the delayed launch vehicle decision and to offset a portion of COVID-19 costs.

Launch Vehicle

The project has resolved uncertainties surrounding its launch vehicle, which were affecting its design progress. The Consolidated Appropriations Act, 2021 stated that Europa Clipper shall launch on an SLS if an SLS is available and if torsional loads analysis—analysis that predicts Clipper's ability to withstand the launch environment—has confirmed Clipper's appropriateness for SLS. In January 2021, the NASA administrator concluded that neither condition stipulated in the act could be met. The torsional loads analysis showed that the project would need to potentially redesign and rebuild much of its hardware to withstand the SLS launch environment, leading it to exceed its schedule and cost baselines by about one year and about $1 billion. In addition, officials said no SLS would be available to launch Europa Clipper until after the project's baseline launch date in 2025 without adversely affecting the Artemis program.

As a result, the Administrator directed the Launch Services Program to procure a commercial launch vehicle for the project. Project officials stated that they are planning to compress their usual 13-month launch vehicle procurement process with a goal to have the procurement complete by the end of calendar year 2021. The project expects this will allow the provider the lead time needed to meet the project's internal launch readiness date.

Design

All nine instruments completed their critical design reviews (CDR), but officials stated that the project spent more of its project-held cost reserves than desired while struggling to control cost growth on several of its instruments and subsystems leading up to these reviews. Three instruments recently went through the project's process to control cost for instruments with cost growth more than 20 percent—the MAss Spectrometer for Planetary EXploration (MASPEX), Europa Imaging System (EIS), and the Mapping Imaging Spectrometer for Europa (MISE). Officials said that the MISE instrument team resolved schedule issues and required no further cost containment measures. NASA instituted cost caps for MASPEX and EIS and removed MASPEX and the Wide-Angle-Camera—a part of EIS—from the project's top-level science requirements. According to project officials, since all instruments are now past CDR, this cost control process can no longer be triggered.

Subsequently, in December 2020, the Europa Clipper project passed its CDR and released 81.5 percent of its design drawings. This is below the best practice of releasing 90 percent of design drawings at this review. According to GAO's best practice, releasing at least 90 percent of design drawings at CDR lowers the risk of projects experiencing design changes and subsequent cost and schedule growth. According to a project official, most of the drawings not yet released are for assembly and support equipment, some are associated with the recent launch vehicle uncertainty, and some are related to the late maturation of some subsystems and instruments.

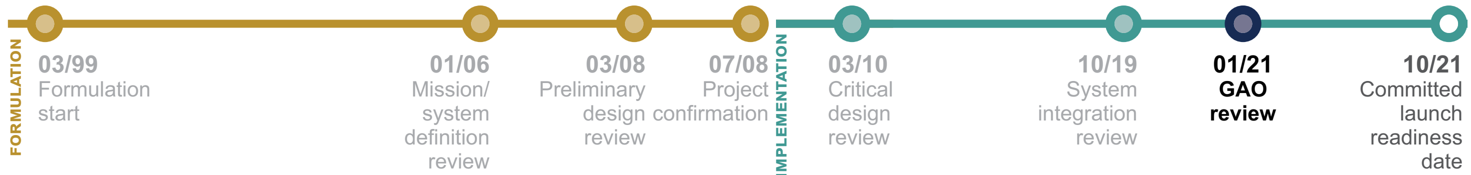
PROJECT OFFICE COMMENTS

When commenting on a draft of this assessment, Europa Clipper project officials stated that they generally agreed with this assessment and the recent direction from NASA to procure a commercial launch vehicle. They said that the project has made excellent progress with their system design, flight hardware, and software deliverables, and that the project remains focused on delivering Europa Clipper in time for a successful launch and start of its cruise to Jupiter in 2024. Project officials also provided technical comments on a draft of this assessment, which were incorporated as appropriate.

Source: NASA. | GAO-21-306

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 gradually open over a period of weeks once JWST is in space. JWST will reside in an orbit about 1 million miles from the Earth at the second Lagrange point.



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)**

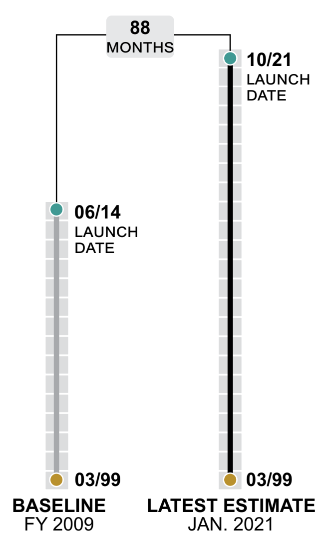
Requirement Derived from: **2001 Astrophysics Decadal Survey**

Budget Portfolio: **Science, Astrophysics**

PROJECT SUMMARY

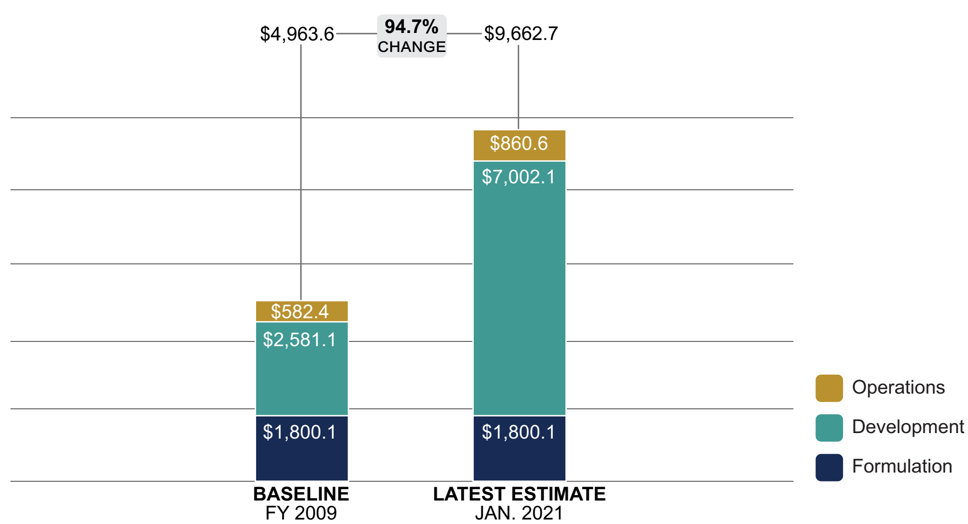
In July 2020, NASA revised its launch readiness date to October 2021, a 7-month delay from its prior estimate, primarily due to environmental and deployment test schedule risks and the effects of COVID-19. Program officials stated that existing cost reserves will support the later launch date within the program's $9.7 billion cost commitment. The project made progress on technical issues that previously caused schedule strain, including replacing key communications components. The project also completed its final set of environmental tests on the fully integrated observatory in October 2020. The project has used about 38 days of its schedule reserve due to electrical issues that delayed the vibration tests and other factors. However, the project continues to implement and test several design changes to address previously identified sunshield deployment risks and a concern that the sunshield could be damaged when the launch vehicle fairing depressurizes in space.

SCHEDULE PERFORMANCE



COST PERFORMANCE

then-year dollars in millions



Cost and Schedule Status

In July 2020, NASA revised its launch readiness date to October 2021, a 7-month delay from its prior estimate established in June 2018. The delay was primarily driven by environmental and deployment test schedule risks and the effects of COVID-19. Program officials stated that existing cost reserves would be sufficient to support the later launch date within the program's $9.7 billion cost commitment. However, the project reported continued cost risk given the extended nature of the COVID-19 situation. The new launch date included 86 days of schedule reserves, which is in line with Goddard Space Flight Center guidance. As of January 2021, the project had consumed about 38 days of this reserve, primarily for environmental test delays and to repair tears and strengthen high wear areas of the sunshield.

Design

The project continues to implement and test design changes to address previously identified sunshield deployment risks associated with membrane retention devices. For example, we previously reported that a non-explosive actuator did not fire during testing.[1] The actuators, which help to unfurl the sunshield, are designed to be electrically redundant, but only one of the two mechanisms used to fire the actuator worked during the test. The project is testing actuators redesigned with thicker wires. Further, the project is analyzing whether to replace certain membrane retention devices that may not be able to withstand combined pressure forces created during launch and, as a result, fail during deployment.

Integration and Test

The project completed its final set of environmental tests on the fully integrated observatory in October 2020. The project also resolved issues concerning malfunctioning communications components and risks presented by defective bolts that previously caused schedule strain.

However, additional technical risks that could affect the schedule remain as NASA completes final folding and stowing of the sunshield. For example, the project returned the spacecraft's two transponder devices to the vendor to investigate recent failures to transmit and receive data. The project expects to use 7 to 14 days of reserve to resolve the issue.

Other Issues to be Monitored

The project recently resolved a risk that the sunshield could be damaged when the launch vehicle fairing depressurizes in space. The project and its partners implemented two fairing design changes—installing actuators to hold the vents open and sealing the internal honeycomb structure. These changes were tested on an Ariane flight in August 2020. Flight data analysis showed that the pressure was reduced but not to the desired level. However, recent tests on the sunshield membranes showed the material is strong enough to accommodate the residual pressure. Project officials stated that they will continue to gather future flight data to further understand the pressure conditions in the fairing.

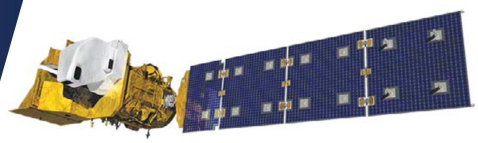
As of February 2021, the project's top risk is that the JWST launch date could be delayed due to two recent Ariane launch anomalies. All launches have been grounded until the cause and corrective actions are determined.

PROJECT OFFICE COMMENTS

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

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

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-21-306

PROJECT INFORMATION

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

International Partner: **None**

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

Launch Vehicle: **Atlas V 401**

Mission Duration: **5 years**

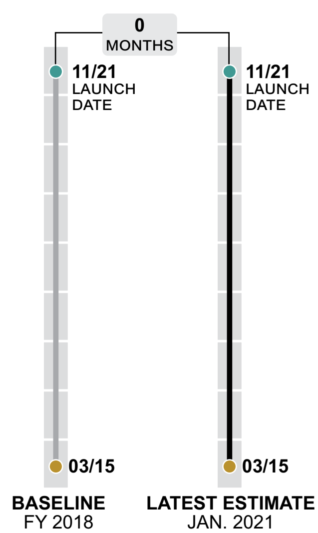
Requirement Derived from: **National Plan for Civil Earth Observations**

Budget Portfolio: **Science, Earth Science**

PROJECT SUMMARY

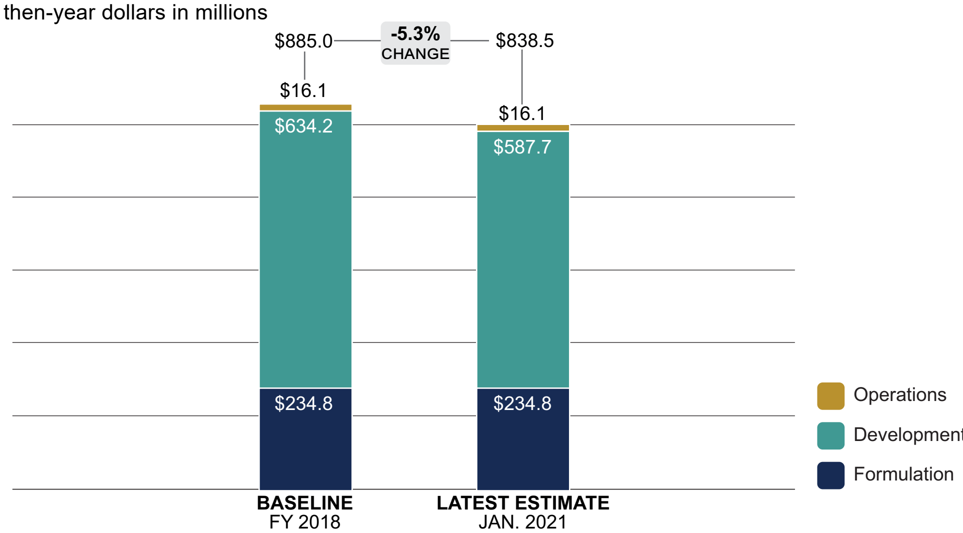
The Landsat 9 project moved into the system assembly, integration and test, and launch phase in May 2020 and is maintaining cost and schedule baselines. However, the project delayed its internal launch date 3 months to September 2021 because of delays from the 2019 government shutdown, contractor performance, and COVID-19; but it expects to still launch by its November 2021 baseline date. In May 2020, NASA reduced Landsat 9's cost baseline by $46.5 million because of the project's mature state and risk posture. Despite previous challenges with schedule, the spacecraft and observatory are complete and are now undergoing further integration and testing. However, the project is tracking risks regarding contractor performance, COVID-19 restrictions, and deep space communication frequency interference that all have the potential to result in more schedule delays.

SCHEDULE PERFORMANCE



COST PERFORMANCE

then-year dollars in millions



Cost and Schedule Status

The Landsat 9 project moved into the system assembly, integration and test, and launch phase in May 2020 and is currently maintaining its November 2021 schedule baseline. However, the project delayed its internal launch date 3 months to September 2021 due to delays from the 2019 government shutdown, contractor performance, and COVID-19. For example, officials said the spacecraft took longer to complete than expected because of continued delays from electronics fabrication and flight software challenges. The contractor completed the spacecraft in June 2020, which Landsat 9 officials said shows performance improvement. While the project is no longer tracking contractor performance as its top risk, the project reported that Landsat 9 mission activities remain at risk from poor contractor performance. If the project experiences future delays, officials said Landsat 9's potential launch date could conflict with the launch windows of two planetary missions scheduled for 2021, Double Asteroid Redirection Test and Lucy. This could then challenge the project's ability to launch before November 2021.

The project continues to operate within its cost baseline. In May 2020, NASA reduced the project's baseline by $46.5 million as a result of the project's mature state and risk posture. As of November 2020, Landsat 9's cost reserves were at planned levels. The project's firm-fixed-price contract allowed Landsat 9 to avoid cost increases associated with contractor schedule delays. In addition, in May 2020, NASA's Earth Science Division decreased project-level reserves by removing an additional $50 million from the project's current budget, which NASA reported was due to this excellent cost performance. Subsequently, project officials told us NASA plans to reduce the budget by an additional $21 million for the same reason. Officials said these decisions were made without incorporating effects from COVID-19 and could be returned to the project if needed.

Integration and test

The project made progress integrating and testing its primary instruments, but COVID-19 poses risk to Landsat 9's integration and test schedule. Both the Operational Land Imager 2 and the Thermal Infrared Sensor 2 are fully integrated with the spacecraft, and the project successfully completed its observatory and started testing. However, officials said COVID-19 initially caused schedule delays to spacecraft and observatory integration and testing because project officials could not travel to the contractor's facility to support integration and testing. However, as of January 2021, project officials stated that limited travel has resumed and the project is monitoring testing remotely and with on-site participation by sufficient critical personnel.

In addition, the project is working with a failure review board to potentially replace the spacecraft's Solar Array Drive Assembly after completion of observatory thermal vacuum testing due to lubrication concerns. If needed, the project expects that it can accommodate a replacement within available project schedule margin to support the September 2021 internal launch date.

Technology

As of December 2020, the Landsat 9 project is working to resolve a major technical risk, which could have a substantial effect on schedule depending on the selected mitigation option. This risk relates to spectral band exceedances of Landsat 9's X-Band frequency, which allows the satellite to communicate Earth imagery data to ground stations, interfering with Deep Space Network's frequencies. If the project chooses to make hardware changes, then the exceedances could pose significant schedule effects. As of January 2021, Landsat 9 is evaluating options to change the hardware or to use it as is, and officials stated that their latest analyses and discussions indicate it is likely they will use the hardware as is.

PROJECT OFFICE COMMENTS

Landsat 9 project officials stated they concur with GAO's assessment and provided technical comments on a draft of this assessment, which were incorporated as appropriate.

Laser Communications Relay Demonstration

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 envisions using optical communication technology as a next generation Earth relay as well as to support near-Earth and deep space science. The project is a mission partner with and will be a payload on a U.S. Space Force Space Test Program satellite.

Source: NASA. | GAO-21-306

PROJECT INFORMATION

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

International Partners: **N/A**

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

Launch Vehicle: **Atlas V 551**

Mission Duration: **2+ years**

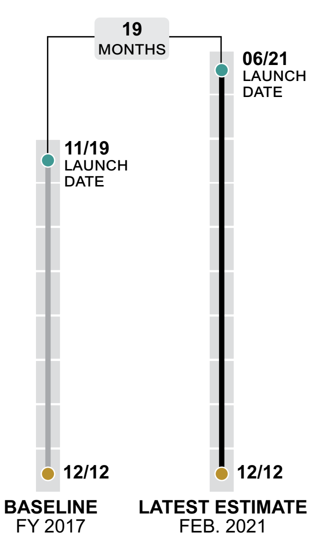
Requirement Derived from: **NASA Strategic Plan**

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

PROJECT SUMMARY

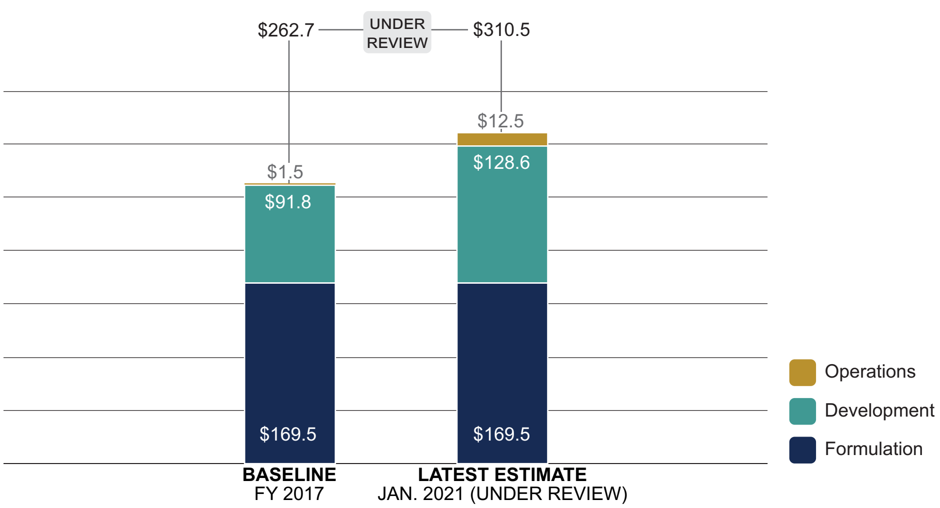
The LCRD project launch date slipped an additional 5 months to June 2021—for a total delay of 19 months—due to launch availability and continued technical issues associated with the U.S. Space Force spacecraft that hosts the LCRD payload. Project costs are under review but expected to increase to accommodate the latest launch date delays. These delays are due, in part, to ongoing issues with the high data rate system in the host spacecraft. The project is tracking as a top risk and, if issues with this system are not fully resolved, LCRD may be unable to declare full mission success. According to officials, the project worked with the U.S. Space Force and mission partners in testing several high data rate system fixes and improvements to mitigate the risk and increase the likelihood of mission success. Although the project was able to minimize the effects of COVID-19 by gaining timely approval for restart activities at key facilities, future COVID-19 restrictions are unknown. Future restrictions could affect the project's ability to support remaining spacecraft integration and test events critical to meeting the new launch readiness date.

SCHEDULE PERFORMANCE



COST PERFORMANCE

then-year dollars in millions



Cost and Schedule Status

The LCRD project's launch date slipped by an additional 5 months to June 2021, which represents a total delay of 19 months from the project's original baseline. Project officials said that the latest launch delay was due to launch availability and technical issues with the U.S. Space Force spacecraft. The project previously experienced a $47.8 million dollar life-cycle cost increase, and officials expect additional unplanned costs to support this latest launch date delay including funds to retain key staff longer than planned. Costs are under review and will be finalized when the project enters the operations and sustainment phase in June 2021.

Integration and Test

The launch delays occurred, in part, because the U.S. Space Force contractor for LCRD's host spacecraft experienced technical issues with its high data rate system that processes data sent between the spacecraft and the ground station. The system caused delays during early integration testing when software issues caused it to lose data when multiple payloads, including LCRD, attempted to downlink data at the same time. Although the contractor was able to resolve this and other early integration issues, failures in other components of the high data rate system continued to add delays to the launch date.

In addition, one of the project's top risks is that issues with this system, which carries LCRD's telemetry data, may not get fully resolved and could render LCRD unable to declare full mission success. According to officials, the project worked with the U.S. Space Force and mission partners in planning, implementing, and testing several high data rate system fixes and improvements with suppliers during the latest launch delay period to mitigate risk and increase the likelihood of mission success.

COVID-19 Effects

LCRD project officials reported that COVID-19 did not affect the project's recent launch delays and had minimal effects on its cost or schedule in 2020. Officials largely attributed this to the project's ability to gain timely approval of restart activities at key facilities. In addition, the project was able to adjust quickly to remote access situations and devise work-arounds to complete tasks at facilities that were closed for all except mission-essential personnel. For example, when COVID-19 restrictions prevented the project from providing an on-site witness to oversee contractor modifications to LCRD's frame prior to installation on the satellite, the project set up cameras to allow officials to observe remotely and avoid further delays. Despite the minimal effects in 2020, as of January 2021 the project was tracking a risk that potential future COVID-19 restrictions could affect its ability to support spacecraft integration and test events critical to support the launch.

PROJECT OFFICE COMMENTS

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

Source: Lockheed Martin. | GAO-21-306

Low Boom Flight Demonstrator

The 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. The LBFD project plans to generate data to inform the development of internationally accepted 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.

FORMULATION
- 03/13 Start of concept formulation studies
- 03/14 Mission definition review
- 09/16 LBFD formulation start
- 08/18 Preliminary design review
- 11/18 Project confirmation

IMPLEMENTATION
- 09/19 Critical design review
- **01/21 GAO review**
- 06/22 First flight date
- 05/23 System acceptance review
- 02/24 Aircraft transfer review

PROJECT INFORMATION

NASA Lead Center: **Virtual project office**

International Partner: **None**

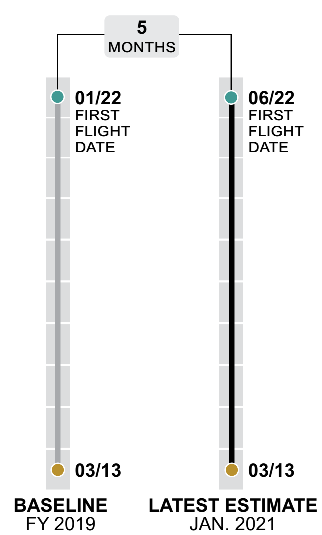
Requirement Derived from: **Aeronautics Research Mission Directorate Strategic Implementation Plan**

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

PROJECT SUMMARY

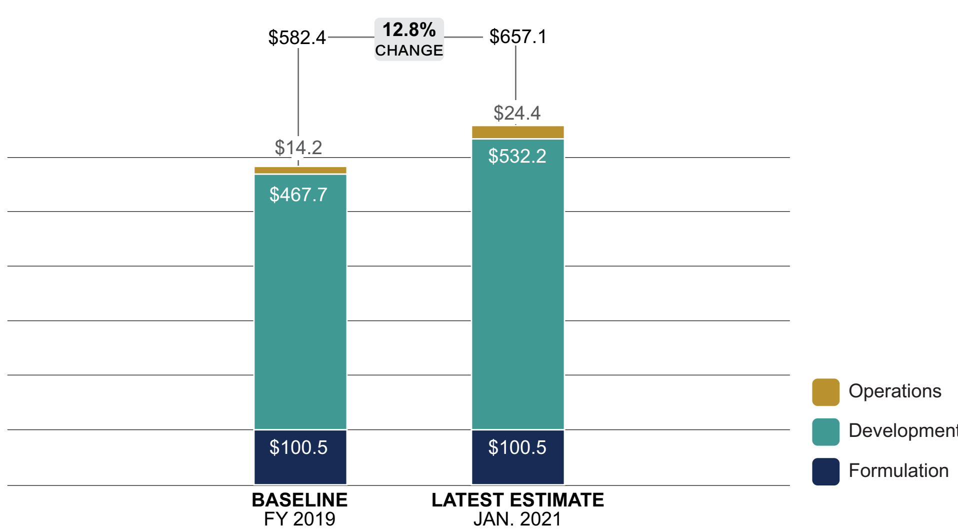
The LBFD project encountered development cost overruns of $64.5 million and 5 months of schedule delays due to the contractor's delayed releases of design drawings and its quality issues with supplier deliveries. Project officials stated that the revised estimates also reflect the effect of contractor facility shutdowns due to COVID-19. However, the project is tracking risks to meeting its revised schedule, including future effects from COVID-19 that could affect production and hardware development and result in additional cost increases and schedule delays. In May 2020, the project successfully completed the last of its subsystem critical design reviews, which allowed it to significantly improve the amount of design drawings it released. The project continues to mitigate a key technical risk that the aircraft weight will exceed targets. Project officials stated they have better defined this technical risk by tracking the weight requirement as maximum takeoff weight to minimize the effect of fuel burned prior to takeoff.

SCHEDULE PERFORMANCE



COST PERFORMANCE

then-year dollars in millions



Cost and Schedule Status

In August 2020, NASA approved a net increase of $74.7 million over the LBFD project's life-cycle cost estimate and a delay of 5 months beyond the schedule baseline. According to officials, development cost overruns of $64.5 million and associated schedule issues stemmed from the contractor's delayed releases of design drawings and its quality issues with supplier deliveries that required expensive rework. For example, one of the large titanium pieces in the plane's tail had errors with drilled holes as well as issues with straightness that required heat treatments to flatten them out. The remaining $10.2 million in increased operations cost is for staffing during the longer schedule.

Project officials stated that these revised cost and schedule estimates incorporate costs to cover two COVID-19 related production shutdowns lasting a total of 28 days at the contractor facility. NASA also included $21.1 million in supplemental costs to restore reserves.

The project is tracking several schedule risks to its first flight, including remaining installation work, system testing, and effects from COVID-19. The project identified potential delays in subsystem installation on the aircraft based on past contractor delays installing components on the wing. In addition, there could be delays if flight readiness test results reveal the need for additional rework or retesting following installation. Lastly, although officials said they have accounted for known COVID-19 cost and schedule effects in their latest estimates, they continue to track potential risks of future COVID-19 effects on production and hardware development. As a result, the project may experience further cost increases and schedule delays due to COVID-19 beyond those captured in the August 2020 estimates.

Design

The project successfully completed the last of its subsystem critical design reviews (CDR) in May 2020. Prior to the mission's CDR in September 2019, the project declared that the NASA-led Flight Test Instrumentation System was not mature enough to pass the review because integration challenges warranted additional design changes. As a result, this subsystem and one other—the NASA-led Power Distribution System—held subsystem CDRs after the mission-level CDR, both of which have been successfully completed.

Following these reviews, the project released 98 percent of its design drawings—up from 37 percent at the mission CDR. This marks a significant improvement. GAO's best practice is 90 percent drawing release at CDR, which lowers the risk of projects experiencing design changes that can lead to cost and schedule growth. As noted above, the delay in design drawing releases contributed to the project's cost overruns and schedule delays. Project officials previously stated they never anticipated meeting GAO's best practice at the project's CDR because its aircraft contractor uses a process that enables it to initiate early fabrication as key design drawings are completed.

Technology

The project continues to mitigate a key technical risk that the aircraft will exceed weight targets, jeopardizing mission performance. Project officials stated they have better defined this technical risk by tracking the weight requirement as maximum takeoff weight to minimize the effect of fuel burned prior to takeoff. After subtracting the weight of fuel burned off during taxi prior to takeoff, the project calculates its weight for takeoff is within the requirement. However, NASA continues to track an additional risk to weight associated with integration equipment that is still undergoing design work.

PROJECT OFFICE COMMENTS

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

Source: Lockheed Martin Space. | GAO-21-306

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 seven Trojans over a 12-year mission. The mission's planned measurements include asteroid surface color and composition, interior composition, and surface geology.

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**

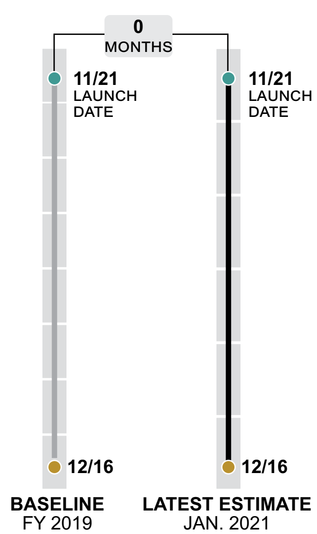
Requirement Derived from: **Discovery Program Announcement of Opportunity 2014**

Budget Portfolio: **Science, Planetary Science**

PROJECT SUMMARY

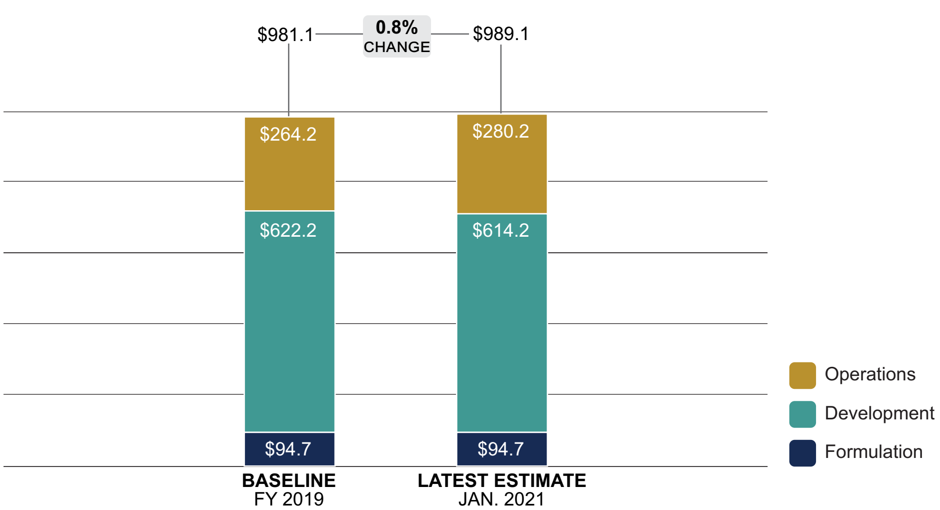
In September 2020, Lucy entered the system assembly, integration and test, and launch phase. The project's life-cycle cost estimate increased to extend the operations of a student collaboration managed outside of the project, but the project has maintained its schedule baseline. The project has received headquarters-held reserves to restore project cost reserves consumed by COVID-19. Officials explained that the project is consuming cost reserves to maintain its November 2021 launch date. The launch date is a planetary window, which means the project would exceed its schedule baseline by approximately 1 year if it misses the current date. Lucy experienced technical and engineering challenges related to its solar arrays, but officials report they have since received delivery of the solar arrays. The project started the final assembly and integration process of its instruments and subsystems, and has received and installed its instruments on the spacecraft.

SCHEDULE PERFORMANCE



COST PERFORMANCE

then-year dollars in millions



Cost and Schedule Status

In September 2020, Lucy entered the system assembly, integration and test, and launch phase, and is maintaining its schedule baseline, but the project's life-cycle cost estimate has increased. The project experienced cost growth of $8 million to extend the operations of an already-underway student collaboration managed outside of the project. As of January 2021, the project has been addressing COVID-19-related issues through the use of cost reserves. Officials explained that the project is consuming cost reserves to support activities such as adding extra shifts to maintain its November 2021 launch readiness date. If Lucy misses the launch window associated with this date, then officials said the next available window is approximately 1 year later.

In order to maintain its launch window, officials said they focused on mitigating schedule delays exacerbated by the COVID-19 situation. Project officials said they anticipated adjusting the project's assembly, test, and launch operations (ATLO) schedule even prior to COVID-19, but the shutdown of the Goddard Space Flight Center and reduced restart efficiency exacerbated the need for a revised schedule. As a result, the project's COVID-19 mitigation strategy is to implement a Feasible ATLO Shortened Timeline approach that physically separates two alternating teams, which promotes safety and allows them to continue working alternating schedules.

Technology

Since its critical design review, Lucy's solar arrays experienced delays from technical, engineering, and COVID-19-related shutdown challenges, which resulted in the project receiving the solar arrays 6 months later than originally planned. For example, the project was tracking a risk that the solar arrays could degrade science capabilities. To mitigate this risk, the project planned to conduct contamination testing and to finalize control protections. Lucy halted the risk reduction testing as facilities shut down in response to COVID-19 and restarted them in August 2020. Since then, the project completed all solar array panels and began array assembly. To further mitigate this risk, the project received delivery of the solar array parts as they were completed instead of as an integrated whole. Project officials stated that, as of March 2021, they have received the solar arrays and are preparing to integrate them with the spacecraft prior to the start of environmental testing.

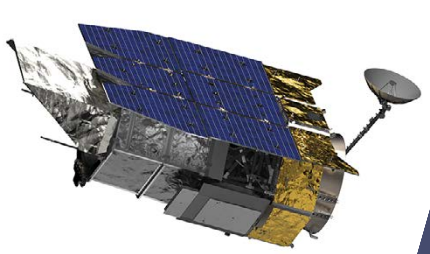
Integration and test

The project started the final assembly and integration process of its instruments and subsystems, and has integrated all of its instruments. Since completing its system integration review, which allows the project to begin integration, the project completed and installed the Lucy Long Range Reconnaissance Imager, Lucy Thermal Emission Spectrometer, and Lucy Ralph instruments. The project also delivered the spacecraft propulsion subsystem, mitigating substantial technical and schedule risk to the integration and test process.

PROJECT OFFICE COMMENTS

When commenting on a draft of this assessment, Lucy project officials stated that they concur that our assessment accurately reflects the project's status at the time of the assessment and provided technical comments, which were incorporated as appropriate. The project also provided updates on the status of the solar arrays, which according to project officials, as of April 2021, have been installed on the spacecraft.

Nancy Grace Roman Space Telescope



The Nancy Grace Roman Space Telescope (Roman), formerly known as Wide-Field Infrared Survey Telescope, 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 Roman 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-21-306

FORMULATION
- 02/16 Formulation start
- 03/18 System requirements/ mission definition review
- 10/19 Preliminary design review
- 02/20 Project confirmation

IMPLEMENTATION
- **01/21 GAO review**
- 09/21 Critical design review
- 07/23 System integration review
- Under review Target launch readiness date
- 10/26 Committed 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: **To be determined (Heavy Class)**

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

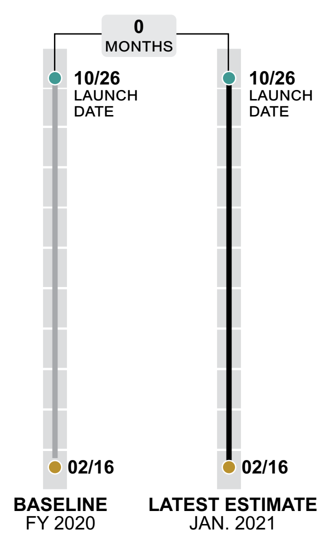
Requirement Derived from: **2010 Astrophysics Decadal Survey**

Budget Portfolio: **Science, Astrophysics**

PROJECT SUMMARY

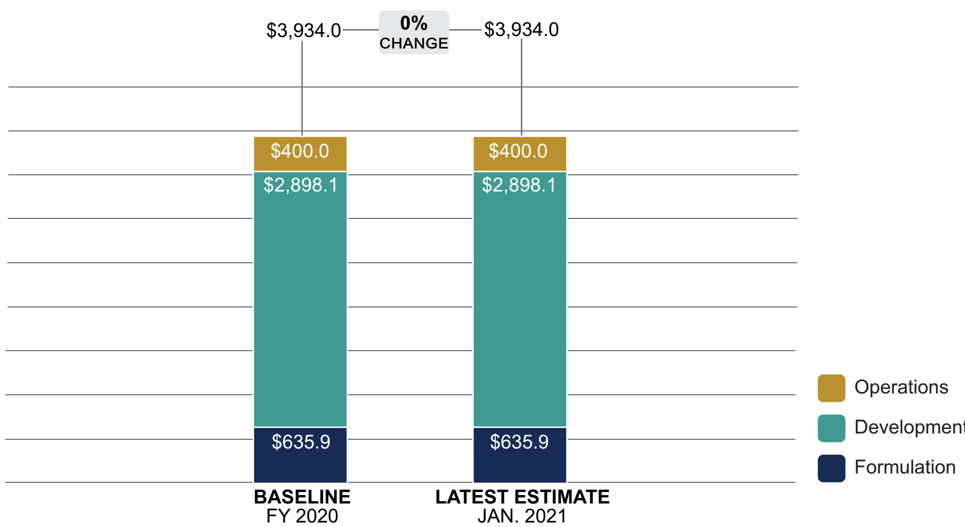
In February 2020, the Roman project entered the implementation phase and formally established a baseline life cycle cost of $3.93 billion and an October 2026 launch readiness date. Within that cost estimate, NASA established an internal development cost cap of $334 million for the Coronagraph Instrument (CGI) to reduce the risk that it could drive Roman cost and schedule growth. The Roman project has continued to refine its design and make progress, but its schedule is slipping due to the effects of COVID-19. NASA will not know the full effects until operations return to normal, but is currently assessing the effects. The project has three technologies that were not mature when it completed its preliminary design review. The project is continuing to mature its design and complete testing for these technologies. While NASA did not request funding for Roman in its fiscal year 2021 budget request, the explanatory statement accompanying the fiscal year 2021 Consolidated Appropriations Act stated that the Act provided $505.2 million for the project. The project continues to progress through its life cycle and is working toward its critical design review, which is planned for September 2021.

SCHEDULE PERFORMANCE



COST PERFORMANCE

then-year dollars in millions



Cost and Schedule Status

The Roman project entered the implementation phase and established its cost and schedule baselines in February 2020. NASA set a baseline life-cycle cost of $3.93 billion and an October 2026 launch readiness date. This is $134 million above the top-end of the project's preliminary cost estimate and 1 month later than its preliminary schedule estimate. Within the development cost baseline, NASA established a separate internal development cost cap of $334 million for the CGI to mitigate concerns that it could drive cost and schedule growth for the project. This baseline does not include $50 million for hardware that international partners will contribute.

The project estimates that cost and schedule effects from COVID-19 will result in it exceeding its internal cost commitment and will delay its launch readiness date from December 2025 to no earlier than March 2026, but project and program officials are currently assessing the effects. Project officials said that mitigating effects from COVID-19 is a top cost risk because the pandemic has made the project less efficient, and all Roman system elements and partners have supply chain effects. For example, the delivery schedule for the Wide-Field Instrument (WFI)—Roman's principle instrument—has slipped 6 months due to supply chain effects from COVID-19. According to project officials, Roman will continue to see significant schedule effects, which will not be fully realized until the project returns to some regularity after COVID-19 has resolved.

The President's fiscal year 2021 budget proposed canceling Roman, the third year the President's budget has done so. However, the explanatory statement accompanying the fiscal year 2021 Consolidated Appropriations Act stated that the Act included $505.2 million for the project.

Design and Technology

Roman passed its preliminary design review (PDR) in October 2019, but it currently has three critical technologies that are not yet matured to technology readiness level (TRL) 6. This does not align with our best practice for technology maturity, which states that critical technologies should achieve a TRL 6 by PDR to minimize risks for further product development. One of these technologies—the WFI optical prism—was a late addition to the WFI and is projected to be at TRL 6 by the planned September 2021 critical design review (CDR). After the mission-level PDR, the spacecraft's deployable aperture cover was redesigned to reduce the risk of a failed deployment, and the project expects to have the new design at TRL 6 by CDR as well. The third technology, the launch loads and vibration isolation system, needs to be qualified to operate in Roman's operating environment and modified to advance from its current TRL 5.

Coronagraph Instrument

The CGI is a leading-edge technology demonstration instrument designed to perform high-contrast imaging and spectroscopy, a technique used to study light, of nearby exoplanets. Project officials explained that they separated CGI management from Roman's and reduced its performance requirements, to give CGI greater decision-making flexibility and to encourage it to remain within its schedule and cost cap. For example, NASA eased requirements on some of CGI's components, which may result in better component engineering designs, fewer design iterations, and less mass. Also, NASA has identified potential technology off-ramps to avoid increased costs.

CGI has also been affected by COVID-19, including delays to optics deliveries from the Japan Aerospace Exploration Agency (JAXA). JAXA is experiencing significant delays in its supply chain due to COVID-19. To mitigate the delays, NASA is exploring pursuit of a parallel procurement path with domestic vendors.

PROJECT OFFICE COMMENTS

When commenting on a draft of this assessment, Roman officials said that COVID-19 effects could reduce reserves needed for technical issues that arise during the development, integration and test phases and could also cause CGI to not meet its development cost cap. Officials also said that formulation costs increased $23 million and development costs decreased $23 million from the baseline to reflect formulation actual costs. They also provided technical comments, which were incorporated as appropriate.

NASA ISRO – Synthetic Aperture Radar

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

Source: © California Institute of Technology/Jet Propulsion Laboratory. | GAO-21-306

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
- 10/20 System integration review
- **01/21 GAO review**
- ***Under review*** Target launch readiness date
- ***Under review*** 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**

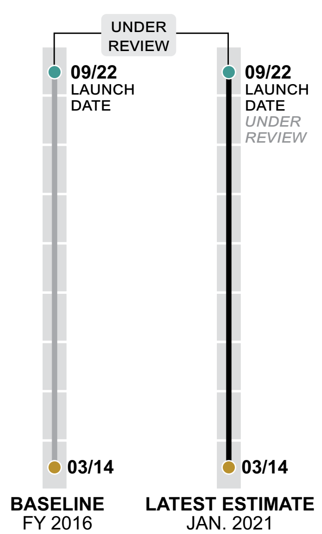
Requirement Derived from: **2007 Earth Science Decadal Survey**

Budget Portfolio: **Science, Earth Science**

PROJECT SUMMARY

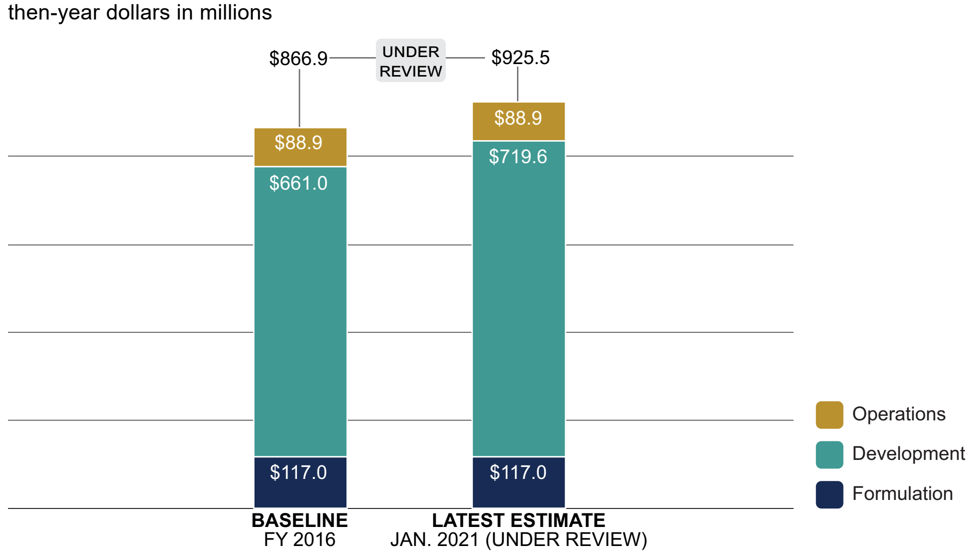
The NISAR project is reevaluating its schedule and associated costs following continued delays with both the NASA- and ISRO-provided radars. COVID-19 has further exacerbated delays for the project, and the effects of those delays are also being incorporated into the revised schedule analysis. The project expects the launch date will be later than the baseline date of September 2022, and it will seek approval from NASA on a new cost and schedule before the project enters the system assembly, integration and test, and launch phase. The project's critical path includes integration and test of both radars, and the project is tracking multiple technical and COVID-19-related risks that could delay its integration and test schedule. The project's international partner, ISRO, is on track to certify the launch vehicle it is providing in time for NISAR's launch.

SCHEDULE PERFORMANCE



COST PERFORMANCE

then-year dollars in millions



Cost and Schedule Status

The NISAR project estimates that it will exceed its cost baseline and is reevaluating both its schedule and associated costs following continued delays with both the NASA- and ISRO-provided radars. The project expects the launch date will be later than the baseline date of September 2022. The project will be seeking approval from NASA for a new cost and schedule before the project enters the system assembly, integration and test, and launch phase.

While COVID-19 is exacerbating schedule issues for the project, the project began reviewing its cost and schedule status prior to COVID-19 because ISRO delayed the delivery of its radar due to hardware delivery delays. Since the project started reassessing its schedule, COVID-19 and technical issues with the NASA-provided radar caused further schedule delays. For example, a number of cables used on the NASA radar did not meet the project's quality requirements. NISAR assessed multiple mitigation options and chose to replace the cables. Project officials do not expect any further schedule effects from this issue.

The project's critical path includes the integration and testing of both the NASA- and ISRO-provided radars, which cannot be completed until the ISRO radar is delivered. Project officials stated that their ongoing schedule analyses plan for ISRO delivering the radar by February 2021, but the schedule can be modified to accommodate a delivery as late as June 2021 by rearranging and descoping test events.

Integration and Test

The NISAR project completed its systems integration review in October 2020 but is tracking risks that it could experience delays in integration and test. In particular, the complexities involved in conducting joint integration and test with ISRO—exacerbated by COVID-19 restrictions—could continue to cause delays. Project officials expressed the concern that key personnel will not be able to travel to facilitate the integration and testing of the ISRO-provided hardware. NISAR formed a team to begin planning for and developing safety protocols for this work.

Spacecraft

The project also resolved a technical concern that, due to a miscommunication during spacecraft design, the spacecraft may not be able to maneuver to avoid full Sun exposure upon arrival in orbit. According to project officials, the temperature differences associated with full Sun exposure could pose a risk to certain flight hardware. Project officials said that they identified options that would allow the spacecraft to maneuver to a position that would protect sensitive equipment and worked with ISRO, which is building the spacecraft, to implement them. Project officials further stated that the option selected only requires minor changes to a few pieces of hardware, which are being made.

Launch Vehicle

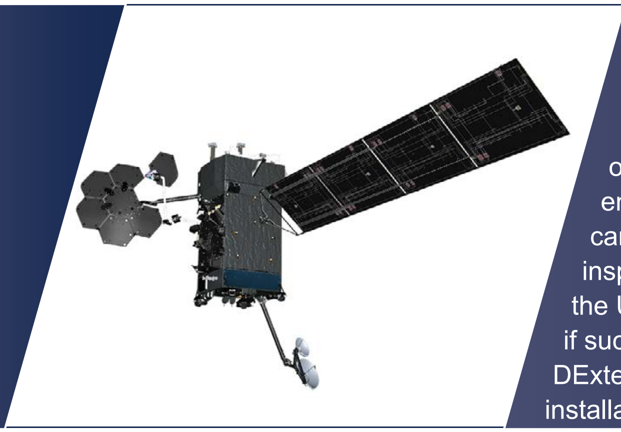
ISRO will provide the project's launch vehicle—the Geosynchronous Satellite Launch Vehicle (GSLV) Mark II—which must meet five criteria before it can be used. As we previously reported, two of the five criteria are already met.[1] To meet another criterion, ISRO must conduct a launch with a 4-meter fairing—the nose cone of the rocket used to protect the payload. The first launch demonstrating this configuration was delayed and, as of January 2021, has not yet launched. The two remaining criteria are a successful launch and another successful 4-meter fairing launch, both prior to NISAR's launch. Four additional flights of the GSLV—three with the 4-meter fairing—are planned before NISAR's launch, which, if successful, should satisfy the criteria.

PROJECT OFFICE COMMENTS

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

[1] GAO, *NASA: Assessments of Major Projects*, GAO-20-405 (Washington, D.C.: Apr. 29, 2020).

On-Orbit Servicing, Assembly and Manufacturing 1



The On-Orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1) project plans to demonstrate a capability to autonomously refuel and extend the life of on-orbit satellites. This technology is available for use by U.S. commercial entities and NASA plans to incorporate elements into its lunar exploration campaign. Specifically, OSAM-1 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, which can extend operations if successfully refueled. The project also plans to use the SPace Infrastructure DExterous Robot (SPIDER) payload to demonstrate on-orbit assembly and installation of an antenna and manufacturing of a beam.

Source: Maxar Technologies. | GAO-21-306

FORMULATION

- 05/16 Formulation start
- 10/16 System requirements/ mission definition review
- 11/17 Preliminary design review
- 06/20 Project confirmation

IMPLEMENTATION

- **01/21 GAO review**
- 06/21 Critical design review
- 02/22 System integration review
- 01/25 Target launch readiness date
- 09/25 Committed launch readiness date

PROJECT INFORMATION

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

International Partner: **None**

Launch Location: **To be determined - Vandenberg Air Force Base, CA or Kennedy Space Center, FL**

Launch Vehicle: **To be determined - Falcon 9 or Atlas V**

Mission Duration: **12 months**

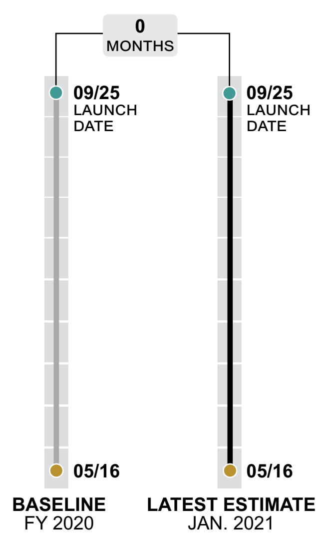
Requirement Derived from: **Consolidated Appropriations Act, 2016**

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

PROJECT SUMMARY

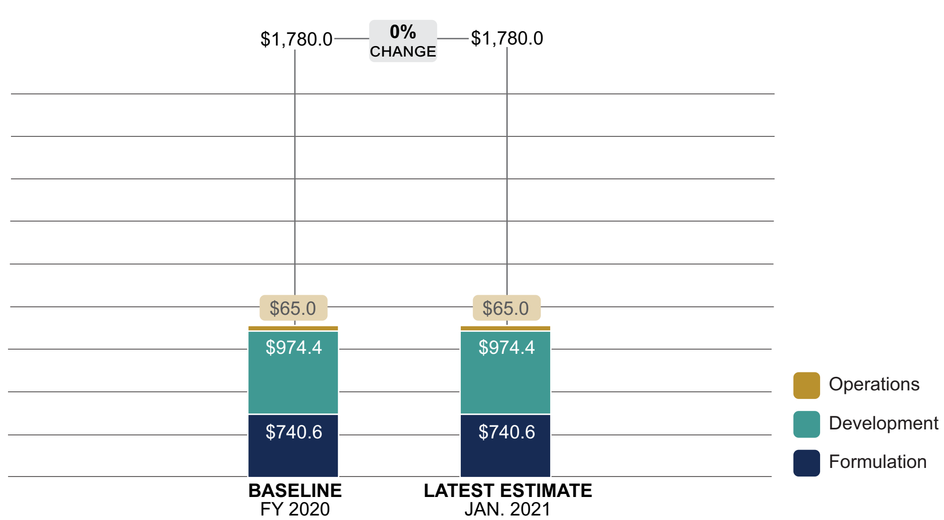
OSAM-1 (formerly known as Restore-L) established cost and schedule baselines in June 2020 at $1 billion above the top-end of the project's preliminary cost estimate and an increase of almost 5 years to the schedule estimate. The cost increases are due to the addition of the SPIDER payload and the decision to launch 5 years later, among other things. Officials said COVID-19's most significant effect on the project was reduced efficiency resulting from site closures, which has led to schedule delays and cost increases. As a result, OSAM-1 is tracking a risk that COVID-19 will challenge OSAM-1's fiscal year 2021 budget, and it will not maintain its current internal launch readiness date of January 2025. Additionally, OSAM-1 is tracking a risk that the Landsat 7 satellite will fail before OSAM-1 can service it, and the project will not complete its technology demonstration.

SCHEDULE PERFORMANCE



COST PERFORMANCE

then-year dollars in millions



Cost and Schedule Status

The OSAM-1 project (formerly known as Restore-L) entered the implementation phase and formally established its cost and schedule baselines in June 2020. The project set a baseline life-cycle cost of $1.78 billion and a launch date of September 2025, which is $1 billion above the top-end of the project's preliminary cost estimate and almost 5 years later than its preliminary schedule estimate. The cost increases reflect, in part, the April 2019 addition of the SPIDER payload and the decision to launch nearly 5 years later than initially planned. Project officials noted that the preliminary estimate was performed more than 3 years before they set the baseline for the mission, which now has a very different scope, complexity, funding profile, and schedule. As a result of the new life cycle cost, mission complexity, and external visibility, NASA has re-categorized the project as a Category 1 mission (i.e., a mission costing greater than $1 billion), which makes the NASA Associate Administrator the decision authority for the project.

According to project officials, COVID-19's most significant effect on the project to date was the reduced efficiency resulting from shutdowns at NASA centers and contractors, which has led to schedule delays and cost increases. To mitigate these effects, OSAM-1 plans to defer milestones and non-critical servicing payload work. For example, the project delayed its critical design review 8 months to June 2021. Because COVID-19 continues to deteriorate project schedule, the project is tracking a risk that OSAM-1 will not maintain its current internal launch readiness date of January 2025.

In addition, project officials stated that their plan to defer milestones will help mitigate OSAM-1's cost reserves status. As of February 2021, the project has a flat budget with low cost reserves that are inconsistent with NASA center policy. For example, the project is tracking a risk that OSAM-1's fiscal year 2021 budget will be challenged by COVID-19 because the project has no funding reserves to address associated effects. However, with the slip of completion of the flight SPIDER Robotic Arm Assembly payment milestones to fiscal year 2022, the project was able to use $5 million as contingency and satisfy a portion of these fiscal year 2021 budget challenges.

Technology

The project is tracking a risk that before OSAM-1 can service the Landsat 7 satellite, the satellite will have a hardware failure and OSAM-1 will be unable to complete its technology demonstration. As a result, a NASA team outside of the project conducted a study identifying potential substitute candidates for the demonstration and identified seven possible alternates. However, project officials explained that changing satellites would likely lead to cost and schedule increases due to redesigns and additional testing, which could affect the project's launch readiness date.

In October 2020, the OSAM-1 project began tracking a new risk regarding a possible redesign of its Two Axis Gimbal (TAG), which supports OSAM-1's Steerable High Gain Antenna. The project reports that the TAG may fail prematurely, which could prevent OSAM-1 from accomplishing its mission objectives. The project is mitigating this risk by modifying its operational plans to rely less on the TAG and researching hardware modifications to prevent the TAG from failing early. However, the project notes that these changes to the mission's operation plans could create undesirable risk to accomplishing mission objectives and may not extend the TAG's life sufficiently, which could result in a complete redesign and replacement of the TAG and late antenna delivery.

Other Issues to be Monitored

To resolve conflicts with the Nancy Grace Roman Space Telescope (Roman) mission for one of the Goddard Space Flight Center clean rooms, the center directed OSAM-1 in July 2020 to vacate the facility and use an alternate clean room, which could increase costs and delays. Moving to another facility requires OSAM-1 to replan the project's integration and test schedule and upgrade the facility. As of December 2020, the project planned to share facility upgrade costs with Roman and was assessing potential cost effects.

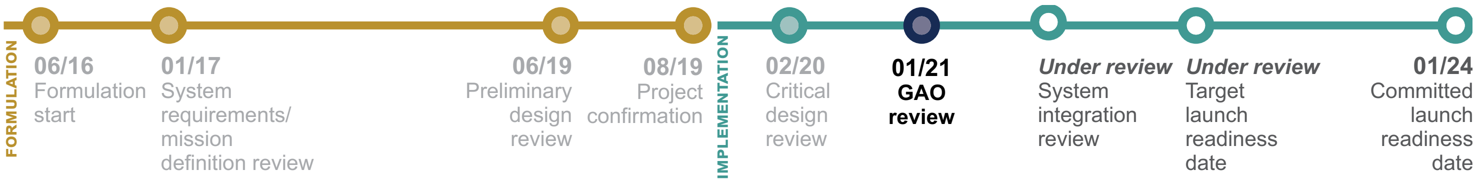
PROJECT OFFICE COMMENTS

When commenting on a draft of this assessment, OSAM-1 project officials stated they agreed with GAO's assessment with the exception of comparing the preliminary cost estimate to the baseline cost estimate due to the change in project scope. We did not characterize this change as cost growth but included the comparison to provide context for the extent to which the project has changed since preliminary estimates. The project also provided technical comments, which were incorporated as appropriate.

Source: NASA. | GAO-21-306

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.



PROJECT INFORMATION

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

International Partner: **Netherlands Space Office (Netherlands)**

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

Launch Vehicle: **Falcon 9**

Mission Duration: **3 years**

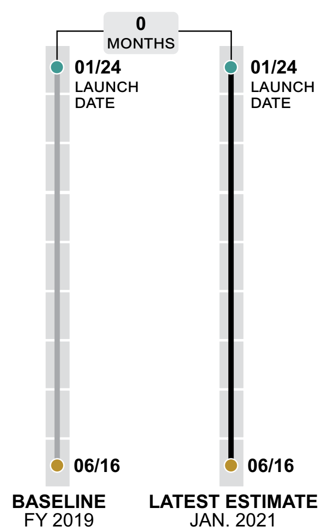
Requirement Derived from: **2007 Earth Science Decadal Survey**

Budget Portfolio: **Science, Earth Science**

PROJECT SUMMARY

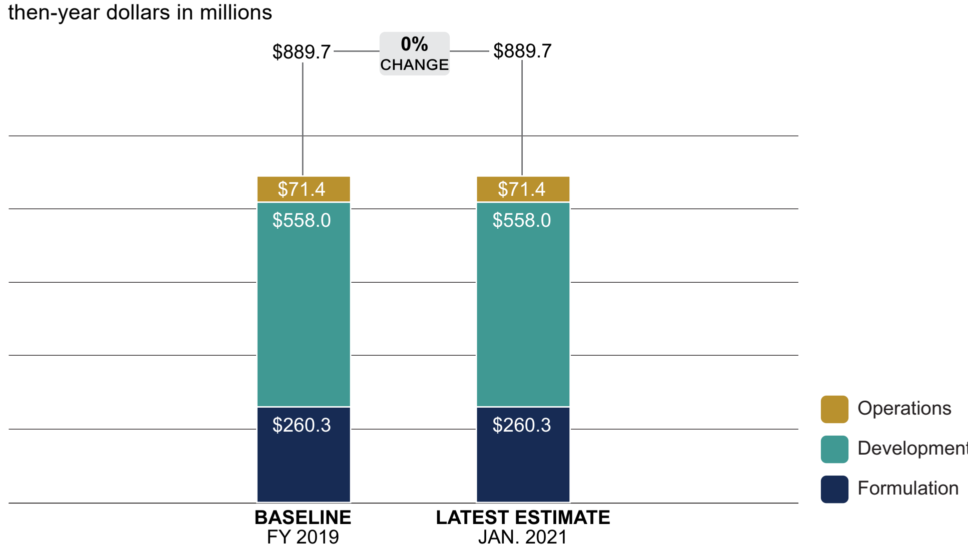
The PACE project has used all of its schedule reserves to address effects from COVID-19, and officials expect costs will soon exceed the project's baseline. COVID-19 effects driving some of these schedule and cost changes include: months of not being able to access lab spaces and reduced efficiency due to COVID-19 mitigations and staff illness. The PACE project held its critical design review in February 2020, at which time it had released 68 percent of its design drawings, which does not align with GAO's best practice that recommends releasing 90 percent of drawings at this review. The project has since released over 90 percent of its design drawings, largely because it was an activity that could be completed remotely during COVID-19. The PACE project has also experienced technical issues with the development of its Ka-band transmitter and is mitigating these issues by establishing a new management team for the component's development, but continued delays may further affect the project's schedule.

SCHEDULE PERFORMANCE



COST PERFORMANCE

then-year dollars in millions



Cost and Schedule Status

The PACE project has used all of its cost and schedule reserves to address the effects of COVID-19, and project officials anticipate costs will increase above the baseline. The PACE project did not have access to lab spaces for several months, resulting in the project not being able to accomplish all of the work it had planned during that time. As of November 2020, the project was restarting activities—including spacecraft hardware development—but reported that COVID-19 mitigations and illnesses were affecting efficiency levels and schedule. As a result, the project estimates that it has no schedule reserves remaining to its January 2024 baseline launch date, down from 10 months of schedule reserve before COVID-19. In addition, as of January 2021, the project had no cost reserves remaining to address risks and any unforeseen technical challenges. Project officials are assessing the project's current cost estimate and anticipate costs will increase to address the effects of COVID-19, including restoring the project's cost reserves.

Similar to the previous 3 years, NASA did not request funding for PACE in its fiscal year 2021 budget request. However, a House report on NASA's 2021 appropriations stated that the committee was providing $145.1 million to PACE, which is slightly below the amount the project had planned for its fiscal year 2021 budget.

Design

PACE held its critical design review (CDR) in February 2020, having released approximately 68 percent of its design drawings, which is below the best practice of releasing 90 percent of design drawings at this review. According to GAO's best practice, releasing at least 90 percent of engineering drawings at CDR lowers the risk of projects experiencing design changes that can lead to cost and schedule growth. Four months following the project's CDR, however, the project had released over 90 percent of drawings, showing that the project progressed in maturing and stabilizing its design. Officials said that completing project paperwork—including design drawings—was a focus during the initial remote work period at the beginning of COVID-19.

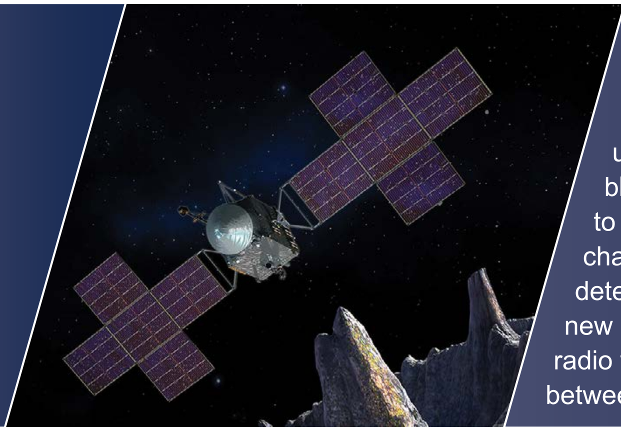
During PACE's CDR, the project's standing review board identified staffing, schedule, and testing concerns regarding the Ocean Color Instrument (OCI), the primary instrument on PACE. Since then, project officials said they addressed the review board's concerns, such as adding staff to support the OCI's development and completing key tests on the OCI engineering model. However, the OCI remains one of the project's critical paths, primarily due to fabrication and testing delays resulting from COVID-19.

Integration and Test

PACE reported that the Ka-band transmitter is experiencing delays to its development schedule due to previously identified software issues with the environmental test unit model of the transmitter. These issues could affect the schedule for building and delivering it to system integration and testing. The project was not able to fully resolve the issues due to restricted lab access as a result of COVID-19. According to project officials, there is a risk that the development of the Ka-band transmitter flight unit will begin before all testing is complete on the environmental test unit model. PACE has appointed a manager and a new project systems engineer to support development of the transmitter to mitigate this risk. The project is also moving forward with flight unit transmitter production using lower-risk components.

PROJECT OFFICE COMMENTS

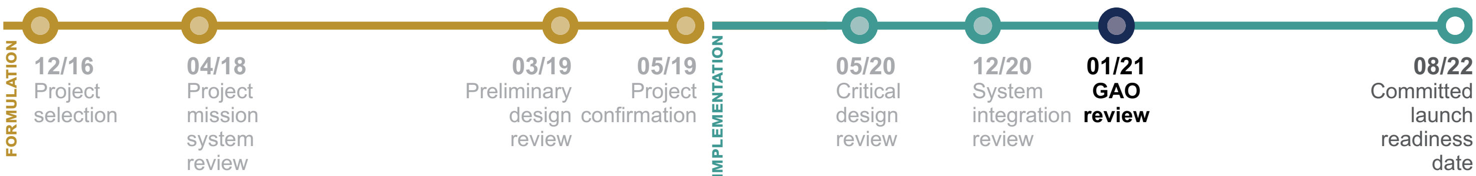
In commenting on a draft of this assessment, PACE project officials offered technical comments, which were incorporated as appropriate.



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 (1) whether it is a planetary core or unmelted material, (2) characterize its topography, (3) assess its elemental composition, and (4) 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-21-306



PROJECT INFORMATION

NASA Lead Center: **Jet Propulsion Laboratory**

International Partner: **Technical University of Denmark**

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

Launch Vehicle: **Falcon Heavy**

Mission Duration: **21 months science operation**

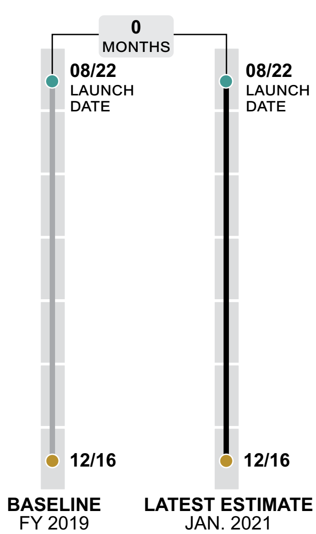
Requirement Derived from: **Discovery Program Announcement of Opportunity 2014**

Budget Portfolio: **Science, Planetary Science**

PROJECT SUMMARY

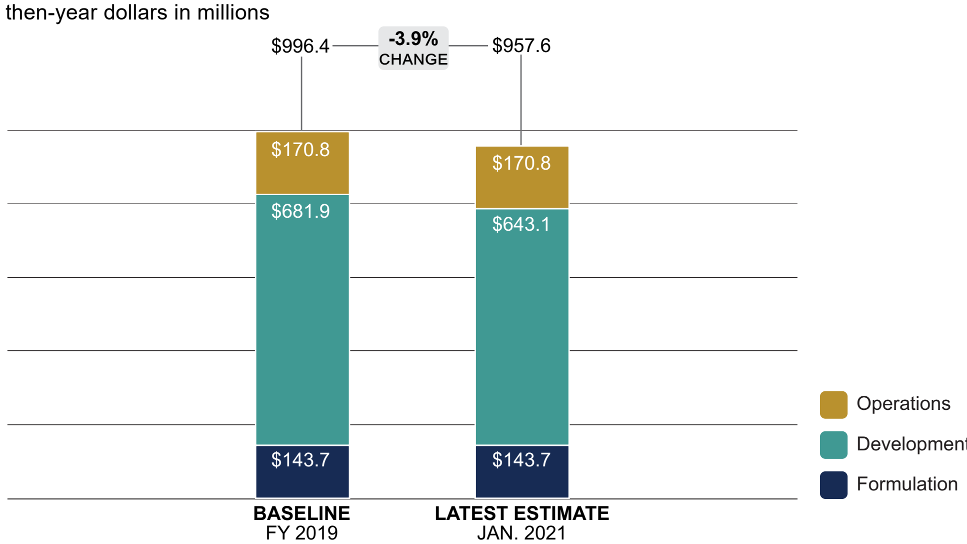
The Psyche project continues to meet its cost and schedule baselines, but COVID-19-related schedule delays could affect the project's launch readiness date. The project is tracking a number of schedule and technical risks exacerbated by the COVID-19 situation, such as the late delivery of its Gamma Ray Neutron Spectrometer (GRNS) instrument. In addition, the project's life-cycle cost estimate decreased by $38.8 million to incorporate cost changes from selecting a launch vehicle. While the launch vehicle costs less than planned, the project needed more cost reserves to accommodate the effects of COVID-19 and is at risk of needing more reserves in the future. The Psyche project also passed its critical design review in May 2020, but some of its design reliability independent assessments are behind schedule, resulting in a technical risk that potential design changes could require rework of already manufactured materials or waivers.

SCHEDULE PERFORMANCE



COST PERFORMANCE

then-year dollars in millions



Cost and Schedule Status

The Psyche project continues to meet its cost and schedule baselines, but COVID-19-related schedule delays could affect the project's launch readiness date. Officials said the project experienced continued schedule deterioration from instrument delivery delays that were exacerbated by COVID-19. The project began tracking schedule delays for the GRNS in early 2019 due to long procurement lead times. As of October 2020, the GRNS schedule will not meet the project's need date as a result of late design changes that required additional development work and COVID-19. In addition, the project noted that COVID-19-related work stoppages affected the production efforts for all areas of the project. The project has little schedule margin and, as of October 2020, began to assess contingency launch possibilities beyond the project's baseline August 2022 date as a schedule mitigation option.

The Psyche project's cost estimate has decreased by $38.8 million below the cost baseline because the launch vehicle costs were lower than expected. In addition, NASA released headquarters-held cost reserves to offset COVID-19 costs. However, the project may need additional reserves because substantial cost and schedule pressures from COVID-19, wildfire-related closure of California facilities, and technical challenges remain.

Design and Technology

Psyche passed its critical design review (CDR) in May 2020. We did not assess if the project met GAO's best practice for design stability at its CDR because this metric relies on design drawings, which the project does not collect. Project officials explained that drawings are not relevant or used by the project because the majority of the spacecraft is a commercial product bought on a fixed-price contract.

Project officials stated that they review all vendor designs and independently assess the reliability of the electronics designs. These officials explained that one of the concerns raised at CDR was the lagging independent assessment of the reliability of some of these electronic designs. Since manufacturing had already started, this resulted in a technical risk that some circuit boards could require rework or waivers if the independent analyses identified significant issues. As of February 2021, the project remains behind in generating and reviewing these analyses and continues to track the technical risk that some rework or waivers could be required to these circuit boards.

In March 2020, the project switched its magnetometer—used to detect and measure the magnetic field of the Psyche asteroid—provider to a new international partner, the Technical University of Denmark, and resolved a top technical risk regarding delivery delays. The original provider was having staffing challenges, which would have delayed the magnetometer delivery and, subsequently, the project's assembly, test, and launch operations schedule. The project mitigated the risk by identifying an alternate provider and confirming the compatibility of the new provider's magnetometer with the Psyche mission and spacecraft design. As a result, the project no longer tracks late magnetometer delivery as a risk and has shifted its attention to addressing the deficit work created by the delays.

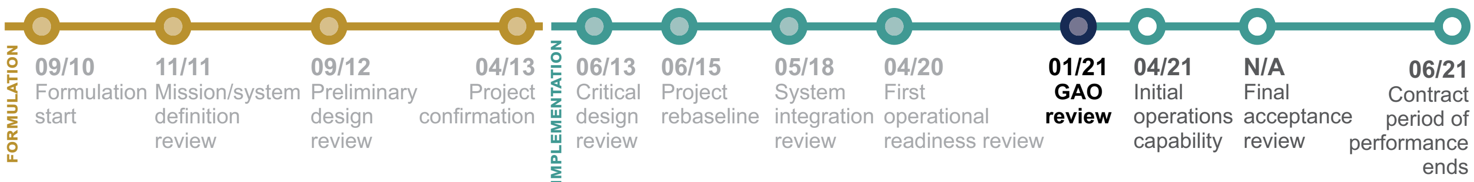
PROJECT OFFICE COMMENTS

Psyche project officials provided technical comments on a draft of this assessment, including additional details about design analyses, which were incorporated as appropriate.

Space Network Ground Segment Sustainment

The Space Network Ground Segment Sustainment (SGSS) project plans to develop and deliver a new ground system at a single site in White Sands, New Mexico. Existing systems are based on 1980s technology and are increasingly obsolete and unsustainable. The new ground system will include updated systems, software, and equipment that will provide critical communications services through the network's Tracking and Data Relay Satellites (TDRS) for the next several decades.

Source: NASA. | GAO-21-306



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**

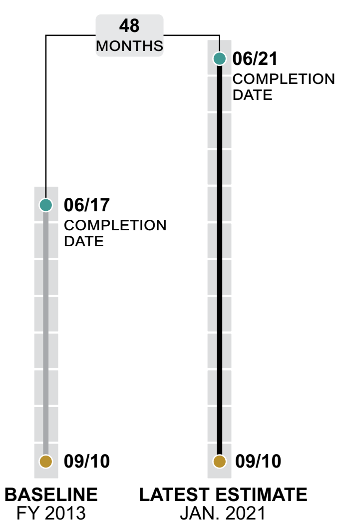
Requirement Derived from: **March 2008 Space Network modernization concept study**

Budget Portfolio: **Low Earth Orbit and Spaceflight Operations, Space and Flight Support**

PROJECT SUMMARY

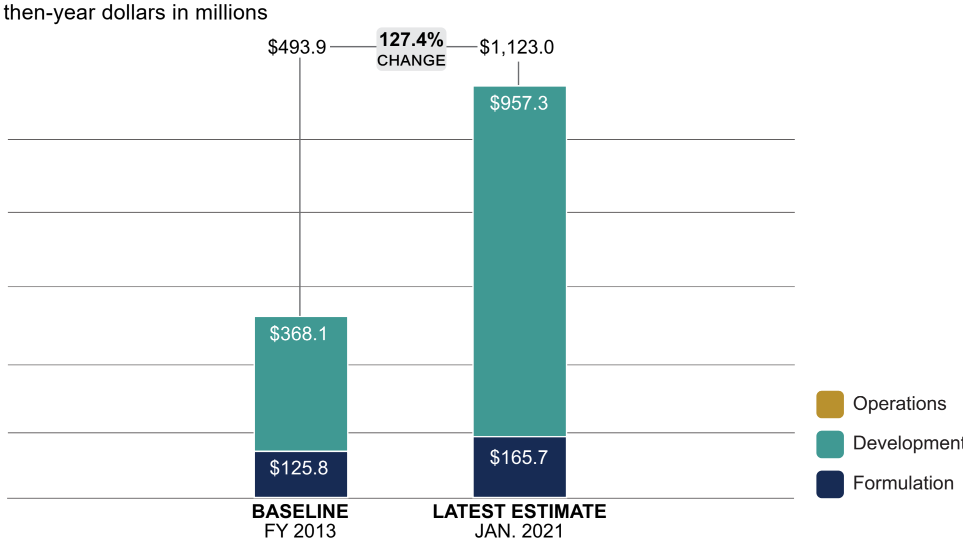
To operate within its latest cost and schedule estimates established in February 2019, SGSS is adjusting its minimum success criteria to declare initial operations capability (IOC) on its first main mission antenna at its White Sands Complex. SGSS previously planned a Final Acceptance Review for six antennas but had to adjust its success criteria because of cost and schedule effects from technical issues, COVID-19 effects, and Artemis I support needs. The SGSS prime contractor plans to deliver all the materials needed to complete the remaining five antenna installations at White Sands prior to its contract period of performance ending in June 2021. SGSS will transfer those materials and provide any residual funding to the Space Communications and Navigation (SCaN) program, which will be responsible for completing the upgrades. COVID-19 restrictions shut down the project's testing facility between March and August 2020 and added costs to keep staff on longer than planned. Incompatibility with the Artemis I mission prevented the project from converting more antennas after its IOC until after the mission is complete.

SCHEDULE PERFORMANCE



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.

Key Changes in the Space Network Ground Segment Sustainment (SGSS) Planned Scope, Cost, and Schedule to Achieve Minimum Success

	2013 – Original baseline	2015 – Rebaseline	2016 - Descope	Estimate as of Jan. 2021
Number of installed ground communication sets	4	4	2	2
Number of upgraded site locations	3	3	1	1
Number of converted main mission antennas	11	11	6	1
Number of generations of Tracking and Data Relay Satellites network is capable of communicating with	All 3 generations	All 3 generations	All 3 generations	1 generation
Total Life Cycle Cost (dollars in millions)	**493.3**	**842.2**	**895.6**	**1,123.0**
Date of SGSS Minimum Success[a]	**June 2017**	**September 2019**	**November 2019**	**April 2021**

Source: GAO analysis of National Aeronautics and Space Administration (NASA) data. | GAO-21-306

Note: The SGSS contractor plans to deliver the hardware, antenna modifications, and software needed to enable the Space Communications and Navigation (SCaN) program to manage modifying five additional main mission antennas at the White Sands Complex site and complete verification and validation of the remaining two generations of Tracking and Data Relay Satellites. In addition, the project received $365.7 million separate from the funds mentioned in the table from network users outside of NASA.

[a] The project's minimum success was the Final Acceptance Review up until the latest estimate, where it is the Initial Operations Capability. Following this event, the project's contract period of performance ends in June 2021 as part of the planned transition to SCaN.

Cost and Schedule Status

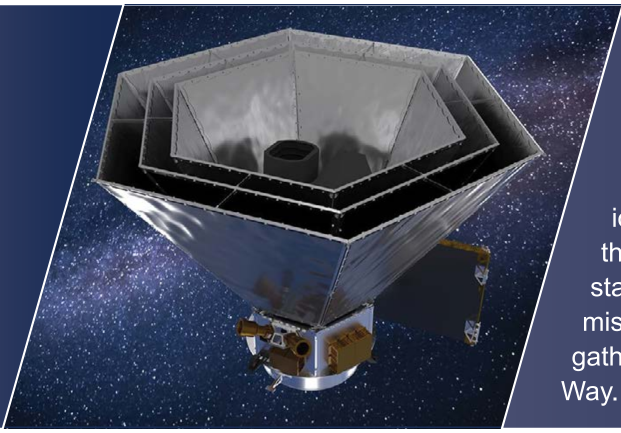
The SGSS project adjusted its minimum success criteria from completing a Final Acceptance Review for six antennas to declaring IOC on its first main mission antenna at its White Sands Complex. The project adjusted its success criteria in order to operate within the latest cost and schedule estimates—established in February 2019—after it experienced cost and schedule effects from unsatisfactory contractor performance, technical issues, COVID-19 effects, and Artemis I support needs. This latest change is one of several descopes and cost increases since it set a baseline in 2013 (see above). The prime contractor plans to deliver all the materials needed to complete the remaining five antenna installations at the White Sands Complex. SGSS will transfer these materials as well as make available remaining funding to SCaN, which will be responsible for the remaining work. SGSS will determine the full amount of funding available after contract close-out.

Unsatisfactory contractor performance, unrelated to COVID-19, delayed the project's first operational readiness review by about 5 months. Technical challenges remaining after the review delayed the project another 4 months and increased costs to retain staff longer than planned. COVID-19 restrictions then shut down the project's testing facility in March 2020, which prevented SGSS from demonstrating technical fixes until after the facility reopened in August 2020. According to officials, COVID-19-related costs contributed to the project's inability to fund efforts beyond IOC. Further, once IOC is reached, NASA cannot convert any additional antennas until the Artemis I mission is complete. Project officials explained that the SGSS upgrades are not yet compatible with the Artemis I mission. As a result, SCaN will manage operations for five legacy antennas for the Artemis I mission—four to support mission requirements and one spare. Officials say the system will be compatible with Artemis II.

In addition to descoping, SGSS reduced originally planned verification and validation for the system from communicating with three generations of TDRS satellites to only one for minimum success (IOC) (see above), which initially limits the number of satellites the system can communicate with. Officials said any funding available after achieving IOC will be used to gain compatibility with one more generation. If insufficient funding is available, additional development work will transfer to SCaN.

PROJECT OFFICE COMMENTS

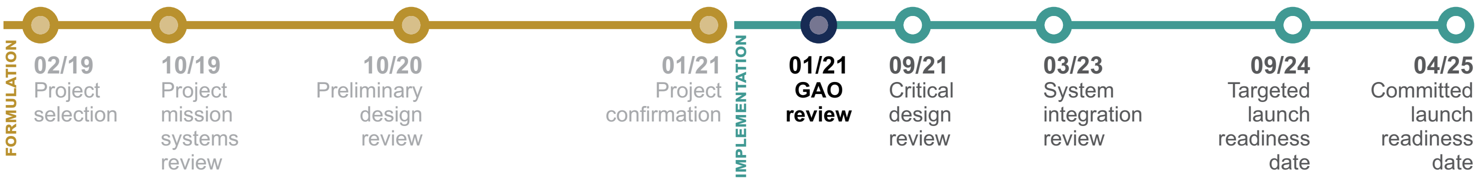
SGSS project officials provided technical comments on a draft of this assessment, which were incorporated as appropriate.



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

The Spectro-Photometer for the History of the Universe, Epoch of Re-ionization and Ices Explorer (SPHEREx) mission will use a telescope to 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.

Source: NASA/Jet Propulsion Laboratory-Caltech. | GAO-21-306



PROJECT INFORMATION

NASA Lead Center: **Jet Propulsion Laboratory**

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

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

Launch Vehicle: **Falcon 9**

Mission Duration: **37 months**

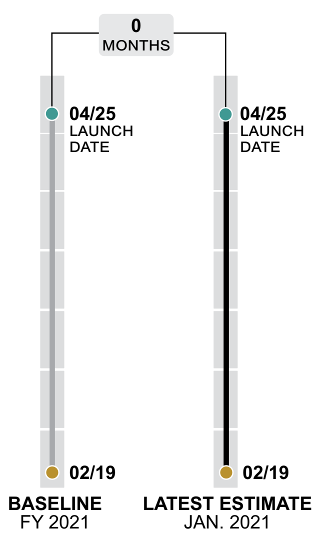
Requirement Derived from: **Astrophysics Decadal Survey 2010**

Budget Portfolio: **Science, Astrophysics**

PROJECT SUMMARY

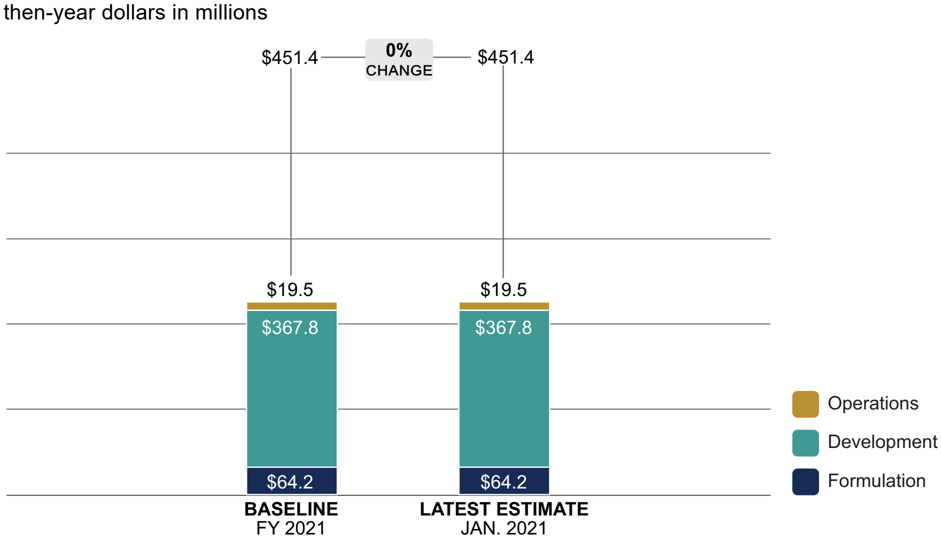
The SPHEREx project established cost and schedule baselines and entered the implementation phase in January 2021. The schedule and cost baselines are 13 months later and $24.4 million more than preliminary estimates. Prior to entering implementation, the project passed its preliminary design review and matured its one critical technology to technology readiness level 6. Project officials said the project is currently operating at reduced efficiency due to COVID-19, and one of the project's top risks is the potential future effects of COVID-19 during implementation. The project is also carrying a risk that the reliability of the science results may be affected by physical constraints and scheduling constraints to the full sky survey plan. According to officials, NASA's Science Mission Directorate and Launch Services Program will assess the opportunity to add a rideshare adapter to the launch vehicle for a secondary payload.

SCHEDULE PERFORMANCE



COST PERFORMANCE

then-year dollars in millions



Cost and Schedule Status

In January 2021, the SPHEREx project established cost and schedule baselines of $451.4 million and April 2025, which is $24.4 million above the high end of the preliminary cost range and 13 months later than its preliminary schedule estimate. The increase included costs for the following: an assessment to evaluate if a secondary payload can be added to the launch, a delayed start to the preliminary design phase, COVID-19 effects to date, and estimated future COVID-19 costs.

Before the confirmation review, the project overran its preliminary schedule estimates as a result of cumulative effects from the 2019 government shutdown and COVID-19, and is tracking a risk that COVID-19 could affect its baseline. The project began teleworking in March 2020 at reduced efficiency, which caused it to delay key reviews including its preliminary design review. SPHEREx's baseline includes projected COVID-19 cost and schedule effects through June 2021, but the project is currently tracking a risk that, if COVID-19 restrictions continue, the project could have to adjust its baseline.

Technology and Design

The SPHEREx project completed its preliminary design review in October 2020 with its only critical technology—the Video8 Multiplexer ASIC—matured to a technology readiness level 6. According to project officials, the Video8 Multiplexer ASIC is an interface chip that processes signals from the video channel of the detector into bits of information readable by a computer. Our best practices work has shown that reaching a technology readiness level 6 by this review can minimize risks for systems entering product development. As a result of developing the Video8 Multiplexer ASIC technology to this maturity level, the project was able to retire several technical risks, including risks related to carrying a backup technology.

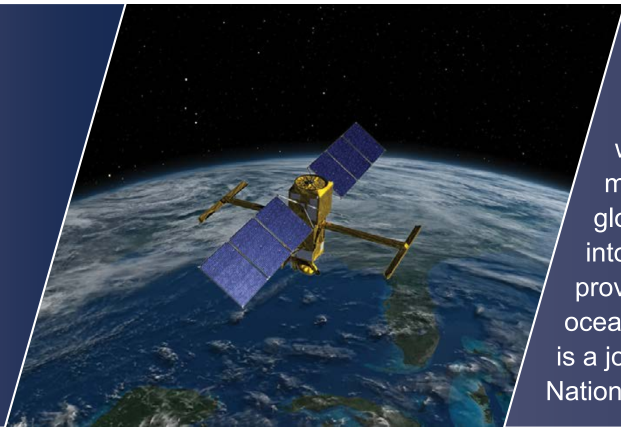
The project is also tracking a risk related to its survey plan estimates, which show that the project will not be able to complete the full sky survey at the required resolution to maximize science results. In particular, deficiencies caused by physical constraints on how the telescope can be pointed and scheduling constraints on observations may affect the reliability of science results. The project is planning to mitigate this risk and continue to mature the survey design by looking for opportunities to improve the survey's efficiency or relaxing the requirement.

Launch

According to project officials, given the relatively small size of SPHEREx, the Science Mission Directorate and the Launch Services Program will assess the opportunity to add a rideshare adapter to SPHEREx's launch vehicle for a secondary payload. The project's baseline cost included $2 million to conduct a secondary payload assessment. In early 2021, NASA selected the Falcon 9 rocket as the launch vehicle for SPHEREx and identified a potential secondary payload. Project officials said the decision on a secondary payload will likely be made at the project's critical design review, currently scheduled for September 2021.

PROJECT OFFICE COMMENTS

SPHEREx 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-21-306

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

IMPLEMENTATION
- **02/18** Critical design review
- **01/21 GAO review**
- ***Under review*** System integration review
- ***Under review*** Target launch readiness date
- ***Under review*** 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**

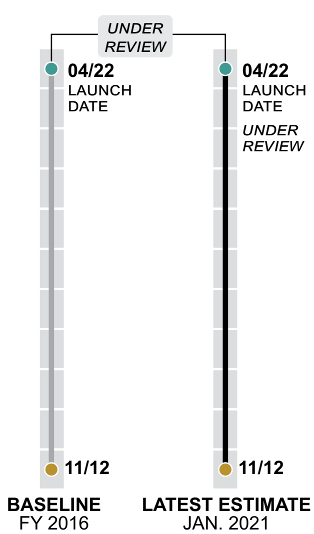
Requirement Derived from: **2007 Earth Science Decadal Survey**

Budget Portfolio: **Science, Earth Science**

PROJECT SUMMARY

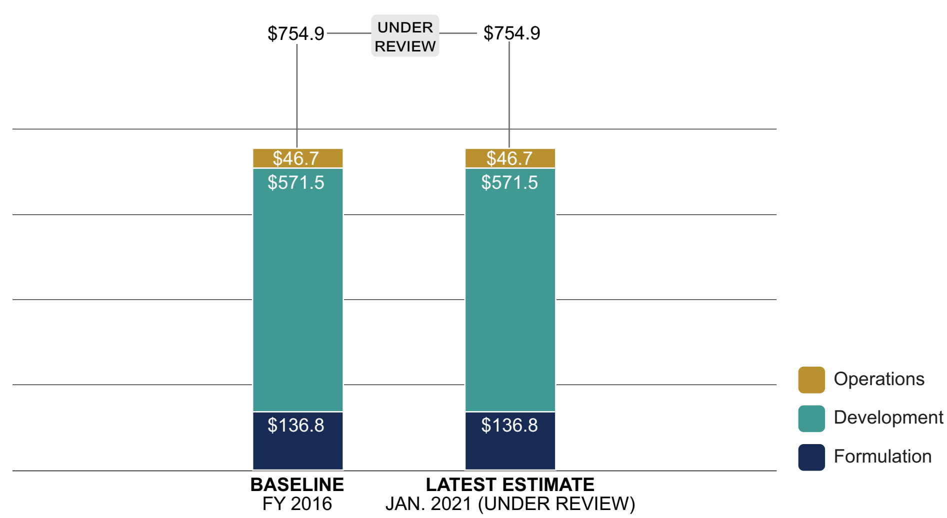
The SWOT project is reviewing its cost and schedule baselines as a result of COVID-19-related schedule delays and cost reserve use. The project delayed its internal launch date due to technical issues prior to the pandemic, and officials said that the project was on track to meet this new date before COVID-19. Officials said the project is reviewing its schedule baseline because the additional delays from facility shutdowns and COVID-19 inefficiencies could prevent it from meeting its baseline launch date. In addition, the project is tracking future cost uncertainty, and officials said they are reviewing estimates that could potentially exceed its cost baseline. As of December 2020, the project completed integration and testing for all individual component elements and started the last integration and test stage before NASA delivers the payload module to CNES. However, the project's inability to conduct planned joint (CNES/NASA) on-site testing due to travel restrictions could delay the project's integration and test activities and create additional costs.

SCHEDULE PERFORMANCE



COST PERFORMANCE

then-year dollars in millions



Cost and Schedule Status

The SWOT project is reviewing its schedule baseline as a result of COVID-19. Prior to the pandemic, the project was experiencing delivery delays with the Ka-Band Radar Interferometer (KaRIn) module. After reviewing its schedule, the project delayed its internal launch date by 5 months to February 2022. According to officials, SWOT was on track to meet this new internal launch date before the pandemic. However, as of December 2020, officials said the project is reviewing its schedule baseline because the additional delays from COVID-19 inefficiencies and pandemic-related facility shutdowns will likely prevent it from meeting its baseline launch date.

The project is also reviewing its cost baseline as a result of schedule delays and cost reserve use. As part of the decision to move its internal launch date to February 2022, NASA released $30.5 million in headquarters-held cost reserves to the project. While the project intended to use these reserves to cover cost effects from the KaRIn delivery delay, project officials stated they now estimate that they will use all of these reserves to mitigate COVID-19 costs from associated delays and integration and test (I&T) inefficiencies. The project has no reserves remaining to cover risks from COVID-19 and any other technical issues that arise. As a result, the project is tracking future cost uncertainty, and officials said they are reviewing estimates that could potentially exceed the project's cost baseline.

Integration and Test

As of December 2020, the project completed testing for all of its individual component elements and integrated them to begin the I&T phase for the payload module. This phase is the last I&T stage before NASA delivers the payload module to CNES for final testing before launch. One of the completed components is the KaRIn module, which was the driver of delays to the project's internal launch readiness date before the pandemic started. The project began to electrically integrate and test the completed Nadir module, Deployable Antenna Assembly (DAA) subsystem, and KaRIn module as a complete payload system in November 2020. NASA project officials estimate that they will deliver the payload module to CNES in July 2021, where it will be integrated with the completed spacecraft bus.

The project is unable to conduct planned joint (CNES/NASA) on-site testing of CNES's instruments due to COVID-19 travel restrictions, which could delay the project's I&T activities and create additional costs. Originally, the project planned for a CNES team to travel to NASA and assist with the I&T of CNES project elements. With travel restrictions, the project now plans to have on-site NASA operators test the equipment under remote CNES direction. However, officials said that preliminary tests of this mitigation strategy show significant inefficiencies that could add time to the project's I&T activities. In addition, officials stated that the project would be responsible for covering the additional cost of hiring operators. As of January 2021, the project was pursuing a hybrid option that would use the remote solutions and have a CNES team travel to the NASA facility in California for support. However, the CNES team's travel was placed on hold due to elevated risk during the spike in COVID-19 cases in California.

PROJECT OFFICE COMMENTS

When commenting on a draft of this assessment, SWOT project officials said that SWOT is a challenging mission making a first-of-a-kind measurement of global surface water. They said that despite work stoppage and interruptions due to COVID-19, the project made significant progress on critical path items, completing the I&T of all payload subsystems. They said that these sub-systems were then integrated into a complete payload module, showing excellent performance. Project officials further said that the project is focused on completing and delivering the payload module to the mission partner, CNES, for observatory I&T. Officials also provided technical comments, 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 V. 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 RussellW@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 are listed in appendix VI.

W. William Russell
Director, Contracting and National Security Acquisitions

List of Committees

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

The Honorable John Hickenlooper
Chairman
The Honorable Cynthia M. Lummis
Ranking Member
Subcommittee on Space and Science
Committee on Commerce, Science, and Transportation
United States Senate

The Honorable Matt Cartwright
Chairman
The Honorable Robert B. Aderholt
Ranking Member
Subcommittee on Commerce, Justice, Science, and Related Agencies
Committee on Appropriations
House of Representatives

The Honorable Don Beyer
Chairman
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

This is our 13th annual report assessing selected large-scale National Aeronautics and Space Administration (NASA) programs, projects, and activities. 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 include projects that held key decision point (KDP) A or its equivalent after December 1, 2020, in this report. The objectives of our review were to assess (1) the cost and schedule performance of NASA's portfolio of major projects, including the effect of the Coronavirus Disease 2019 (COVID-19) pandemic on the portfolio's performance; and (2) the development and maturity of technologies and progress in achieving design stability. We also described the status and assessed the risks and challenges faced by 33 of the 34 NASA major projects. We did not complete an individual assessment for one project, Mars 2020, which launched during our review in July 2020, but included data from this project in other analyses, as appropriate. We also included an assessment of the Orion Docking System, which is a capability upgrade within the Orion program for which NASA does not plan to establish a separate baseline.

To respond to the objectives of this review, we developed several standard data questionnaires. Multiple questionnaires were completed by NASA's Office of the Chief Financial Officer to gather cost and schedule data for projects in development. We used another questionnaire that was completed by project offices to gather data on projects' technology and design maturity and development partners. The information available on individual projects depends on where a project is in its life cycle. For example, for projects in an early stage of development—called formulation—there are still unknowns about requirements, technology, and design. We also compared these data to questionnaire data from our prior reviews in order to analyze long-term trends.

To assess the cumulative cost and schedule performance of NASA's major projects, we compared development cost and schedule data as of January or February 2021 for the 20 projects in the implementation phase during our review to previously established development cost and schedule baselines. The Commercial Crew Program has a tailored project life cycle and project management requirements, so it was excluded from these analyses. All cost and schedule data as of January or February 2021 was provided by NASA based on our questionnaires, with the exception of Mars 2020, which launched in July 2020 and for which we used the development cost data from its December 2020 KDP E memorandum. All cost and schedule baseline data are from estimates documented at each project's confirmation review, with the exception of the Space Launch System (SLS) project for which we used updated original cost and schedule baselines, established at its rebaseline in June 2020, because they are more closely aligned with the current scope of the program. To examine longer-term trends for NASA's portfolio of major projects in development, we compared the baseline development costs as well as the total cumulative cost and schedule overruns for the portfolio between 2009 and January or February 2021. The portfolio's cost and schedule performance data for each year is reported in each of our annual reports since 2009.

To assess annual cost and schedule performance, we compared the cumulative cost and schedule performance as of January or February 2021 to the performance data presented in the prior year's report for the 20 projects in the implementation phase during our review. This analysis determines if a project's latest development cost or schedule estimate is overrunning or underrunning the estimates from our prior year report. Prior year report cost and schedule estimates were generally based on data collected from NASA early in the calendar year. All cost information in this report is presented in nominal then-year dollars for consistency with budget data. We did not assess the cost performance of projects in formulation because they have not yet established baselines.

To determine the effects of COVID-19 on the cost and schedule performance of NASA's portfolio of major projects in development, we reviewed project documentation—including monthly status reports, schedules, risk assessments, and major project review documentation—and interviewed project officials and officials with the Office of the Chief Financial Officer. We also reviewed recurring baseline performance review data that included NASA's Office of the Chief Financial Officer's assessment of how the pandemic was affecting major projects' costs and schedules. To estimate the future effects of COVID-19, we compared latest cost and schedule estimates, including project and headquarters-held cost and schedule reserves, to projects' reported COVID-19-related cost and schedule threats. We also analyzed whether the risks or threats tracked by projects were estimated to exceed current cost or schedule reserves.

To assess technology maturity, we used questionnaire data that provided the technology readiness levels (TRL) of each of the project's critical technologies at various stages of project development, including at the preliminary design review (PDR). Originally developed by NASA, TRLs 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 TRLs. Due to changes in our methodology surrounding how projects reported critical technologies, we did not compare this year's results against those in prior years.

For our analysis of critical technologies, we updated our definition of critical technology in June 2020 as well as the associated methodology for collecting data on critical technologies for each project. We made this change to align with GAO's January 2020 updated Technology Readiness Assessment Guide.[1] In prior years, we requested that projects report data on both heritage technologies—technologies flown on prior missions—and critical technologies. We stopped collecting information on heritage technologies unless projects identified them as critical, which we instructed projects to do when those technologies are being used in a new or novel manner in alignment with GAO's guide.

We took steps to assess the reliability of the data on the TRL of technologies and classification of technologies as critical that were provided in the questionnaire. For example, we consulted GAO experts in technology assessments and conducted a pilot of our new methodology with NASA project officials to collect feedback on the changes and associated data collection practices. We revised and updated our questionnaire based upon this feedback. We also compared the critical technology data received from NASA projects in response to our updated methodology with data received in prior-years' data requests to determine how reporting had changed. We corroborated the data provided by reviewing project documentation and meeting with project officials.

For the 14 projects that identified critical technologies and held their PDR, we compared the TRLs of those projects' reported critical technologies against our technology maturity best practice to determine the extent to which these projects were meeting the best practice. Our best practices work has shown that reaching a TRL 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 PDR is the level of maturity needed to minimize risks for space systems entering product development.[2] We did not assess technology

[1] GAO-20-48G.

[2] GAO-20-48G.

maturity for those projects that had not yet reached the PDR at the time of this assessment or for projects that reported no critical technologies.

Our analysis of technology maturity included two technology demonstration projects: the Laser Communication Relay Demonstration (LCRD) and On-orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1) projects. The Mission Directorate in charge of technology demonstration projects policy does not require technology demonstrations to mature all of their technologies to TRL 6 by PDR.[3] 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 infeasible for these projects to achieve this level of maturity by PDR. However, we included LCRD and OSAM-1 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 did not include technologies in this analysis that were added after the project's PDR; in the case of OSAM-1, that includes all technologies related to the SPace Infrastructure DExterous Robot (SPIDER). We excluded two other technology demonstrations from this analysis—Solar Electric Propulsion and Low Boom Flight Demonstrator—because NASA does not plan to mature these technologies before operations or qualification testing.

To assess design stability, we reviewed 13 projects that had held a critical design review (CDR) and reported data on design drawings. We reviewed questionnaire data on the number of engineering drawings completed or projected for release by the project's CDR and as of our current assessment.[4] We took steps to assess the reliability of the project office-supplied data on the number of released and expected engineering drawings. For example, we collected the project offices' rationales for

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

[4]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 current 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 reflects the design stability of the project.

cases where it appeared that only a small percentage of the expected drawings were completed by the time of the design review or where the project office reported significant growth in the number of drawings released after the critical design review. In accordance with GAO's best practice, projects were assessed as having achieved design stability if at least 90 percent of projected drawings were released by the CDR.[5] We compared this year's results against those in prior years to assess whether NASA was improving in this area. We did not assess the design stability for those projects that had not yet reached the CDR at the time of this assessment.

Project Profile Information on Each Individual Project Assessment

This year, we developed individual project assessments for 33 projects with an estimated life-cycle cost greater than $250 million and one capability upgrade planned for Orion. We did not complete individual assessments for projects that launched during our review. For each project assessment, we included a description of each project's objectives; information concerning the NASA center and international partners involved in the project, if applicable; the project's cost and schedule performance, when available; 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 either obtained data directly from NASA's Office of the Chief Financial Officer through our questionnaire or used preliminary estimates provided in project documentation. We had NASA confirm that preliminary estimates remained accurate as of January 2021 as part of the agency's review of project assessments. For the Commercial Crew Program and the Space Network Ground Segment Sustainment project, we obtained current 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.

To assess project time frames, we tracked acquisition cycle times as well as key milestone events in the life of the project. Acquisition cycle time 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 KDP A or the beginning of the formulation phase.

[5] GAO-02-701.

Projects selected as a result of a one-step announcement of opportunity (AO) enter formulation at KDP A. Projects selected as a result of a two-step AO process perform a concept development study and go through evaluation for down-selection, which serves as KDP B. The end of the acquisition cycle is the projected or actual launch 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 generally 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 technologies, the number of releasable design drawings at project milestones, and international partnerships.[6] GAO also held interviews with representatives from all of the projects across multiple NASA centers to discuss the information on the questionnaire. We then reviewed project documentation—including monthly status reports, project plans, schedules, risk assessments, and major project review documentation—to corroborate any testimonial evidence we received in the interviews. These reviews led to identification of further challenges faced by NASA projects. The second page of our project assessments highlights key challenges that have affected that project or could affect project performance. For this year's report, we identified challenges across the projects we reviewed in the categories of cost and schedule, COVID-19, design, integration and test, launch, software, spacecraft, and technology. These challenges do not represent an exhaustive or exclusive list and are based on our definitions and assessments, not those of NASA.

Data Limitations

NASA provided preliminary estimated life-cycle cost ranges and associated schedules—which are generally established at KDP B—for three projects that had not yet entered implementation, one of which is under review. For the other 10 projects in formulation, NASA has not yet established preliminary cost estimates. 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. NASA formally establishes cost and schedule baselines, committing itself to cost and

[6]We did not collect this information for the Commercial Crew Program or the Exploration Ground Systems program.

schedule targets for a project with a specific and aligned set of planned mission objectives at KDP C, which follows a PDR. KDP C reflects the life-cycle point where NASA approves a project to leave the formulation phase and enter into the implementation phase. Due to changes that occur to a project's scope and technologies between KDP B and KDP C, the estimates of project cost and schedule can be significantly altered between the two KDPs.

We conducted this performance audit from April 2020 to May 2021 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: Estimated Costs and Launch Dates for Major NASA Projects Assessed in GAO's 2021 Report

In this report, we assessed 34 major National Aeronautics and Space Administration (NASA) projects. Table 5 shows the preliminary launch readiness data and cost estimates for projects in the formulation phase, which takes the project from concept to preliminary design. Table 6 shows the original cost and schedule baseline as well as the current launch readiness dates and cost estimates for projects in implementation, which includes building, launching, and operating the system, among other activities.

Table 5: Cost and Schedule of Major NASA Projects in Formulation in GAO's 2021 Report

Project	Preliminary launch readiness date	Preliminary cost estimate (dollars in millions)
Dragonfly	2027	TBD
EPFD[a]	December 2023 - August 2024	311.8 - 469.4
Gateway-DSL	TBD	TBD
Gateway-xEVA[a]	December 2023	TBD
Gateway-HALO	January 2024	TBD
Gateway-PPE	January 2024	TBD
HLS	September 2024	TBD
IMAP	February 2025	707.7 - 776.3
ML2	Fiscal Year 2026	TBD
NEO Surveyor	TBD	TBD
PUNCH[b]	September- December 2023	170.0 - 270.1
SLS Block 1B	Fiscal Year 2026	TBD
VIPER	November 2023	TBD

Legend: EPFD: Electrified Powertrain Flight Demonstration; DSL: Deep Space Logistics; xEVA: Exploration Extravehicular Activity; HALO: Habitation and Logistics Outpost; PPE: Power and Propulsion Element; HLS: Human Landing System; IMAP: Interstellar Mapping and Acceleration Probe; ML2: Mobile Launcher 2; NEO: Near Earth Object; PUNCH: Polarimeter to Unify the Corona and Heliosphere; SLS: Space Launch System; VIPER: Volatiles Investigating Polar Exploration Rover.

Source: GAO analysis of National Aeronautics and Space Administration (NASA) data. | GAO-21-306

[a]The EPFD and Gateway-xEVA projects expect to mark the end of development with events equivalent to a launch readiness date. The EPFD project will complete development after a first flight of its aircraft, and the xEVA project will designate a delivery date for the space suits.

[b]The PUNCH project noted its latest preliminary estimates are under review and could incur cost increases or delays due to future COVID-related effects.

Table 6: Cost and Schedule of Major NASA Projects in Implementation in GAO's 2021 Report

Project	Baseline launch readiness date	Current launch readiness date	Baseline life-cycle cost estimate (in millions)	Current life-cycle cost estimate (in millions)
CCP-SpaceX[a]	April 2017	November 2020	2,599.0	2,720.8
CCP-Boeing[a]	August 2017	Under Revision	4,229.6	4,487.0
DART	February 2022	February 2022	313.9	315.4
EGS	November 2018	November 2021	2,812.9	3,471.1
Europa Clipper[b]	September 2025	September 2025	4,250.0	4,250.0
JWST	June 2014	October 2021	4,963.6	9,662.7
Landsat 9	November 2021	November 2021	885.0	838.5
LBFD[c]	January 2022	June 2022	582.4	657.1
LCRD[b]	November 2019	June 2021	262.7	310.5
Lucy	November 2021	November 2021	981.1	989.1
Mars 2020	July 2020	July 2020	2,443.5	2,741.4
NISAR[b]	September 2022	September 2022	866.9	925.5
Orion	April 2023	August 2023	11,283.5	12,158.4
OSAM-1	September 2025	September 2025	1,780.0	1,780.0
PACE	January 2024	January 2024	889.7	889.7
Psyche	August 2022	August 2022	996.4	957.6
Roman	October 2026	October 2026	3,934.0	3,934.0
SGSS[d]	June 2017	June 2021	493.9	1,123.0
SEP[b]	December 2024	December 2024	335.6	335.6
SLS	November 2018	November 2021	9,064.0	11,782.3
SPHEREx	April 2025	April 2025	451.4	451.4
SWOT[b]	April 2022	April 2022	754.9	754.9

Legend: CCP: Commercial Crew Program; DART: Double Asteroid Redirection Test; EGS: Exploration Ground Systems; LBFD: Low Boom Flight Demonstrator; LCRD: Laser Communications Relay Demonstration; JWST: James Webb Space Telescope; NISAR: NASA Indian Space Research Organisation - Synthetic Aperture Radar; Orion: Orion Multi-Purpose Crew Vehicle; OSAM-1: On-Orbit Servicing, Assembly and Manufacturing 1; PACE: Plankton, Aerosol, Cloud, ocean Ecosystem; Roman: Nancy Grace Roman Space Telescope; SEP: Solar Electric Propulsion; SGSS: Space Network Ground Segment Sustainment; SLS: Space Launch System; SPHEREx: Spectro-Photometer for the History of the Universe, Epoch of Re-ionization and Ices Explorer; SWOT: Surface Water and Ocean Topography.

Source: GAO analysis of National Aeronautics and Space Administration (NASA) data. | GAO-21-306

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

[b]The Europa Clipper, LCRD, NISAR, SEP, and SWOT projects are currently under review. Until those reviews are complete, information presented above is based on the latest estimates we received from NASA for the projects

[c]The LBFD project does not have a launch readiness date but has an equivalent first flight event that marks the end of development.

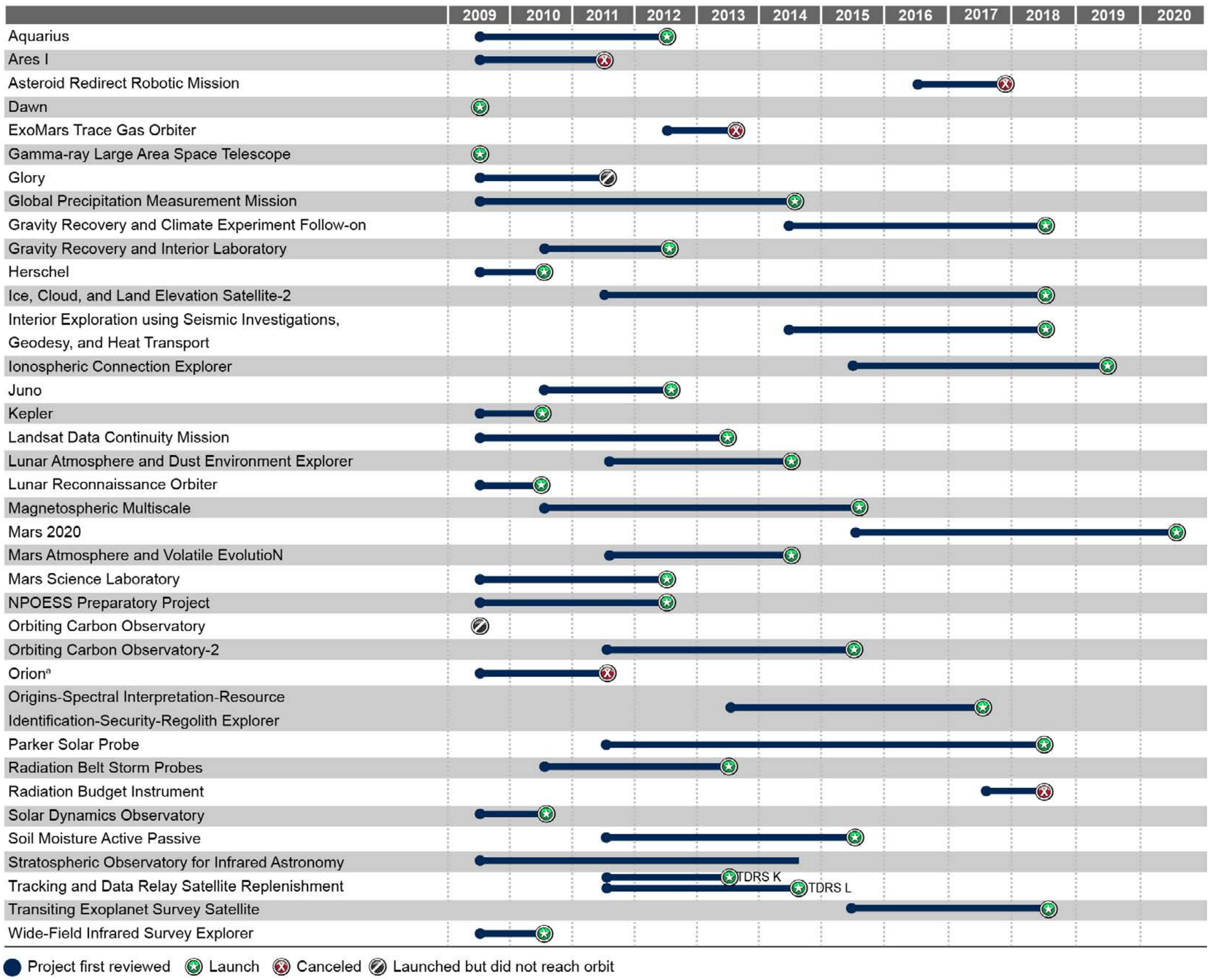
[d]In 2016, NASA reclassified SGSS as a hybrid sustainment effort, rather than a major project. A hybrid sustainment effort still includes development work. As a result, we continue to include SGSS in our assessment. SGSS is a ground system that does not have a launch readiness date, but this date

represents the end of the period of performance for the contract as part of the planned transition to the Space Communication and Navigation program.

Appendix III: List of Major NASA Projects Included in GAO's Annual Assessments from 2009 to 2020

We reviewed 70 major National Aeronautics and Space Administration (NASA) projects or programs since our initial review in 2009. See figure 8 for a list of 37 projects that were included in our assessments from 2009 to 2020. These projects were not included in the 2021 project assessments because they launched, were canceled, or launched but failed to reach orbit.

Figure 8: Major NASA Projects Reviewed in GAO's Annual Assessments from 2009 to 2020



Source: GAO analysis of National Aeronautics and Space Administration (NASA) data. | GAO-21-306

[a]In 2014, NASA adopted Orion as the common name for Orion Multi-Purpose Crew Vehicle; 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 7: NASA Hardware Technology Readiness Levels (TRL)

TRL	Definition	Hardware description
1	Basic principles observed and reported.	Scientific knowledge is generated, underpinning hardware technology concepts/applications.
2	Technology concept and/or application formulated.	Invention begins. Practical application is identified but speculative, and no experimental proof or detailed analysis is available to support the conjecture.
3	Analytical and experimental proof-of-concept of critical function and/or characteristics.	Research and development are initiated, including analytical and laboratory studies to validate predictions regarding the technology.
4	Component and/or breadboard validation in a laboratory environment.	A low fidelity system/component breadboard is built and operated to demonstrate basic functionality in a laboratory environment.
5	Component and/or brassboard validated in a relevant environment.	A medium-fidelity component and/or brassboard, with realistic support elements, is built and operated for validation in a relevant environment to demonstrate overall performance in critical areas. Performance predictions are made for subsequent development phases.
6	System/sub-system model or prototype demonstration in a relevant environment.	A high-fidelity prototype of the system/subsystems that adequately addresses all critical scaling issues is built and tested in a relevant environment to demonstrate performance under critical environmental conditions.
7	System prototype demonstration in an operational environment.	A high-fidelity prototype or engineering unit that adequately addresses all critical scaling issues is built and functions in the actual operational environment and platform (ground, airborne, or space).
8	Actual system completed and “flight qualified” through test and demonstration.	The final product in its final configuration is successfully demonstrated through test and analysis for its intended operational environment and platform (ground, airborne, or space). If necessary, life testing has been completed.
9	Actual system flight proven through successful mission operations.	The final product is successfully operated in an actual mission.

Source: GAO analysis and representation of National Aeronautics and Space Administration (NASA) TRLs from NPR 7123.1C, Appendix E. | GAO-21-306

Table 8: NASA Software Technology Readiness Levels (TRL)

TRL	Definition	Software description
1	Basic principles observed and reported.	Scientific knowledge is generated, underpinning basic properties of software architecture and mathematical formulation.
2	Technology concept and/or application formulated.	Practical application is identified but speculative, and no experimental proof or detailed analysis is available to support the conjecture. Basic properties of algorithms, representations, and concepts defined. Basic principles are coded, and experiments are performed with synthetic data.
3	Analytical and experimental proof-of-concept of critical function and/or characteristics.	Development of limited functionality to validate critical properties and predictions using non-integrated software components occurs.
4	Component and/or breadboard validation in a laboratory environment.	Key, functionality critical software components are integrated and functionally validated to establish interoperability and begin architecture development. Relevant environments are defined and performance in the environment predicted.

TRL	Definition	Software description
5	Component and/or brassboard validated in a relevant environment.	End-to-end software elements implemented and interfaced with existing systems/simulations conforming to target environment. End-to-end software system tested in relevant environment, meeting predicted performance. Operational environment performance predicted.
6	System/sub-system model or prototype demonstration in a relevant environment.	Prototype implementations of the software demonstrated on full-scale, realistic problems. Partially integrated with existing hardware/software systems. Limited documentation available. Engineering feasibility fully demonstrated.
7	System prototype demonstration in an operational environment.	Prototype software exists having all key functionality available for demonstration and test. Well integrated with operational hardware/software systems demonstrating operational feasibility. Most software bugs removed. Limited documentation available.
8	Actual system completed and “flight qualified” through test and demonstration.	All software has been thoroughly debugged and fully integrated with all operational hardware and software systems. All user documentation, training documentation, and maintenance documentation completed. All functionality successfully demonstrated in simulated operational scenarios. Verification and Validation completed.
9	Actual system flight proven through successful mission operations.	All software has been thoroughly debugged and fully integrated with all operational hardware and software systems. All documentation has been completed. Sustaining software support is in place. System has been successfully operated in the operational environment.

Source: GAO analysis and representation of National Aeronautics and Space Administration (NASA) TRLs from NPR 7123.1C, Appendix E. | GAO-21-306

Appendix V: Comments from the National Aeronautics and Space Administration

National Aeronautics and
Space Administration

Office of the Administrator
Washington, DC 20546-0001

April 30, 2021

Mr. W. William Russell
Director
Contracting and National Security Acquisitions
United States Government Accountability Office
Washington, DC 20548

Dear Mr. Russell:

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-21-306).

The GAO's congressionally mandated annual assessment is a good opportunity for NASA to receive an independent perspective on its performance in the acquisition of major programs and projects. We appreciate the open and constructive dialogue between NASA and the GAO engagement team, and we look forward to continuing to work with the GAO to identify and address any challenges that may enable cost and schedule improvements in our current and future projects.

This year's report represents the 13th annual assessment of NASA's major acquisitions. Since the inaugural report's issuance in 2009, the GAO has provided NASA with several valued insights into various aspects of our acquisition approaches, many of which have resulted in programmatic developments and enhancements. NASA has worked closely with GAO to find and implement improvements in our programs. However, as the NASA portfolio expands to reflect expanded congressional objectives, the number of major projects in this annual engagement is expected to continue to grow. The 2020-2021 engagement cycle included 34 projects, which is a 36 percent increase from the prior year's project portfolio and is the highest number of projects reviewed in the history of this annual assessment. We continue to monitor and refine strategies to implement reviews on a sustainable basis, given the anticipated continued expansion of the scope of activities assigned to the Agency by the Administration. We also welcome suggestions from GAO to identify any options for streamlining the assessment process.

In this year's report, the GAO notes challenges with continued cost increases and schedule delays, both of which were primarily attributed to the James Webb Space Telescope (JWST) and the Space Launch System (SLS). These two projects are ambitious undertakings that represent a great leap forward in exploring the unknown and extending human presence to the Moon and beyond. Such unprecedented efforts are often accompanied by challenges in cost and schedule estimation, as NASA continues to dedicate substantial resources toward ensuring mission success. NASA anticipates that JWST's upcoming launch and SLS' initial launch will contribute to a reduction in the cost and schedule performance deterioration noted by the GAO. We further note that the increase in major projects in NASA's portfolio likely contributes to cost and schedule growth, as each of those projects continue to push the frontiers of aeronautics and space research and exploration.

The challenges brought on by the COVID-19 pandemic are being felt by nearly all programs involved in this year's assessment. NASA appreciates the GAO's flexibility in implementing virtual project meetings amidst telework arrangements and mission requirements. NASA will continue to monitor and address the cost and schedule impacts of COVID-19 on its major projects. COVID-19 is an unprecedented event, and NASA's understanding of the impact of COVID-19 continues to evolve. A final accounting of the full impact of COVID-19 on Agency activities will not be available until well after the Agency and its contractors and partners are operating in a post-pandemic environment.

In spite of the pandemic's obstacles, NASA achieved several important milestones over the past year: the launch of the Mars 2020 project, and its subsequent landing of the Perseverance rover; the launch of NASA astronauts from U.S. soil on American-produced rockets as a result of our Commercial Crew Program; and the successful green run tests of the SLS Core Stage for Artemis I, leading to its upcoming delivery to Kennedy Space Center. NASA is proud of these accomplishments in the face of unprecedented challenges and recognizes that the GAO's continued monitoring of these efforts helped us realize these goals.

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, NASA has accordingly worked over many years to improve policies and procedures that control cost and schedule while ensuring mission success. NASA has made substantial progress in the implementation of its High-Risk Corrective Action Plan (CAP), having completed six initiatives since its establishment in December 2018. In 2020, NASA renewed its CAP in response to GAO's continued designation of NASA's acquisition management practices on its High-Risk List. This renewed CAP contains four new initiatives, in addition to two already in progress from the 2018 plan. These initiatives are designed to strengthen the Agency's cutting-edge program and project management efforts and to improve transparency for NASA's stakeholders. NASA is pleased to see GAO's recognition of our progress in this High-Risk area in the most recent High-Risk Report published in March 2021. NASA further appreciates the GAO's recognition of these initiatives in the Quick Look 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 appreciates the GAO evaluation of the Artemis programs during their formulation and development to send the first woman and next man to the surface of the Moon. These programs have made significant progress toward the ambitious goal set before them. Considering the FY 2021 Appropriations funding for Exploration Research & Development was less than half of the requested funding, the Gateway and HLS Programs are rapidly aligning their plans to the available FY 2021 budget and the implication of this appropriation on future year budgets. We encourage GAO to consider the anticipated impact of this reduced funding as it evaluates and provides recommendations to the audited programs. Preliminary estimates on milestone dates, reviews, and launch are directly linked to multi-year funding profiles. Changes to multi-year funding profiles can cause schedule changes that are unrelated to performance or technical issues. NASA thanks the GAO for this consideration during this dynamic period for Artemis.

We continue to encourage the GAO to assess cost and schedule performance against baseline commitments, rather than preliminary estimates. Preliminary estimates are made in the early stages of project formulation, prior to sufficient development of mission scope and design maturity and prior to any external cost and schedule commitments. NASA appreciates that GAO recognizes this important nuance to how NASA describes its cost and schedule commitments and looks forward to continuing to work with GAO to ensure future assessments consistently measure against projects' baseline commitments.

The GAO's assessment also included an analysis of technology maturity. NASA emphasizes that technology demonstration projects achieve Technology Readiness Level (TRL) 6 or higher only after the integrated mission/system has been flown and tested in space, not at Preliminary Design Review (PDR). While the On-orbit Servicing, Assembly, Manufacturing 1 (OSAM-1) and Laser Communication Relay Demonstration (LCRD) projects may have had a few technology elements at TRL 6 at PDR, the majority of the technology elements for OSAM-1 and LCRD were not at TRL 6 (nor was the system as a whole) at the time of PDR. This is reasonable and expected for most technology demonstration projects. Technology demonstration flight projects are designed to be high-risk, high-reward missions and therefore are very different than science and human space flight activities.

NASA no longer uses the GAO's design stability best practice of requiring 90 percent of design drawings to be completed by the Critical Design Review, though GAO continues to measure against that legacy standard. NASA believes that the standard was developed prior to the use of computerized drawings. However, NASA is pleased that the GAO has started to update their best practices for assessing product development and looks forward to continued collaboration with the GAO to identify and implement a design stability metric that reflects modern techniques of flight project design.

NASA thanks 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

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presentation of each project's 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 Mike O'Neil at (650) 604-2166 or Kevin Gilligan at (202) 358-4544 if you have any questions or require additional information.

Sincerely,

Stephen G. Jurczyk
Administrator (Acting)

Appendix VI: GAO Contacts and Staff Acknowledgments

GAO Contact

W. William Russell, (202) 512-4841 or RussellW@gao.gov

Staff Acknowledgments

In addition to the contact named above, Molly Traci (Assistant Director), Juli Steinhouse (Analyst-in-Charge); Kala Amos; Pete Anderson; Alyssa Bertoni; Brian Bothwell; Tina Cota-Robles; Lorraine Ettaro; Kurt Gurka; Chad Johnson; Erin Kennedy; Joy Kim; Meredith Allen Kimmett; Jonathan Munetz; Jeanine Navarrete; Eve Nealon; John Ortiz; Jose A. Ramos; Carrie Rogers; Edward J. SanFilippo; Ron Schwenn; Eli Stiefel; Ryan Stott; Roxanna T. Sun; Hai Tran; Tom Twambly; Kristin Van Wychen; John Warren; Alyssa Weir; Tonya Woodbury; and Lauren Wright made significant contributions to this report.

Related GAO Products

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