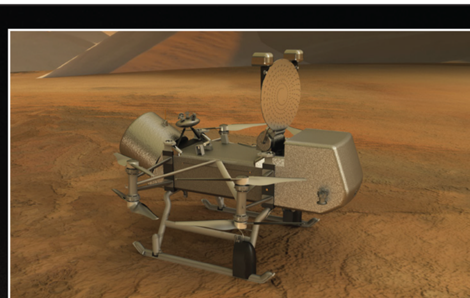
United States Government Accountability Office

Report to Congressional Committees

May 2023

NASA | Assessments of Major Projects

LUNAR EXPLORATION | ASTROPHYSICS | PLANETARY SCIENCE | AERONAUTICS



GAO-23-106021

GAO
Highlights

Highlights of GAO-23-106021, a report to congressional committees

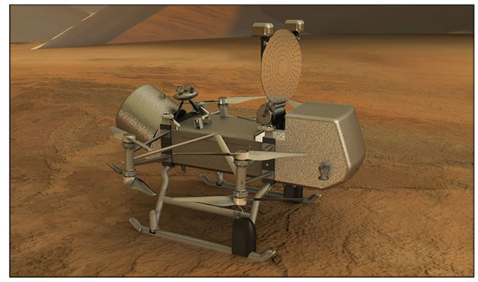
May 2023

NASA

Assessments of Major Projects


Gateway – Lunar outpost


Low Boom Flight Demonstrator


Dragonfly – Planetary explorer

Source: NASA, NASA, Johns Hopkins University Applied Physics Laboratory. | GAO-23-106021

Why GAO Did This Study

NASA plans to invest more than $83 billion in its portfolio of major projects to continue exploring Earth, the moon, and the solar system. GAO defines these major projects as those with costs over $250 million. A House explanatory statement includes a provision for GAO to prepare status reports on NASA's major projects. This is GAO's 15th annual assessment.

This report describes the cost and schedule performance of NASA's major projects and includes assessments of their technology development. It also includes individual assessments of the major projects.

GAO collected and analyzed data; reviewed project status reports; and interviewed NASA officials. GAO reviewed projects in the formulation phase (which takes a project through its preliminary design), and those in the subsequent development phase (which includes building and launching the system).

What GAO Recommends

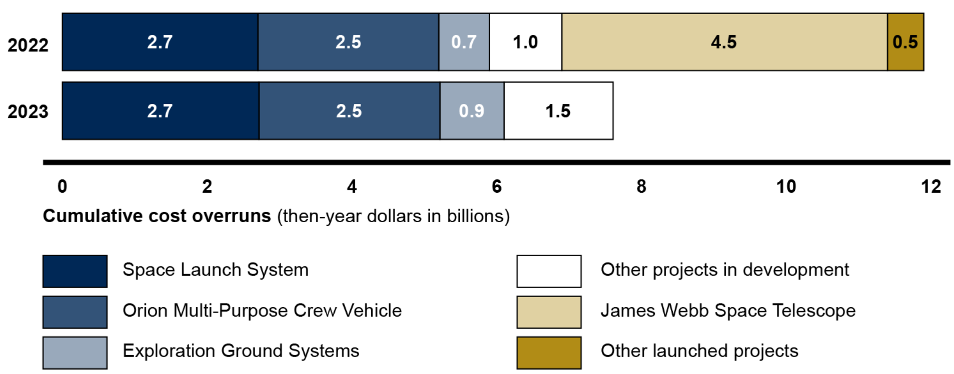
In prior work, GAO made multiple recommendations to improve NASA's management of major projects. As of March 2023, NASA had not yet fully addressed 16 recommendations.

View GAO-23-106021. For more information, contact W. William Russell at (202) 512-4841 or russellw@gao.gov.

What GAO Found

Total cumulative cost performance for NASA's current portfolio of 16 major projects in development improved since 2022, with cost overruns significantly decreasing from $12 to $7.6 billion.

Cumulative Development Cost Overruns by Project in 2022 and 2023



Source: GAO analysis of NASA data. | GAO-23-106021

Category 1 projects in development—NASA's highest priority and most costly, such as James Webb Space Telescope—drive NASA's cumulative cost performance. Cost overruns were smaller in 2023 than last year because the James Webb Space Telescope launched, and its $4.5 billion in overruns from prior years are no longer part of the portfolio. In addition, compared to 2022 performance, some of the largest category 1 projects—the Space Launch System, Orion, and Exploration Ground Systems—had little to no new cost growth. Overall, since 2022, eight of the 16 major projects experienced some cost or schedule growth, with cost overruns totaling $637.3 million and schedule delays ranging from 5 months to over a year.

As the portfolio of major projects evolves, NASA has identified opportunities to improve cost and schedule performance. For example, NASA plans to have earlier discussions on acquisition strategies. This and other initiatives are important as NASA plans to make cost commitments—estimated at nearly $16 billion—for eight new category 1 projects in 2023.

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Abbreviations

AEPS	Advanced Electric Propulsion System
ARMD	Aeronautics Research Mission Directorate
ASAP	Aerospace Safety and Advisory Panel
ATLO	assembly, test, and launch operations
CCP	Commercial Crew Program
CDR	critical design review
CGI	Coronagraph Instrument
CLPS	Commercial Lunar Payload Services
CoDICE	Compact Dual Ion Composition Experiment
DAVINCI	Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging

DM	Deformable Mirror
DrACO	Drill for Acquisition of Complex Organics
DraGMet	Dragonfly Geophysics and Meteorology Package
DraMS	Dragonfly Mass Spectrometer
DSL	Deep Space Logistics
EAP	Electrified Aircraft Propulsion
EGS	Exploration Ground Systems
EHP	Extravehicular Activity and Human Surface Mobility Program
EPFD	Electrified Powertrain Flight Demonstration
ESA	European Space Agency
ESPRIT-RM	European System Providing Refueling, Infrastructure, and Telecommunications Refueler Module
EUS	Exploration Upper Stage
GDC	Geospace Dynamics Constellation
GE	GE Aviation
GERS	Gateway External Robotic System
GNC	guidance, navigation, and control
GSLV	Geosynchronous Satellite Launch Vehicle Mark II
HALO	Habitation and Logistics Outpost
HLS	Human Landing System
IBR	integrated baseline review
I-HAB	International Habitat
ICPS	Interim Cryogenic Propulsion Stage
IMAP	Interstellar Mapping and Acceleration Probe
ISRO	Indian Space Research Organisation
ISS	International Space Station
JPL	Jet Propulsion Laboratory
JWST	James Webb Space Telescope
KDP	key decision point
LBFD	Low Boom Flight Demonstrator
LIDAR	light detection and ranging
LTV	Lunar Terrain Vehicle
MCR	mission concept review
MDR	mission definition review
ML2	Mobile Launcher 2
MSR	Mars Sample Return
NASA	National Aeronautics and Space Administration
NEO	Near Earth Object
NEOCam	NEO Camera
NISAR	NASA ISRO – Synthetic Aperture Radar
NRHO	near rectilinear halo orbit

OCI	Ocean Color Instrument
Orion	Orion Multi-Purpose Crew Vehicle
ORR	operational readiness review
OSAM-1	On-Orbit Servicing, Assembly, and Manufacturing 1
PACE	Plankton, Aerosol, Cloud, ocean Ecosystem
PDP	Plasma Diagnostics Package
PDR	preliminary design review
PMAR	post-mission assessment review
PPE	Power and Propulsion Element
RAS	robot arm system
Roman	Nancy Grace Roman Space Telescope
RPOD	rendezvous proximity operations and docking
SCA	Sensor Chip Assemblies
SDR	system definition review
SEP	Solar Electric Propulsion
SFD	Sustainable Flight Demonstrator
SIR	system integration review
SIT-3	System Integration and Test Level 3
SIT-4	System Integration and Test Level 4
SLD	Sustaining Lunar Development
SLS	Space Launch System
SMD	Science Mission Directorate
SPHEREx	Spectro-Photometer for the History of the Universe, Epoch of Re-ionization and Ices Explorer
SPIDER	SPace Infrastructure DExterous Robot
SRR	system requirements review
STMD	Space Technology Mission Directorate
SWOT	Surface Water and Ocean Topography
TRL	technology readiness level
VERITAS	Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy
VIPER	Volatiles Investigating Polar Exploration Rover
xEVA	Exploration Extravehicular Activity

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
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May 31, 2023

Congressional Committees

NASA plans to invest more than $83 billion in its 2023 portfolio of 34 major projects, which we define as those projects or programs with a life-cycle cost of over $250 million. The goals of these projects include exploring Earth and the solar system, extending human presence beyond low-Earth orbit to the lunar surface, and understanding climate change, among other things. This report provides an overview of NASA's planning and execution of these major acquisitions—an area that has been on GAO's high-risk list since 1990.[1] It includes assessments of NASA's key projects across mission areas, such as the Orion Multi-Purpose Crew Vehicle (Orion) for human exploration; Europa Clipper for planetary science; Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) for Earth science; and the Nancy Grace Roman Space Telescope (Roman) for astrophysics.

The explanatory statement of the House Committee on Appropriations accompanying the Omnibus Appropriations Act, 2009 includes a provision for us to prepare project status reports on selected large-scale NASA programs, projects, and activities.[2] The joint explanatory statement accompanying the Consolidated Appropriations Act, 2023 includes a similar provision.[3] This is our 15th annual report responding to these provisions.

This report includes our analysis of (1) the cost and schedule performance of NASA's portfolio of major projects; (2) the development and maturity of NASA's technologies; and (3) the current status of major NASA projects, as reflected in individual project assessments. Appendix I includes individual assessments for 31 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

[1]GAO, *High-Risk Series: Efforts Made to Achieve Progress Need to Be Maintained and Expanded to Fully Address All Areas,* GAO-23-106203 (Washington, D.C.: Apr. 20, 2023).

[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 since this is the term used by NASA.

[3]Explanatory Statement, 168 Cong. Rec. S7898 (daily ed., Dec. 20, 2022), accompanying the Consolidated Appropriations Act, 2023, Pub. L. No. 117-328.

launch or the end of development. We do not provide individual assessments for the Exploration Ground Systems (EGS), the Space Launch System (SLS), or the Surface Water and Ocean Topography (SWOT) projects that launched or completed development in 2022, although they are included in our various analyses.

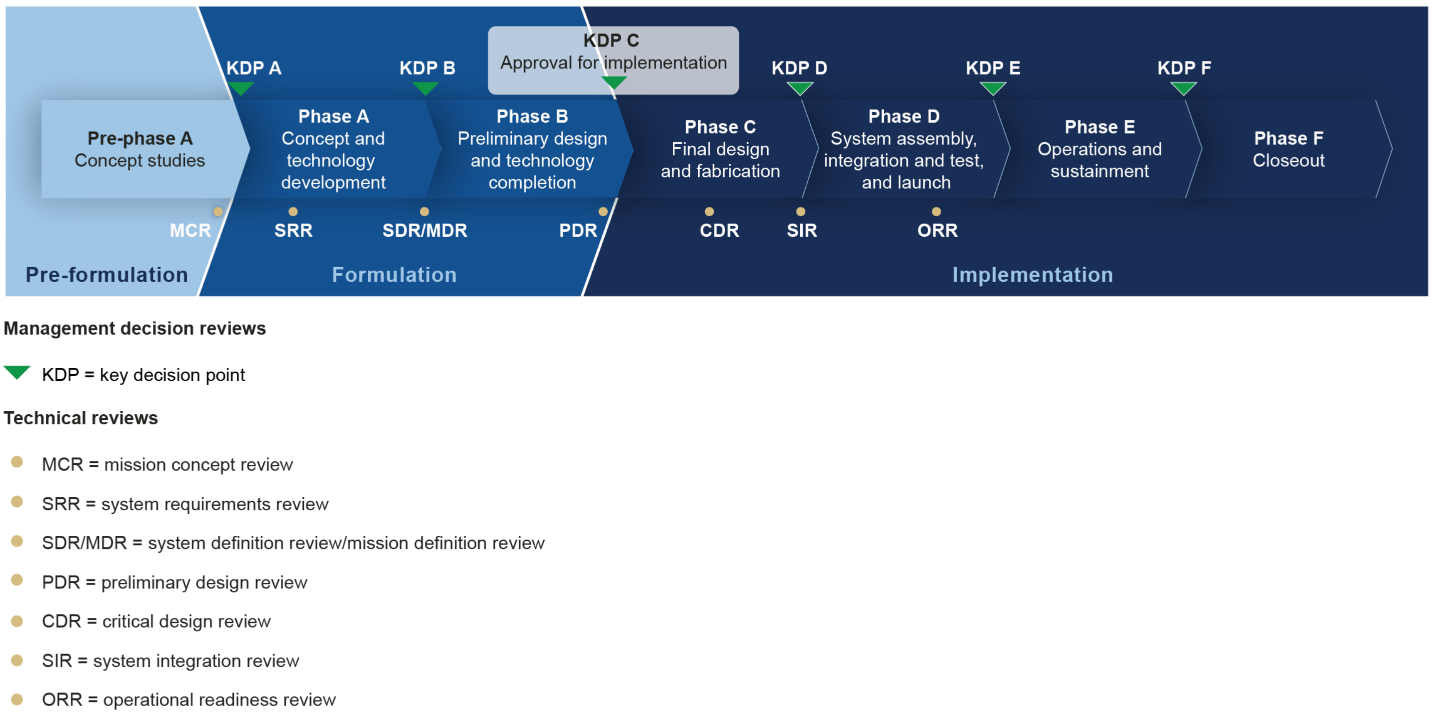
To conduct our analyses, we collected cost, schedule, and technology maturity data via questionnaires sent to NASA headquarters and project offices. We analyzed these data, and, where appropriate, we compared data against best practices we have identified for product development. We also collected and analyzed NASA guidance for managing technology development for technology and flight demonstration projects to identify how NASA oversees these projects. We met with NASA headquarters and mission directorate officials to discuss this topic as well. To complete our individual project assessments, we reviewed monthly status reports, analyzed questionnaire data, and interviewed project officials. Appendix II contains detailed information on our scope and methodology.

We conducted this performance audit from May 2022 to May 2023 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—(1) formulation, which takes a project from concept development to preliminary design, and (2) implementation, which includes activities like building, launching, and operating the system. NASA further divides formulation and implementation into phases A through F. Major projects must get approval from senior NASA officials at key decision points (KDP) before they can enter each new phase. Figure 1 depicts NASA's life cycle for space flight projects.

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



Source: GAO analysis of NASA data. | GAO-23-106021

Project formulation consists of phases A and B, during which a project team develops and defines requirements, cost and schedule estimates, and the system's design for implementation. Prior to beginning phase A, NASA conducts a mission concept review to evaluate the feasibility and maturity of proposed mission concepts and associated planning. In phase A, a project team develops a range of cost and schedule estimates for uses such as budget planning. The agency conducts a system requirements review (SRR) and system definition review / mission definition review (SDR/MDR) to ensure the project's performance requirements and proposed system architecture or technical approach are aligned with the mission's performance requirements. During phase B, the project team also develops programmatic measures and technical leading indicators that track various project metrics such as requirement changes, staffing demands, and mass and power utilization. Near the end of formulation, leading up to the preliminary design review (PDR), the project team completes technology development and its preliminary design. Formulation culminates in a review at KDP C, where senior leaders approve the cost and schedule agency baseline commitments.

After a project holds KDP C, 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. The project team holds a critical design review (CDR) during the latter half of phase C to determine whether 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 team 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 team performs system assembly, integration, test, and launch activities. During the latter half of phase D, the project team holds an operational readiness review to ensure that all system and support hardware, software, personnel, and procedures are ready for operations. Phases E and F consist of operations and sustainment and project closeout.

NASA Cost and Schedule Commitments

Major NASA projects have two sets of cost and schedule commitments—the management agreement and the agency baseline commitment. The management agreement is between the agency and the executing center. The executing center's project manager has the authority to manage the project within the parameters outlined in the agreement. The management agreement includes cost and schedule reserves that the project manager controls.[4] Cost reserves are for costs that projects expect to incur—for instance, risk mitigations—but are not yet allocated to a specific part of the project. Schedule reserves are extra time in project schedules that managers can allocate to specific activities, elements, and major subsystems to mitigate delays or address unforeseen events. 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 agency baseline commitment includes the cost and schedule baselines against which the agency's performance on a project is measured. The baselines include life-cycle costs broken out by formulation, development, and operations costs and a key schedule milestone event such as a launch readiness date to denote the end of development and start of operations. To inform the management agreement and the agency baseline commitment, each project with a life-cycle cost estimate of greater than $250 million must also develop a joint

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

cost and schedule confidence level unless NASA waives the requirement. A joint cost and schedule confidence level 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.[5]

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 also varies by NASA center. 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's KDP C review and 10 percent at the time of delivery to the launch site.[6] Projects track their reserves between phases to help ensure they hold reserves consistent with these requirements.

When a project is no longer meeting certain conditions in the agency baseline commitment, NASA replans or rebaselines the project. In certain cases, NASA is required to notify Congress when this occurs. See Table 1 for an overview of characteristics of NASA replans and rebaselines.

[5]NASA, *NASA Cost Estimating Handbook Version 4.0* (February 2015).

[6]NASA, *Funded Schedule Margin and Budget Margin for Flight Projects,* Goddard Procedural Requirements 7120.7B (Sept. 17, 2018).

Table 1: Characteristics of NASA Program Replans and Rebaselines

	Description	Potential congressional reporting
Replan	A replan is a process by which a program updates or modifies its plans. It 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]
Rebaseline	Rebaselining is the process that results in a change to the project's agency baseline commitment. NASA initiates a rebaseline 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.	In addition to the replan reporting noted above, should a program exceed its development cost baseline by more than 30 percent, the program must be reauthorized by Congress and rebaselined in order to expend funds to continue work beyond a specified time frame.[b]

Source: GAO analysis of NASA policy and 51 U.S.C. § 30104. | GAO-23-106021

[a]51 U.S.C. § 30104(e)(1).

[b]51 U.S.C. § 30104(f).

NASA Organization and Portfolio Management

NASA has five mission directorates to manage its programs and projects (see Table 2). These directorates initiate or select new projects, oversee project performance, and manage budgets and resources for their portfolio of projects. They report to various agency forums on project progress, including any variations in cost, schedule, technical, and risk performance that could affect agency commitments and performance goals. Mission directorates also consult academia and the science community, which play a large role in helping the mission directorates shape priorities and goals and decide on upcoming projects to pursue. For example, decadal surveys provide NASA with the science communities' opinions on mission goals, and are one of the inputs NASA uses to determine when to add new missions. The agency also provides mission and technical support to its major projects through its 10 NASA Centers.

Table 2: NASA Mission Directorates with Associated Mission Descriptions

Mission directorate	Mission
Aeronautics Research Mission Directorate	Conducts research that generates concepts, tools, and technologies to enable advances in future aircraft
Science Mission Directorate	Carries out the scientific exploration of Earth and space to expand the fields of Earth science, heliophysics, planetary science, astrophysics, and biological and physical sciences

Mission directorate	Mission
Space Technology Mission Directorate	Develops and demonstrates high-payoff technologies with the intent to infuse them into current and future NASA missions or transition them for commercial aerospace applications
Exploration Systems Development Mission Directorate	Defines and manages systems development for programs critical to Artemis missions (a series of missions that will return astronauts to the moon) and plans the moon-to-Mars exploration approach
Space Operations Mission Directorate	Focuses on launch and space operations, including the International Space Station, the commercialization of low-Earth orbit, and eventually, sustaining operations on and around the moon

Source: GAO analysis of NASA data. | GAO-23-106021

The primary policy that guides project management for major projects is NASA Procedural Requirements 7120.5F, which we refer to throughout this report as NASA's key project management policy.[7] This policy establishes the requirements by which NASA formulates and implements space flight programs and projects. The requirements include a definition of category thresholds that determine the level of internal oversight and approval a project receives depending on its life-cycle cost and other criteria (see Table 3). These category definitions do not affect NASA's statutory external reporting requirements to report progress against cost and schedule baselines to congressional committees for projects with a life-cycle cost over $250 million, although officials told us they are pursuing a potential increase of the threshold.[8]

Table 3: NASA Project Category Cost Threshold Definitions

Category	Project life-cycle cost threshold	Decision authority
1	Over $2 billion	NASA Associate Administrator
2	$365 million to $2 billion	Mission Directorate Associate Administrator
3	Less than $365 million	

Source: GAO analysis of NASA Procedural Requirements 7120.5F. | GAO-23-106021

Note: Beside its life-cycle cost estimate, other factors might lead NASA to increase the category level of a project. These factors include the project's level of radioactive material, distinction as a human space flight project, or its priority level. Priority level is determined by the importance of the activity to NASA, the extent of international participation (or joint effort with other government agencies), or level of risk associated with the development of the spacecraft or payload.

[7]NASA, *NASA Space Flight Program and Project Management Requirements,* Procedural Requirements 7120.5F (Aug. 3, 2021).

[8]51 U.S.C. § 30104.

NASA Projects Reviewed in Our Annual Assessment

Of the 34 projects we reviewed this year, 14 are related to the Artemis missions—a series of missions that will return astronauts to the moon. The Artemis I and II missions are the first planned uncrewed and then crewed demonstration missions of the Orion, Space Launch System (SLS), and EGS programs. NASA successfully launched Artemis I in November 2022 and is currently planning Artemis II for no earlier than November 2024. The Artemis III mission, expected to take place no earlier than December 2025, will be a crewed lunar landing using a Human Landing System (HLS) that docks in lunar orbit with Orion. Table 4 identifies the Artemis-related projects included in our 2023 assessment.

Table 4: Artemis-Related Major NASA Projects Reviewed in GAO's 2023 Assessment

Life-cycle phase	Project name	Project description	Project category
Projects in formulation	**Extravehicular Activity and Human Surface Mobility Program (EHP) – Lunar Terrain Vehicle (LTV)**	Lunar surface transportation system to extend the range of crew excursions and enable remote science operations during uncrewed periods	1
	EHP – Exploration Extravehicular Activity (xEVA)	Space suits and associated tools for NASA's return to the lunar surface as well as the International Space Station	1
	Gateway – Deep Space Logistics (DSL)	Transportation services that will provide the Gateway, an outpost in lunar orbit, with cargo and supplies prior to crew arrival to maximize the length of crew stays	2
	Gateway – Habitation and Logistics Outpost (HALO)	The initial crew module for the Gateway that will provide living quarters and communication functions to the lunar surface and for visiting vehicles	1
	Gateway – Power and Propulsion Element (PPE)	Solar electric propulsion spacecraft that will provide the Gateway with power, communications, and the ability to change orbits	1
	Human Landing System (HLS) – Initial Capability	Human lander that will provide crew access to the lunar surface and demonstrate initial capabilities required for deep space missions	1
	HLS – Sustaining Lunar Development (SLD)	Expanded lunar landing capabilities beyond Artemis III to support a lasting crewed presence on the moon such as: transporting additional crew and increased mass, docking with the Gateway, and operating near the lunar south pole	1
	Mobile Launcher 2 (ML2)	Newly designed launch platform and tower for the SLS Block IB vehicle with the upgraded Exploration Upper Stage	1
	Space Launch System (SLS) Block IB	Planned evolution of SLS with greater in-space thrust that will use an Exploration Upper Stage and associated capabilities to increase the amount of mass that can be delivered to the moon and other deep space destinations	1

Life-cycle phase	Project name	Project description	Project category
Projects in implementation	**Orion Multi-Purpose Crew Vehicle (Orion)**	A crew module, service module, and launch abort system atop NASA's SLS to transport and support astronauts beyond low-Earth orbit	1
	Solar Electric Propulsion (SEP)	Technology demonstration of high power solar electric propulsion technologies that consist of the Advanced Electric Propulsion system effort, a critical technology for the Gateway Power and Propulsion Element	2
	Volatiles Investigating Polar Exploration Rover (VIPER)	Rover that aims to understand how much water is on the moon and where it is located	2
Projects in implementation that recently launched or completed development	**Exploration Ground Systems (EGS)**	Modernized and upgraded infrastructure at Kennedy Space Center to support Artemis launches	1
	Space Launch System (SLS)	NASA's first human rated heavy-lift vehicle designed for deep space operations	1

Source: GAO analysis of NASA data. | GAO-23-106021

The 20 non-Artemis major projects are primarily science and aeronautics projects. See table 5 for descriptions of the non-Artemis major projects.

Table 5: Non-Artemis Major NASA Projects Reviewed in GAO's 2023 Assessment

Life-cycle phase	Project name	Project description	Project category
Projects in formulation	**Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging (DAVINCI)**	Spacecraft and deep atmosphere probe to measure the composition and environmental properties of Venus's atmosphere and surface to understand how its evolution diverged from Earth's and determine whether it ever had oceans of liquid water	2
	Dragonfly	Robotic rotorcraft that will explore Titan—Saturn's largest moon—and study chemical components and prebiotic processes needed for the development of life	1
	Electrified Powertrain Flight Demonstration (EPFD)	Flight demonstration aircraft for high-power hybrid electric propulsion system technologies to be used on commercial aircraft	2
	Geospace Dynamics Constellation (GDC)	Multiple spacecraft planned to study Earth's upper atmosphere and produce insights into space weather processes	2
	Helioswarm	Constellation of nine spacecraft—one hub spacecraft, and eight co-orbiting small satellites—that will investigate solar wind turbulence and its evolution	2
	Mars Sample Return (MSR)	Robotic systems and a Mars ascent rocket to collect samples of Martian rocks, sediment, and atmosphere to return back to Earth for study	1
	Sustainable Flight Demonstrator (SFD)	Flight demonstration project that plans to develop and test an environmentally sustainable airframe technology for single-aisle aircraft	2

Life-cycle phase	Project name	Project description	Project category
	Venus Emissivity, Radio science, InSAR, Topography, And Spectroscopy (VERITAS)	Spacecraft that will map Venus's surface to determine the planet's geologic history and understand why it developed differently than Earth	2
Projects in implementation	**Commercial Crew Program (CCP)**	Commercially developed crew transportation systems to carry NASA astronauts to and from the International Space Station	1
	Europa Clipper	A spacecraft that will orbit Jupiter and conduct flybys of Europa to investigate whether the Jupiter moon could harbor conditions suitable for life	1
	Interstellar Mapping and Acceleration Probe (IMAP)	Spacecraft that will help researchers better understand the boundary where the heliosphere—the bubble created by the solar wind—collides with material from the rest of the galaxy	2
	Low Boom Flight Demonstrator (LBFD)	Flight demonstration aircraft that plans to show that noise from supersonic flight—sonic boom—can be reduced to levels acceptable to the public for eventual commercial use in overland flight paths	2
	Nancy Grace Roman Space Telescope (Roman)	An infrared space telescope to perform wide-field imaging and surveys of the near-infrared sky to answer questions about the structure and evolution of the universe	1
	NASA Indian Space Research Organisation - Synthetic Aperture Radar (NISAR)	Joint satellite mission with the Indian Space Research Organisation to study the solid Earth, ice masses, and ecosystems and address various environmental questions	2
	Near Earth Object Surveyor (NEO Surveyor)	Space-based telescope to identify potentially hazardous asteroids greater than 140 meters across	2
	On-Orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1)	Technology demonstration of a robotic spacecraft that plans to autonomously refuel an on-orbit satellite, assemble and install an antenna, and manufacture a beam	1
	Plankton, Aerosol, Cloud, ocean Ecosystem (PACE)	Spacecraft that will use advanced global remote-sensing instruments on a polar-orbiting mission to improve understanding of ocean biology, biogeochemistry, ecology, aerosols, and cloud properties; and extend climate-related observations begun under earlier missions	2
	Psyche	Spacecraft that will be the first mission to visit a metal asteroid and aims to understand iron cores, a component of the early building blocks of planets	2
	Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ices Explorer (SPHEREx)	Survey satellite that will use a telescope to probe the origin and destiny of the universe and create a map of the entire sky to gather data on galaxies and stars in the Milky Way	2
Project in implementation that recently launched	**Surface Water and Ocean Topography (SWOT)**	Satellite that will take repeated high-resolution measurements of Earth's oceans and freshwater bodies to develop a global survey	2

Source: GAO analysis of NASA data. | GAO-23-106021

Five of the projects in the portfolio are flight and technology demonstration projects—Electrified Powertrain Flight Demonstration (EPFD), Low Boom Flight Demonstrator (LBFD), On-Orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1), Solar Electric Propulsion (SEP), and Sustainable Flight Demonstrator (SFD). The purpose of the technology demonstration projects is to execute system-level demonstrations of new technologies in space or in a relevant environment to prove capabilities that can be used on future NASA missions or to facilitate commercialization of the technology. For example, SEP will demonstrate a solar electric propulsion thruster that will be used to propel the Gateway's Power and Propulsion Element (PPE). OSAM-1 will demonstrate the ability to refuel a satellite on orbit, among other capabilities, which can then be used by commercial entities and other government agencies. Likewise, flight demonstration projects such as EPFD and LBFD will demonstrate new capabilities for aircraft or generate data that may be used to inform commercial practices in the future.

Appendix III includes a list of all projects in this year's portfolio and their current cost and schedule estimates. Appendix IV includes a list of all the projects that we reviewed from 2009 to 2022.

Our Recent Work on NASA's Portfolio of Major Projects

We first designated NASA's acquisition management as a high-risk area in 1990 in view of NASA's history of persistent cost growth and schedule slippage in the majority of its major systems. We identified management weaknesses that have exacerbated the inherent technical and engineering risks faced by NASA's largest projects, including the Orion, SLS, and EGS programs. In our spring 2023 High-Risk Update, we found that NASA completed several initiatives to strengthen its cost and schedule estimating capacity, such as embracing tools to support better cost and scheduling practices, but it continues to face challenges in its ability to manage and oversee its category 1 projects.[9]

We previously found that cost and schedule growth associated with NASA's category 1 missions can have cascading effects on the rest of the portfolio.[10] For example, when James Webb Space Telescope (JWST) costs increased, NASA proposed canceling the Nancy Grace Roman

[9]GAO-23-106203.

[10]GAO, *NASA: Lessons from Ongoing Major Projects Could Improve Future Outcomes,* GAO-22-105709 (Feb. 9, 2022); and *NASA: Lessons from Ongoing Major Projects Can Inform Management of Future Space Telescopes,* GAO-22-105555 (Dec. 1, 2021).

Space Telescope project several years in a row to allow the agency to use those resources to focus on higher priorities, such as the completion of JWST.[11] Additionally, in our 2022 annual assessment of major NASA projects, NASA officials from the Science Mission Directorate told us that cost overruns in implementation projects affected their ability to budget for new formulation projects.[12]

Since we initially designated NASA's acquisition management as high risk, we have made numerous recommendations to reduce acquisition risk. Through these recommendations, we identified multiple areas where NASA should take action to improve the management of its portfolio of major projects. For example, we have recommended that NASA establish cost and schedule baselines for additional SLS and EGS capabilities and develop guidance for its lunar mission schedules.[13] NASA has generally agreed with our recommendations and implemented changes in response to many of them, but it needs to take additional actions to fully address all of the recommendations. As of March 2023, we identified 16 recommendations related to this high-risk area that remain open.

NASA's Largest Projects Drive Portfolio Cost and Schedule Performance

Category 1 projects in development—NASA's highest priority and most costly, such as James Webb Space Telescope—drive NASA's cumulative cost performance. For example, cost overruns were significantly smaller in 2023 than last year because the James Webb Space Telescope launched, and its $4.5 billion in overruns from prior years are no longer part of the portfolio. In addition, compared to 2022 performance, some of the largest category 1 projects—the Space Launch System, Orion, and Exploration Ground Systems—had little to no new cost growth. Overall, since 2022, eight of the 16 major projects experienced some cost or schedule growth. We also found that most of the major projects in development were not meeting their original cost or schedule baselines. As the portfolio of major projects evolves, NASA has identified opportunities to improve cost and schedule performance.

[11] GAO-22-105709.

[12] GAO, *NASA: Assessments of Major Projects,* GAO-22-105212 (Washington, D.C.: June 23, 2022).

[13] GAO-23-106203.

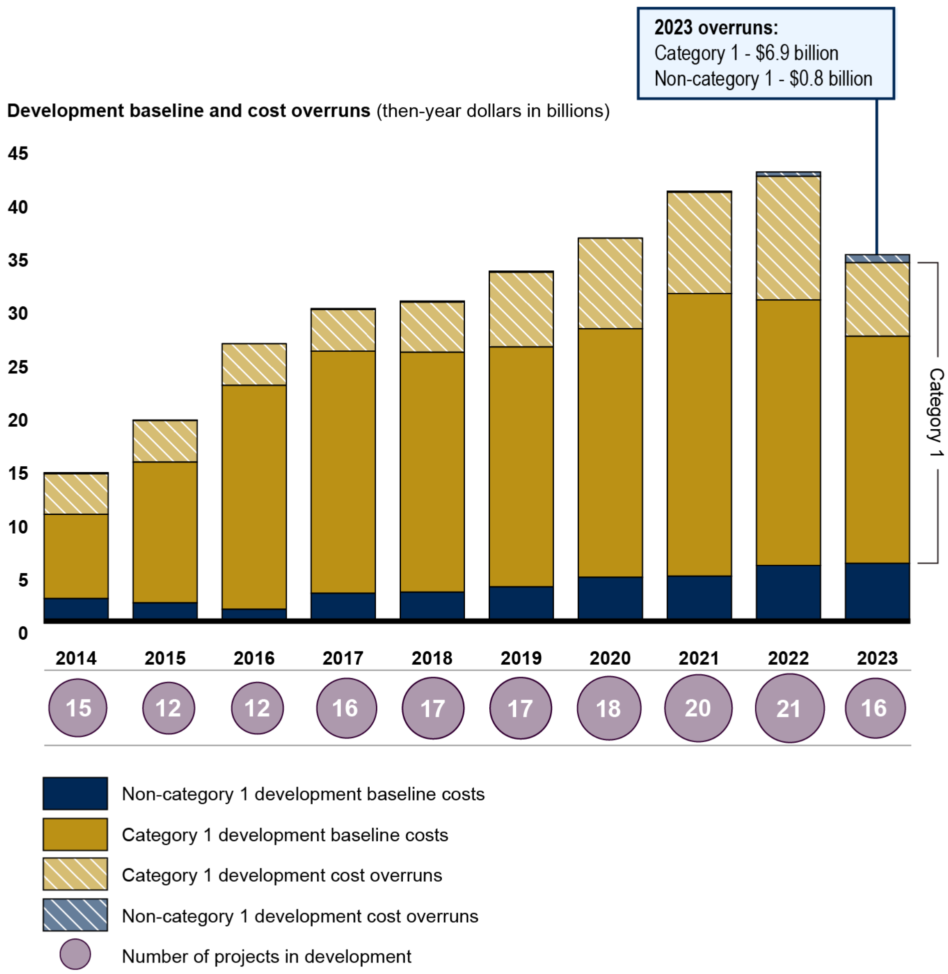
Category 1 Projects Continue to Drive Portfolio Cost Overruns

Category 1 projects in development are continuing to drive NASA's cumulative cost performance. Most of the cumulative cost overruns for category 1 projects accrued prior to 2022. For example, SLS, EGS, and Orion—all Artemis-related category 1 projects—contributed about 80 percent, or $6.1 billion, of the current portfolio's total $7.6 billion in cumulative cost overruns, though they had little to no new cost growth in 2023.[14] We previously reported on key cost drivers for the Artemis-related category 1 projects, which include schedule delays as well as manufacturing challenges for SLS, and contractor performance issues for Orion.[15] This is a longer-term trend—since 2014, the category 1 projects in development accounted for the majority of the portfolio's total baseline costs and cumulative cost overruns (see fig. 2).

[14]NASA currently has 17 major projects in the implementation phase, but we excluded the Commercial Crew Program from this analysis to be consistent with prior years because it has a tailored project life cycle and project management requirements and did not establish a baseline. Therefore, the portfolio of major projects in development consists of 16 projects.

[15]GAO, *NASA Human Space Exploration: Significant Investments in Future Capabilities Require Strengthened Management Oversight,* GAO-21-105 (Washington, D.C.: Dec. 15,2020); *NASA: Assessments of Major Projects*, GAO-19-262SP (Washington, D.C.: May 30, 2019); *NASA: Assessments of Major Projects*, GAO-20-405 (Washington, D.C.: Apr. 29, 2020); and GAO-22-105212.

Figure 2: Cumulative Development Cost Overruns for NASA's Portfolio of Major Projects by Category



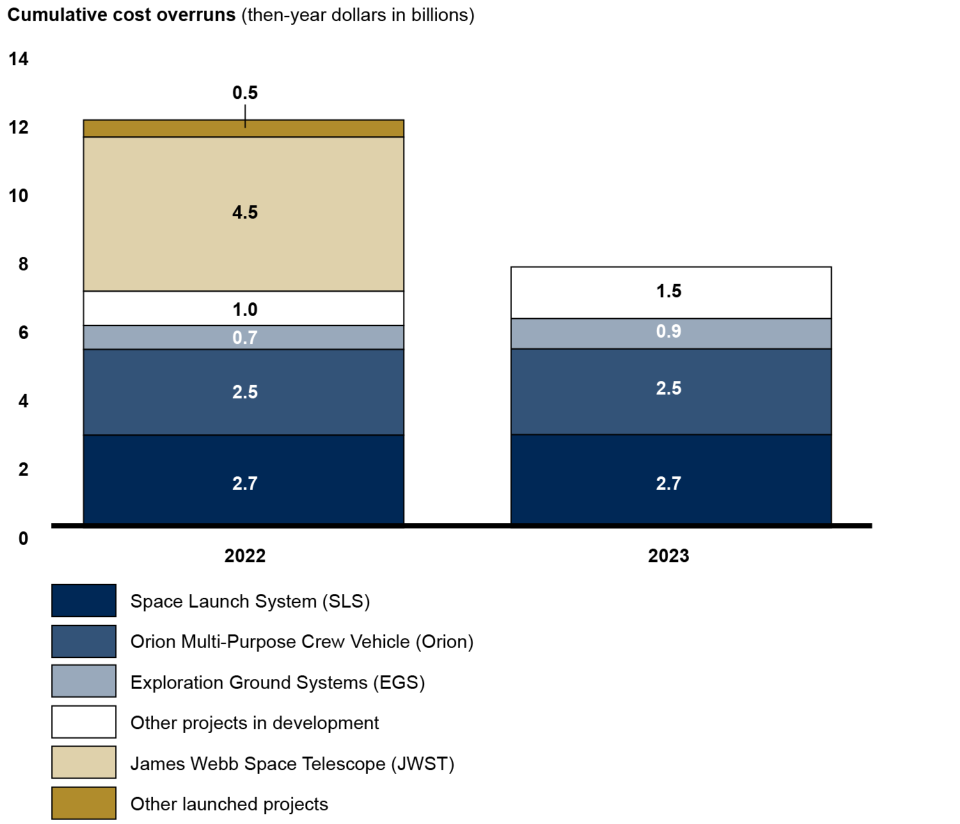
Source: GAO analysis of NASA data. | GAO-23-106021

Notes: The years in the figure denote the year we issued our annual assessment of major NASA projects. Data are primarily as of January 2023.

Category 1 projects that exit the portfolio can have a significant effect on NASA's reported cumulative cost performance. For example, the total cost overruns for NASA's portfolio of major projects in development significantly decreased from $12 billion in 2022 to $7.6 billion in 2023. This was mainly due to JWST—one of the agency's largest category 1 projects—exiting the portfolio along with its accumulated cost overruns (see fig. 3). We anticipate a similar outcome in next year's analysis when

SLS and EGS leave the portfolio and take with them over $3.6 billion in accumulated cost overruns.[16]

Figure 3: Comparison of Cumulative Development Cost Overruns by Project in 2022 and 2023



Source: GAO analysis of NASA data. | GAO-23-106021

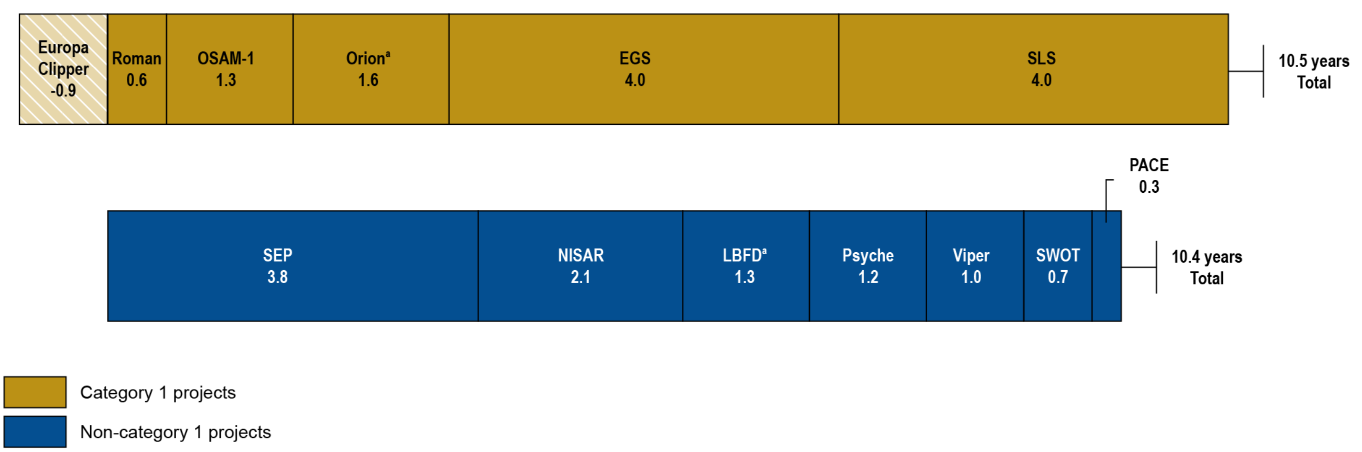
Notes: The years in the figure denote the year GAO issued our annual assessment of major NASA projects. Data for our current assessment are as of January 2023.

Twelve of NASA's 16 major projects in development have experienced schedule delays. While the portfolio's cumulative cost performance is driven by category 1 projects, NASA's smaller projects are contributing to the portfolio's combined schedule delays in nearly equal measure to the category 1 projects. On the other hand, one project—Europa Clipper—is currently planning to complete development 11 months ahead of its

[16]NASA successfully launched Artemis I in November 2022, at which point SLS and EGS demonstrated their initial capability.

baseline, due to updates to its launch trajectory made after its launch vehicle selection. Figure 4 shows each project's cumulative schedule delays.

Figure 4: Total Cumulative Schedule Delays for NASA Major Projects in Development (in years)



Legend: EGS: Exploration Ground Systems; SLS: Space Launch System; Orion: Orion Multi-Purpose Crew Vehicle; OSAM-1: On-Orbit Servicing, Assembly, and Manufacturing 1; Roman: Nancy Grace Roman Space Telescope; SEP: Solar Electric Propulsion; NISAR: NASA Indian Space Research Organization – Synthetic Aperture Radar; LBFD: Low Boom Flight Demonstrator; VIPER: Volatiles Investigating Polar Exploration Rover; SWOT: Surface Water and Ocean Topography; PACE: Plankton, Aerosol, Cloud, ocean Ecosystem

Source: GAO analysis of NASA data. | GAO-23-106021

Notes: Positive values indicate launch delays while negative values indicate schedule decreases. Data for our current assessment are as of January 2023. The category 1 values do not sum to the total because of rounding.

[a]LBFD and Orion expect to have additional schedule delays, but the exact magnitude is unknown. The projects were reevaluating their schedules at the time of our review. GAO used the latest schedule estimates provided by NASA for these projects.

Most Major Projects in Development Exceeded Statutory Cost and Schedule Performance Thresholds

Regardless of their category, most major NASA projects in development have experienced cost overruns or schedule delays that meet key thresholds identified in statute. Projects trigger a congressional notification when they are likely to exceed their development cost baselines by 15 percent or to incur 6 months of schedule delays.[17] In addition, according to statute, if a project exceeds its development cost baseline by more than 30 percent, it must be reauthorized by Congress.[18]

When assessed against these thresholds, our analysis showed that most of the major projects in development are not meeting their original cost or schedule baselines. In particular, 11 of the 16 projects exceeded the notification thresholds. Of these 11, five also exceeded the reauthorization threshold. These 11 projects represent about $7.5 billion in cost overruns, which puts pressure on the rest of NASA's portfolio. When projects experience cost growth and schedule delays in development, the magnitude of those changes worsens NASA's overall performance until those projects exit the portfolio. For a comprehensive list of the cumulative cost and schedule changes by project, see appendix V. Figure 5 shows our assessment of performance of major projects in development against statutory cost and schedule thresholds.

[17] Under section 30104(d) of title 51, U.S. Code, the NASA Administrator must notify certain congressional committees when there is reasonable cause to believe that either a project's development cost is likely to exceed the estimate provided in its Baseline Report by 15 percent or more or a milestone is likely to be delayed by 6 months or more from the date provided in its Baseline Report. This notification explains the reason for the change in the cost or milestone.

[18] 51 U.S.C. § 30104(f).

Figure 5: GAO Assessment of Performance of Major NASA Projects in Development against Statutory Cost and Schedule Thresholds as of January 2023

Projects that have not met statutory thresholds	Projects that have met the statutory threshold for notification	Projects that have met the statutory threshold for reauthorization
Europa Clipper	LBFD	EGS
IMAP[a]	OSAM-1	NISAR
NEO Surveyor[a]	Psyche	Orion
PACE	Roman	SEP
SPHEREx[a]	SWOT	SLS
	VIPER	

Projects with cost overruns less than 15 percent and schedule delays of less than 6 months from their original baseline

Projects with cost overruns between 15 and 30 percent or a schedule delay over 6 months from their original baseline

Projects with cost overruns over 30 percent from their original baseline

Legend: IMAP: Interstellar Mapping and Acceleration Probe; NEO: Near Earth Object; PACE: Plankton, Aerosol, Cloud, ocean Ecosystem; SPHEREx: Spectro-Photometer for the History of the Universe, Epoch of Re-ionization and Ices Explorer; LBFD: Low Boom Flight Demonstrator; OSAM-1: On-Orbit Servicing, Assembly, and Manufacturing 1; Roman: Nancy Grace Roman Space Telescope; SWOT: Surface Water and Ocean Topography; VIPER: Volatiles Investigating Polar Exploration Rover; EGS: Exploration Ground Systems; NISAR: NASA Indian Space Research Organization – Synthetic Aperture Radar; Orion: Orion Multi-Purpose Crew Vehicle; SEP: Solar Electric Propulsion; SLS: Space Launch System

Source: GAO analysis of NASA data and 51 U.S.C. § 30104(d), (f). | GAO-23-106021

[a]IMAP, NEO Surveyor, and SPHEREx set baselines in the past 2 years and are currently performing at their cost and schedule baselines.

Half of the Projects Experienced Cost Increases or Schedule Delays and Half Remained Within Cost and Schedule Estimates Compared to Last Year

Since our last report, NASA's portfolio of major projects in development increased its estimated costs by $637.3 million and delayed its collective schedule by nearly 6 years. Half of the 16 projects experienced cost overruns or schedule delays since our last report, while half did not.[19] Table 6 summarizes the cost and schedule performance over the past year for the programs we reviewed.

[19]GAO-22-105212.

Table 6: Annual Development Cost Overruns and Schedule Delays for Major NASA Projects in Development since GAO's 2022 Assessment

		Changes between last GAO assessment and current assessment	
Annual performance status	**Project(s)**	**Schedule delay (years)**	**Cost growth (millions of dollars)**
First year estimate reported	NEO Surveyor	N/A	N/A
No change from prior year	Europa Clipper, IMAP, PACE, Roman, SEP, SPHEREx	0	0
Underrunning prior estimate	SWOT[a]	(0.5)	(29.2)
Mixed cost or schedule performance	SLS[b]	0.5	(3.5)
Overrunning prior estimate	Orion[c]	0.5	0
	LBFD[c]	0.4	35.2
	VIPER	1	63.9
	OSAM-1	1.3	123.5
	EGS	0.5	137.9
	NISAR	1.1	146.8
	Psyche	1.2	162.7
Totals		**5.9**	**637.3**

Legend: NEO: Near Earth Object; IMAP: Interstellar Mapping and Acceleration Probe; 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; SLS: Space Launch System; Orion: Orion Multi-Purpose Crew Vehicle; LBFD: Low Boom Flight Demonstrator, VIPER: Volatiles Investigating Polar Exploration Rover; OSAM-1: On-Orbit Servicing, Assembly, and Manufacturing 1; EGS: Exploration Ground Systems; NISAR: NASA Indian Space Research Organisation – Synthetic Aperture Radar

Source: GAO analysis of NASA data. | GAO-23-106021

Note: Positive values indicate cost growth or launch delays. Values in parentheses indicate cost and schedule decreases. Data for our current assessment were collected as of January 2023.

[a]SWOT launched 6 months earlier and for $29.2 million less than last year's estimates. However, the project was still 8 months behind its schedule baseline and $38.3 million over its cost baseline.

[b]SLS's cost estimate was $3.5 million less than last year's estimate due in part to underrunning initial workforce estimates. However, the project was still $2,714.8 million over its cost baseline.

[c]The costs or schedules for the Orion and LBFD projects are under review. Until those reviews are complete, information presented above is based on the latest estimates GAO received from NASA.

According to NASA officials, technical issues are the driving factor as to why most of the eight projects experienced cost or schedule growth since our last report.[20] With the exception of VIPER, all eight projects experienced annual cost or schedule growth for at least the second year

[20]GAO-22-105212.

in a row. Examples of projects with repeated cost growth or schedule delays are described below:

- Last year we reported that while the Psyche project experienced annual cost growth due to COVID-19 effects, the project was underrunning its baseline by $30.8 million due to its launch vehicle costs being lower than anticipated.[21] This year, Psyche costs grew by $162.7 million. The project missed its fall 2022 launch window due to incomplete flight software and testing issues and subsequently extended its schedule. Psyche is now working to an October 2023 launch date, a 14-month schedule delay with associated development cost growth of $131.9 million above its original baseline.
- We also reported last year that the NASA Indian Space Research Organisation (ISRO) - Synthetic Aperture Radar (NISAR) project was replanned in 2021, adding a 1-year delay and $113.3 million in costs due to technical issues and COVID-19, among other issues.[22] This year, NISAR costs grew by another $146.8 million and its launch was further delayed after the project experienced technical issues with its radars during integration. The project had to rebaseline and is now working toward a launch date of October 2024, an approximately 2-year delay from its original baseline.

After setting cost and schedule baselines in 2021, VIPER experienced its first overruns in the past year. NASA officials said they wanted to lower the risk of mission failure on VIPER, which resulted in the overruns. To decrease risk for the project, NASA directed Astrobotic—the contractor delivering VIPER to the lunar surface—to conduct additional testing on Astrobotic's Griffin lander propulsion system. As a result, the VIPER project incurred a 1-year schedule delay that resulted in a $63.9 million increase to the project's development costs.

Additional details on cost and schedule performance for each project are included in our individual project assessments in appendix I.

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[21]GAO-22-105212.

[22]GAO-22-105212.

NASA Has Identified Opportunities to Improve Project Performance as Portfolio Evolves

Our 2023 High-Risk report stated that NASA will need to identify ways to improve its management of category 1 projects to continue reducing acquisition risk and demonstrating progress.[23] As noted earlier, these projects drive cumulative cost performance for the entire portfolio when they overrun their baselines. While NASA is closing out the development of category 1 projects such as SLS and EGS, it is adding a new set of large, complex category 1 Artemis projects. In 2023, NASA anticipates setting baselines for nine projects with estimated development costs of over $16 billion. Of these, eight are designated as category 1 projects, and six of the eight will support NASA's Artemis missions. We previously reported that as NASA makes these commitments, it has an opportunity to strengthen its management of major acquisitions by adopting lessons learned from its past major projects.[24]

NASA has identified opportunities to improve the cost and schedule performance of its projects:

- In 2020, NASA conducted an internal review of its lessons learned on large missions following cost and schedule overruns in some of its largest strategic missions like the Eugene Parker Solar Probe and JWST.[25] The study included findings and recommendations aimed at the creation, execution, and oversight of large strategic missions. For example, the study recommended that these large missions conduct requirements analysis and architecture trades prior to phase A to quantify science and cost trade-offs. The agency started implementing some of these recommendations for Mars Sample Return, a category 1 project currently in formulation with a preliminary estimated cost of approximately $6 billion.
- NASA published an updated Corrective Action Plan in August 2022 as part of its efforts to address recent programmatic performance and its inclusion in our biennial High-Risk Report.[26] The plan describes a number of actions the agency intends to take to improve acquisition and program management. For example, projects should have early decision framing meetings to discuss critical questions and acquisition strategies. Further, as part of separate acquisition strategy meetings, projects

[23]GAO-23-106203.

[24]GAO-22-105709, GAO-22-105555.

[25]NASA, Science Mission Directorate, *Large Mission Study Report*.

[26]NASA, *2022 High Risk Corrective Action Plan*, 2022.

should propose acquisition strategy options that consider trades between cost, schedule, workforce, and other factors before the agency decides on an acquisition strategy. NASA's acquisition policy also directs its mission directorate leadership to consider these options when developing acquisition plans.[27] In addition, NASA plans to develop and emphasize areas for mentoring and training future project managers, and reinvigorate lessons learned capture and distribution methods.

- NASA assembled a team of specialists in 2021 to review the agency's acquisition practices and is now considering implementing its recommendation that the agency's senior leadership only approve project cost and schedule baseline commitments that are estimated at or above a 70 percent joint cost and schedule confidence level. NASA's policy currently provides flexibility for the decision authority to approve cost and schedule commitments at less than 70 percent confidence. According to its Corrective Action Plan, NASA is reviewing its options for implementing this recommendation, including revising its key project management policy, cost estimating or project management handbooks, and decision memorandum templates. Senior agency officials told us they already applied this recommendation by not approving a cost and schedule baseline for SLS Block 1B in summer 2022. Officials said they plan to create a strategy for setting a baseline with adequate reserves at a higher confidence level than previously proposed.
- NASA senior leaders said that other recent efforts may help control project cost and schedule growth. These efforts include having projects document when they deviate from the agency's policy for establishing cost and schedule baselines and develop plans to remove work if cost growth or schedule delays occur.

Senior NASA officials said that they plan to explore additional ways to control project cost and schedule performance, especially for category 1 projects. NASA also plans to implement several Corrective Action Plan initiatives, including initiatives to improve scheduling and increase transparency into the long-term costs and affordability of human spaceflight programs. Officials said these initiatives are intended to improve project performance. We will continue to monitor implementation of these efforts and any effect on the portfolio's cost and schedule performance.

[27]NASA, *Policy for NASA Acquisition,* Directive 1000.5C (revised 2022).

NASA Continues to Mature Its Critical Technologies

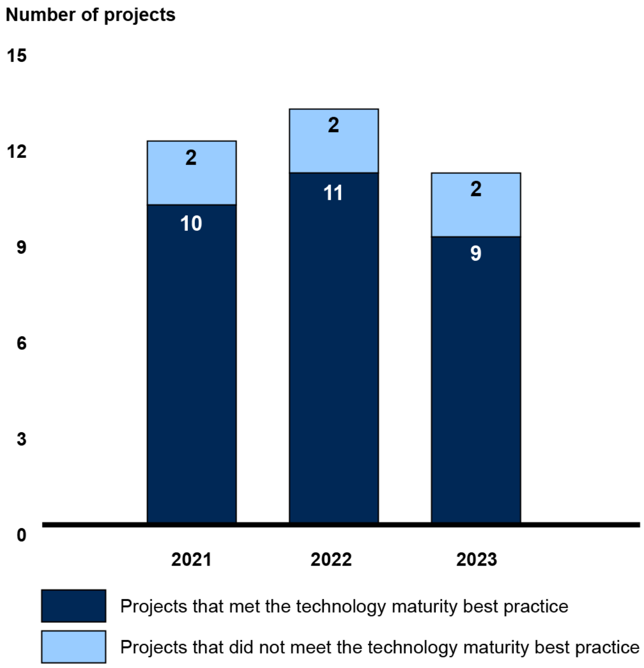
Most major NASA projects matured their technologies to the level recommended in our best practice by their preliminary design review (PDR). While NASA does not apply this best practice to technology demonstration projects due to their unique objectives, the agency provides policies and guidance for these projects to tailor their requirements. All of the flight and technology demonstration major projects in this year's portfolio have plans to develop and mature their technologies to the level needed to meet project objectives.

Most Major Projects Met Our Best Practice for Technology Maturity

We found that of the 11 major NASA projects that held PDR and identified critical technologies, nine met our best practice of maturing all critical technologies to a technology readiness level (TRL) 6 by PDR.[28] Achieving a TRL 6 involves demonstrating a representative prototype of the technology in a relevant environment that simulates the harsh conditions of space. 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. NASA's technology maturity levels in 2023 were generally consistent with the last 2 years (see fig. 6).

[28]In our analysis, we excluded 11 of the 22 projects past PDR that we reviewed for technology maturity. We excluded four of the 11 because they are technology demonstration projects that did not intend to mature their technologies before PDR, and six because they did not report any critical technologies. We also excluded the last of the 11, the HLS – Initial Capability. While the project held a PDR-equivalent review in December 2020, the project does not receive information about critical technologies or TRLs from its contractor. HLS officials told us that they have a variety of ways to gain insight on the contractor's performance, such as through an interim design review that officials said functioned as a checkpoint between PDR and CDR. For a full explanation of our methodology, see appendix II.

Figure 6: Most Major NASA Projects Met GAO's Best Practice of Achieving a Technology Readiness Level 6 by Preliminary Design Review from 2021 to 2023



Source: GAO analysis of NASA data. | GAO-23-106021

Note: The years in the figure denote the year we issued our annual assessment of major NASA projects. The 2023 data are current as of January and February 2023. The data include projects that completed preliminary design review and identified critical technologies, and exclude technology demonstration projects from all years.

According to our Technology Readiness Assessment Guide, a program identifying and maturing its critical technologies to a TRL 6 by PDR can minimize risks for the systems entering product development.[29] 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 for its design and program officials could be at risk of approving a design that is less likely

[29]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). This guide recommends that critical technologies are matured to TRL 7 by PDR. However, for NASA space flight projects, TRL 6 is acceptable because testing technology in the operational environment of space would be impractical.

to remain stable.[30] NASA's Systems Engineering policies align with our technology maturity best practice for achieving TRL 6 by PDR.[31] For more information about TRLs, see appendix VI.

We previously reported on the two projects—Roman and PPE—that did not meet our technology maturity best practice at the time of their PDRs.[32]

- Roman finished maturing the last one of its nine critical technologies to TRL 6 in 2022, over 2 years after its PDR and after the project had held its CDR.
- As of January 2023, PPE had matured over half of its critical technologies to TRL 6. None of the technologies were mature at the project's PDR in November 2021. Among PPE's immature technologies is a thruster required for the high-powered solar electric propulsion system. The SEP project, which is responsible for maturing the thruster, expects to mature the technology in late summer 2023 after completing acceptance testing on one of its qualification thrusters. The SEP project will not complete full wear testing of these thrusters before the PPE launches. SEP project officials said that this wear testing is intended to reduce uncertainty in and inform on-orbit operations. SEP project officials said they mitigated this risk by ensuring that they will complete the first 4,500 hours of this testing ahead of the PPE flight thruster operations on-orbit. If the SEP project identifies issues with the thrusters during acceptance or wear testing, it could result in design changes to the flight thrusters and delays to the PPE project's schedule.

  PPE is required to use a high-powered solar electric propulsion system because it is the only option that can meet the Gateway's requirements. We previously recommended that the Gateway program assess the technical risks of the SEP thrusters used by PPE to determine if it should consider off-ramps or trade-offs such as the reduction of requirements or reassessing schedule.[33] NASA assessed the thruster risks and determined there is no back-up option. NASA continues to assess the schedule in advance of establishing an

[30] GAO-20-48G.

[31] NASA, *NASA Systems Engineering Processes and Requirements*, Procedural Requirements 7123.1C (Feb. 14, 2020).

[32] GAO-20-405 and GAO-22-105212.

[33] GAO, *NASA Lunar Programs: Significant Work Remains, Underscoring Challenges to Achieving Moon Landing in 2024*, GAO-21-330 (Washington, D.C.: May 26, 2021).

agency baseline commitment for the Gateway Initial Capability (which includes PPE), which is planned for June 2023.

Near Earth Object (NEO) Surveyor was added to the analysis this year and met our technology maturity best practice by maturing all three of its critical technologies by its PDR in September 2022. NEO Surveyor's critical technologies include two Sensor Chip Assemblies (SCA), which consist of detectors that sense different infrared wavelengths, and the Sensor Control Electronics, which interface with the SCAs to transfer data from the instrument to the spacecraft. The project's technologies have previously flown on JWST and other space-based astronomy missions. Project officials said the only difference between NEO Surveyor and prior missions is that the project is going to use four detectors for its SCAs instead of two.

Demonstration Projects Mature Their Technologies Using a Tailored Approach

Four flight and technology demonstration projects in our portfolio—EPFD, LBFD, OSAM-1, and SEP—are tailoring the maturation of their technologies to meet unique project objectives, which is consistent with NASA policy.[34] While NASA does not apply a best practice of TRL 6 by PDR to these technology demonstration projects, all the projects have plans to develop and mature their technologies and all use TRL data to assess the maturity of critical technologies. Since entering formulation, each of the technology demonstration projects in our portfolio has further matured at least some of its technologies. For example, as of January 2023, SEP matured four of its five critical technologies from TRL 4 to TRL 5, and matured the fifth from a TRL 1-2 to a TRL 5.

NASA provides policies and guidance about project management and technology development to projects.[35] These policies allow for projects to

[34]One flight demonstration project, the Sustainable Flight Demonstration (SFD), was excluded from this analysis as the project is still in the concept and technology development phase and has not yet held KDP B.

[35]NASA, *NASA Space Flight Program and Project Management Requirements,* Procedural Requirements 7120.5F (Aug. 3, 2021); NASA, *NASA Systems Engineering Processes and Requirements,* Procedural Requirements 7123.1C (Feb. 14, 2020); NASA, Office of the Chief Technologist, *Technology Readiness Assessment Best Practices Guide,* SP-20205003605 (June 30, 2020); NASA, *NASA Space Flight Program and Project Management Handbook,* SP-20220009501 (May 2022); NASA, *Expanded Guidance for NASA Systems Engineering Volume 1: Systems Engineering Practices,* SP-2016-6105-SUPPL (Mar. 2016); NASA, *Expanded Guidance for NASA Systems Engineering Volume 2: Crosscutting Topics, Special Topics, and Appendices,* SP-2016-6105-SUPPL (Mar. 2016).

tailor requirements to best meet mission needs. For example, projects are required to document plans to develop technologies as part of systems engineering management plans and formulation agreements.[36] According to NASA policy, projects should also include information on how they will develop technologies to TRL 6 by PDR. However, NASA's Technology Readiness Assessment Best Practices Guide acknowledges that some projects, such as technology demonstrations, may not be held to that standard because the nature of the project may require a different risk posture.[37]

Beyond NASA agency-level policies and guidance, two mission directorates—the Space Technology Mission Directorate (STMD) and the Aeronautics Research Mission Directorate (ARMD)—manage and provide additional guidance to demonstration projects. STMD and ARMD demonstration projects have different approaches for maturing technologies compared to other major NASA projects because of the unique nature of the STMD and ARMD projects' objectives.

- STMD's charter is to invest in a wide array of emerging, high-risk/high-reward technologies with the understanding that only a subset of them will be successful. As a result, the risk tolerance for STMD projects is typically higher than human exploration or science missions. STMD's plans state that these projects are intended to start at a TRL 5. Throughout development, the project should achieve TRL 6 or higher. If successful, the project should achieve a TRL 7—system prototype demonstration in an operational environment—when the demonstration is complete. In essence, if the goal of these projects is to reach a TRL 6 by the end of development, then maturing technologies to a TRL 6 by PDR may be unrealistic.
- In ARMD, each project develops its own metrics that reflect its unique characteristics. ARMD approves performance expectations and decisions about technology maturation on a project-by-project basis to ensure the measures are appropriate for the technologies being demonstrated. For example, ARMD considers LBFD a research tool to capture public response to low sonic booms and enable regulatory change. The

[36]A Systems Engineering Management Plan is used to establish the technical content of the engineering work early in the formulation phase for each project and updated as needed throughout the project's life cycle. The Formulation Agreement is prepared by the project to establish the technical and acquisition work that needs to be conducted during formulation.

[37]NASA, Office of the Chief Technologist, *Technology Readiness Assessment Best Practices Guide,* SP-20205003605 (June 30, 2020).

project's only technology is the outer mold line of the aircraft, which is the shape of the aircraft. As a result, the performance of LBFD is purely associated with flying the aircraft at the required speed and altitude to measure acoustic performance.

According to ARMD documentation, demonstration projects typically seek to achieve TRL 6 following the flight demonstration. Furthermore, ARMD officials said that aeronautics missions are different than other NASA missions because if issues are found on the aircraft, the project can land the aircraft and fix the problem. Spaceflight missions, on the other hand, do not have this opportunity. As a result, ARMD officials said they are able to accept a different risk posture.

Agency Comments

We provided a draft of this report to NASA for its review and comment. In written comments, reprinted in appendix VII, NASA generally agreed with the findings of the report. 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 VIII.

W. William Russell
Director, Contracting and National Security Acquisitions

List of Committees

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

The Honorable Kyrsten Sinema
Chair
The Honorable Eric Schmitt
Ranking Member
Subcommittee on Space and Science
Committee on Commerce, Science, and Transportation
United States Senate

The Honorable Hal Rogers
Chair
The Honorable Matt Cartwright
Ranking Member
Subcommittee on Commerce, Justice, Science, and Related Agencies
Committee on Appropriations
House of Representatives

The Honorable Brian Babin
Chairman
The Honorable Eric Sorensen
Ranking Member
Subcommittee on Space and Aeronautics
Committee on Science, Space, and Technology
House of Representatives

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Appendix I: Individual Project Assessments

In the following section, we present assessments for 31 projects:

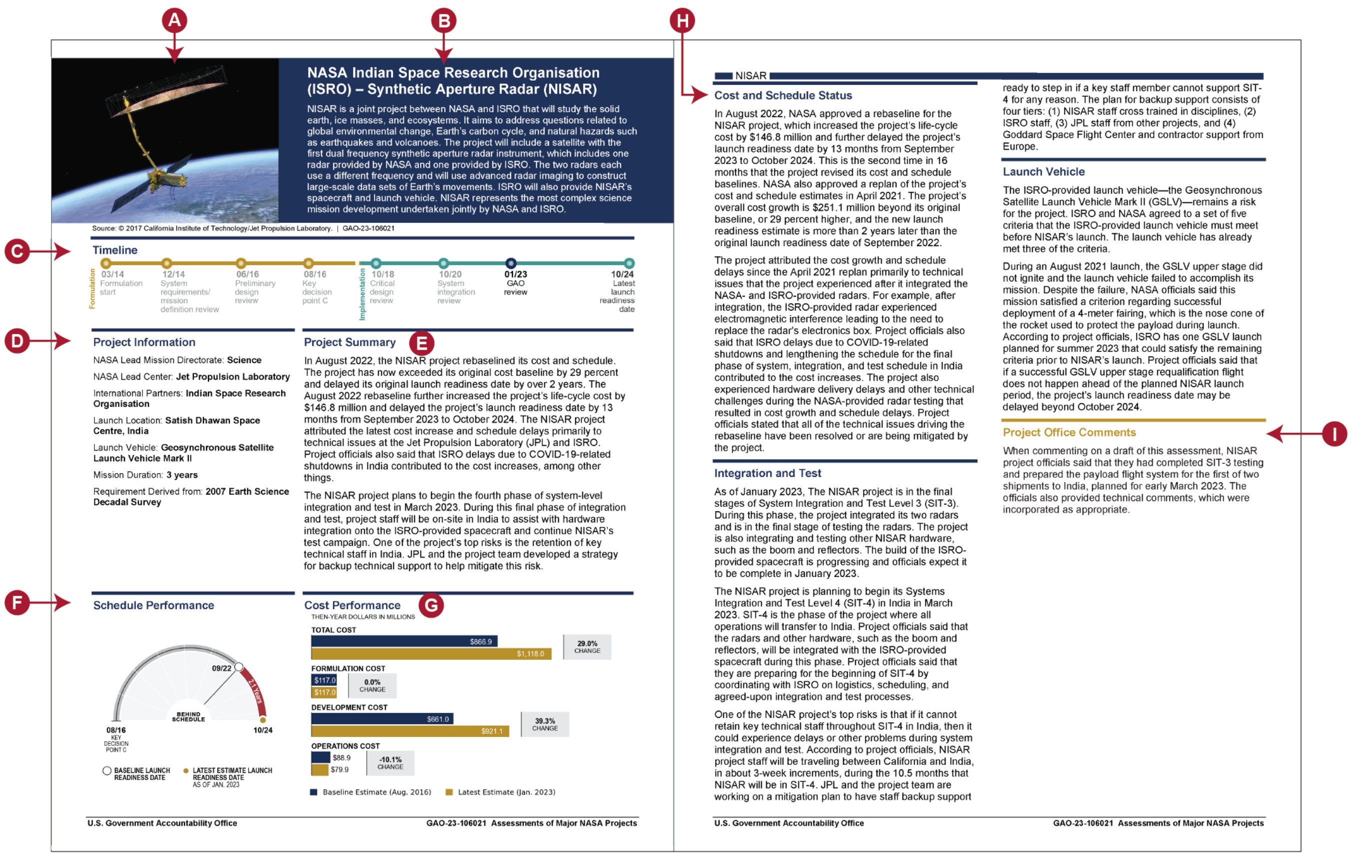
- There are 25 individual assessments in a two-page or one-page profile format. Each of these assessments generally includes a description of the project's objectives, information about the NASA centers and international partners involved in the project, the project's cost and schedule performance, a timeline identifying key project dates, and a brief narrative describing the current status of the project. These assessments also 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.
- There are six abbreviated assessments for projects that are early in formulation—or have not yet held preliminary design review—and that NASA designated as category 2. These assessments include a project description and preliminary cost and schedule estimates, if available.

We also included three summaries. First is a summary of NASA's Artemis missions, including the projects involved and timing of each mission, as well as a description of the mission. We also have summaries of the Gateway program and the Extravehicular Activity and Human Surface Mobility Program.

We provided NASA's project offices with an opportunity to review drafts of the assessments and summaries prior to their inclusion in this report. 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 and summary.

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

Figure 7: Illustration of a Sample Project Assessment



NASA Indian Space Research Organisation (ISRO) – Synthetic Aperture Radar (NISAR)

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 a satellite with the first dual frequency synthetic aperture radar instrument, which includes one radar provided by NASA and one provided by ISRO. The two radars each use a different frequency and will use advanced radar imaging to construct large-scale data sets of Earth's movements. ISRO will also provide NISAR's spacecraft and launch vehicle. NISAR represents the most complex science mission development undertaken jointly by NASA and ISRO.

Source: © 2017 California Institute of Technology/Jet Propulsion Laboratory. | GAO-23-106021

Timeline

Formulation: 03/14 Formulation start; 12/14 System requirements/mission definition review; 06/16 Preliminary design review; 08/16 Key decision point C

Implementation: 10/18 Critical design review; 10/20 System integration review; 01/23 GAO review; 10/24 Latest launch readiness date

Project Information

NASA Lead Mission Directorate: **Science**

NASA Lead Center: **Jet Propulsion Laboratory**

International Partners: **Indian Space Research Organisation**

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**

Project Summary

In August 2022, the NISAR project rebaselined its cost and schedule. The project has now exceeded its original cost baseline by 29 percent and delayed its original launch readiness date by over 2 years. The August 2022 rebaseline further increased the project's life-cycle cost by $146.8 million and delayed the project's launch readiness date by 13 months from September 2023 to October 2024. The NISAR project attributed the latest cost increase and schedule delays primarily to technical issues at the Jet Propulsion Laboratory (JPL) and ISRO. Project officials also said that ISRO delays due to COVID-19-related shutdowns in India contributed to the cost increases, among other things.

The NISAR project plans to begin the fourth phase of system-level integration and test in March 2023. During this final phase of integration and test, project staff will be on-site in India to assist with hardware integration onto the ISRO-provided spacecraft and continue NISAR's test campaign. One of the project's top risks is the retention of key technical staff in India. JPL and the project team developed a strategy for backup technical support to help mitigate this risk.

Schedule Performance

Cost Performance

THEN-YEAR DOLLARS IN MILLIONS

	Baseline Estimate (Aug. 2016)	Latest Estimate (Jan. 2023)	Change
TOTAL COST	$866.9	$1,118.0	29.0%
FORMULATION COST	$117.0	$117.0	0.0%
DEVELOPMENT COST	$661.0	$921.1	39.3%
OPERATIONS COST	$88.9	$79.9	-10.1%

U.S. Government Accountability Office — GAO-23-106021 Assessments of Major NASA Projects

NISAR

Cost and Schedule Status

In August 2022, NASA approved a rebaseline for the NISAR project, which increased the project's life-cycle cost by $146.8 million and further delayed the project's launch readiness date by 13 months from September 2023 to October 2024. This is the second time in 16 months that the project revised its cost and schedule baselines. NASA also approved a replan of the project's cost and schedule estimates in April 2021. The project's overall cost growth is $251.1 million beyond its original baseline, or 29 percent higher, and the new launch readiness estimate is more than 2 years later than the original launch readiness date of September 2022.

The project attributed the cost growth and schedule delays since the April 2021 replan primarily to technical issues that the project experienced after it integrated the NASA- and ISRO-provided radars. For example, after integration, the ISRO-provided radar experienced electromagnetic interference leading to the need to replace the radar's electronics box. Project officials also said that ISRO delays due to COVID-19-related shutdowns and lengthening the schedule for the final phase of system, integration, and test schedule in India contributed to the cost increases. The project also experienced hardware delivery delays and other technical challenges during the NASA-provided radar testing that resulted in cost growth and schedule delays. Project officials stated that all of the technical issues driving the rebaseline have been resolved or are being mitigated by the project.

Integration and Test

As of January 2023, The NISAR project is in the final stages of System Integration and Test Level 3 (SIT-3). During this phase, the project integrated its two radars and is in the final stage of testing the radars. The project is also integrating and testing other NISAR hardware, such as the boom and reflectors. The build of the ISRO-provided spacecraft is progressing and officials expect it to be complete in January 2023.

The NISAR project is planning to begin its Systems Integration and Test Level 4 (SIT-4) in India in March 2023. SIT-4 is the phase of the project where all operations will transfer to India. Project officials said that the radars and other hardware, such as the boom and reflectors, will be integrated with the ISRO-provided spacecraft during this phase. Project officials said that they are preparing for the beginning of SIT-4 by coordinating with ISRO on logistics, scheduling, and agreed-upon integration and test processes.

One of the NISAR project's top risks is that if it cannot retain key technical staff throughout SIT-4 in India, then it could experience delays or other problems during system integration and test. According to project officials, NISAR project staff will be traveling between California and India, in about 3-week increments, during the 10.5 months that NISAR will be in SIT-4. JPL and the project team are working on a mitigation plan to have staff backup support ready to step in if a key staff member cannot support SIT-4 for any reason. The plan for backup support consists of four tiers: (1) NISAR staff cross trained in disciplines, (2) ISRO staff, (3) JPL staff from other projects, and (4) Goddard Space Flight Center and contractor support from Europe.

Launch Vehicle

The ISRO-provided launch vehicle—the Geosynchronous Satellite Launch Vehicle Mark II (GSLV)—remains a risk for the project. ISRO and NASA agreed to a set of five criteria that the ISRO-provided launch vehicle must meet before NISAR's launch. The launch vehicle has already met three of the criteria.

During an August 2021 launch, the GSLV upper stage did not ignite and the launch vehicle failed to accomplish its mission. Despite the failure, NASA officials said this mission satisfied a criterion regarding successful deployment of a 4-meter fairing, which is the nose cone of the rocket used to protect the payload during launch. According to project officials, ISRO has one GSLV launch planned for summer 2023 that could satisfy the remaining criteria prior to NISAR's launch. Project officials said that if a successful GSLV upper stage requalification flight does not happen ahead of the planned NISAR launch period, the project's launch readiness date may be delayed beyond October 2024.

Project Office Comments

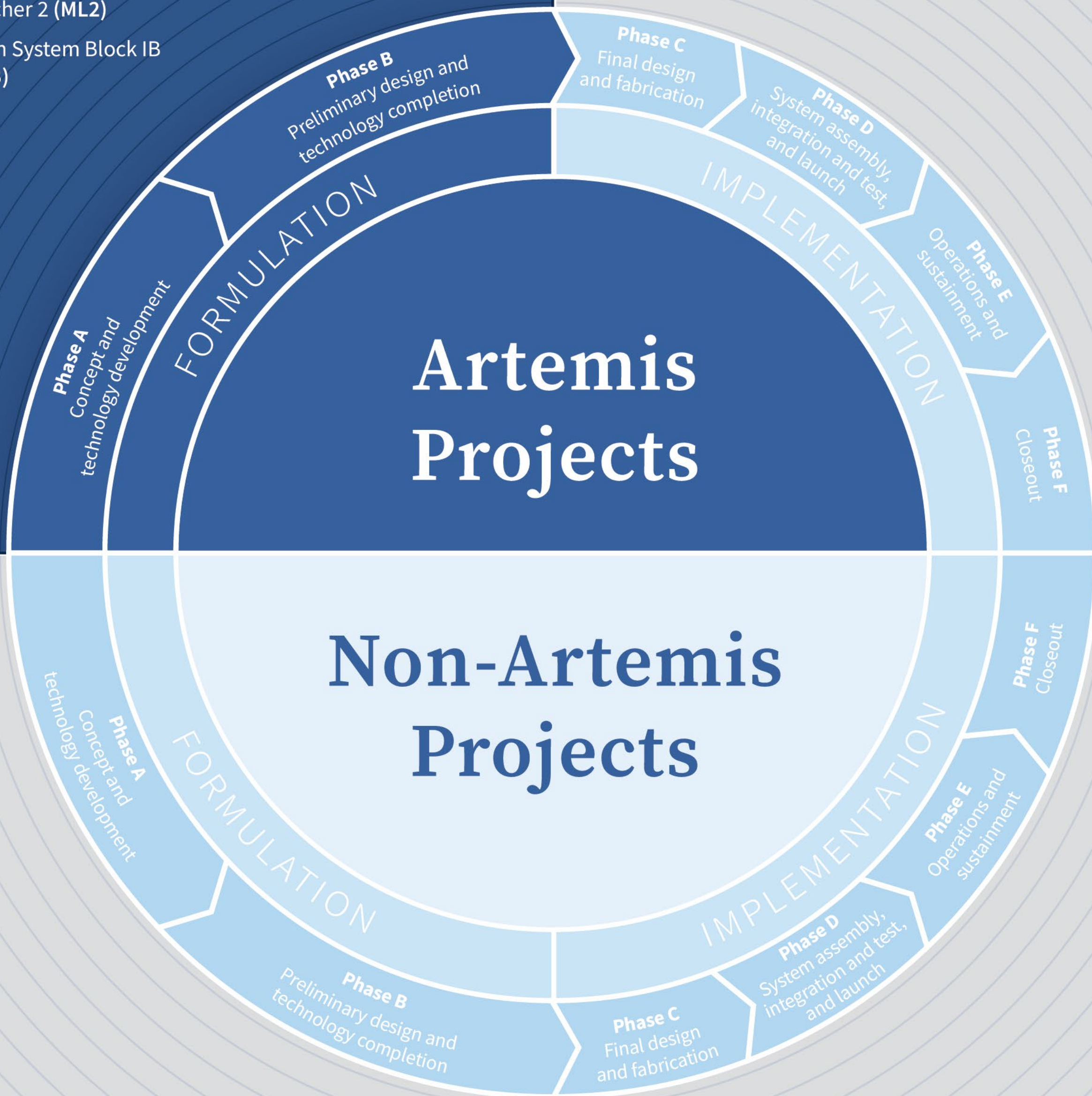
When commenting on a draft of this assessment, NISAR project officials said that they had completed SIT-3 testing and prepared the payload flight system for the first of two shipments to India, planned for early March 2023. The officials also provided technical comments, which were incorporated as appropriate.

U.S. Government Accountability Office — GAO-23-106021 Assessments of Major NASA Projects

- **A** Illustration of the spacecraft, instrument, aircraft, launch vehicle, ground system, or space suit.
- **B** General description of the mission's objectives.
- **C** **Timeline** identifying key dates for the project including when the project began formulation, held major design reviews, began implementation after key decision point (KDP) C, and launched or fielded an operating capability.
- **D** **Project Information:** Information on the responsible NASA center and lead mission directorate, international partners, launch plans, mission duration, and the source of the mission's requirements.
- **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-23-106021

- Extravehicular Activity and Human Surface Mobility Program **(EHP)**
- EHP – Exploration Extravehicular Activity **(xEVA)**
- EHP – Lunar Terrain Vehicle **(LTV)**
- Gateway
- Gateway – Habitation and Logistics Outpost **(HALO)**
- Gateway – Power and Propulsion Element **(PPE)**
- Human Landing System **(HLS)** – Initial Capability
- HLS – Sustaining Lunar Development **(SLD)**
- Mobile Launcher 2 **(ML2)**
- Space Launch System Block IB **(SLS Block IB)**



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Artemis

MAJOR NASA PROJECTS AND PROGRAMS SUPPORTING ARTEMIS MISSIONS

NASA broadly refers to its series of missions to return astronauts into lunar orbit and onto the lunar surface as Artemis. These missions—illustrated in the timeline below and on the following page—require extensive coordination across NASA programs, contractors, and international partners. Initial missions will focus on establishing a long-term presence around the moon and later missions will focus on sending the first astronauts to Mars.

Orion

11/22

ARTEMIS I

PROGRAMS
SLS
Orion
EGS

NASA successfully launched an uncrewed Orion spacecraft on top of the SLS vehicle on November 16, 2022. During the Artemis I mission, the spacecraft traveled to a distant orbit some 70,000 kilometers beyond the moon before returning to Earth on December 11, 2022.

Exploration Ground Systems

11/24

ARTEMIS II

PROGRAMS
SLS
Orion
EGS

The Artemis II mission will be a 10- to 14-day crewed flight with up to four astronauts. The crew will orbit the moon and return to Earth to demonstrate the baseline Orion spacecraft capability ahead of a crewed lunar landing.

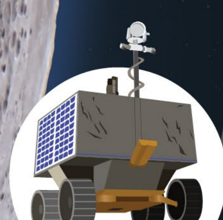
12/25

ARTEMIS III

PROGRAMS
SLS
Orion
EGS
HLS – Initial Capability
EHP: xEVA
VIPER*

The Artemis III mission will be a crewed lunar landing mission. The Orion spacecraft will transport crew from Earth to a lunar orbit, where it will dock with HLS. The HLS will take crew, who will wear new space suits, to the lunar surface to conduct operations. The HLS will then return crew back to the Orion spacecraft, which will transport them back to Earth.

**NASA plans to use the scientific data that VIPER collects to inform the first global water resources map of the moon and the Artemis III lunar landing site decisions.*



Volatiles Investigating Polar Exploration Rover

Legend:
Exploration Extravehicular Activity (**xEVA**)
Exploration Ground Systems (**EGS**)
Extravehicular Activity and Human Surface Mobility Program (**EHP**)
Human Landing System (**HLS**)
Orion Multi-Purpose Crew Vehicle (**Orion**)
Space Launch System (**SLS**)
Volatiles Investigating Polar Exploration Rover (**VIPER**)

Source: GAO analysis of NASA documentation (data and images); manuelhuss/stock.adobe.com (moon image); NASA (Artemis logo). | GAO-23-106021

ARTEMIS IV

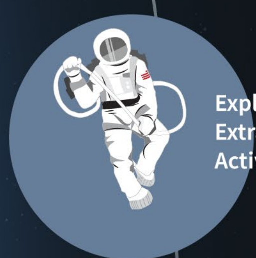
PROGRAMS

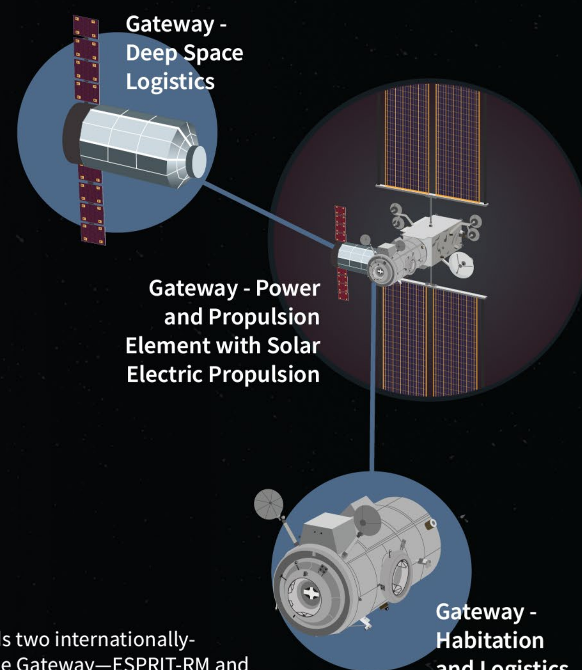
SLS Block 1B
Orion
EGS: ML2
HLS – SLD
EHP: xEVA
Gateway: PPE, HALO, DSL, I-HAB
SEP

09/28

The Artemis IV mission will be a lunar orbiting and lunar landing mission. Prior to the mission, NASA plans to launch Gateway's PPE and HALO into a lunar orbit. The PPE will demonstrate the use of high-power solar electric propulsion thrusters that the SEP project is qualifying.

For the mission, NASA plans to launch crew in the Orion spacecraft and the I-HAB component of Gateway. This will be the first launch of the SLS Block 1B rocket using ML2. The crew will help integrate I-HAB with the HALO. The I-HAB is an international contribution that will provide additional living space to crew on the Gateway. NASA also plans to use a DSL flight to deliver cargo and other equipment to the Gateway.





09/29

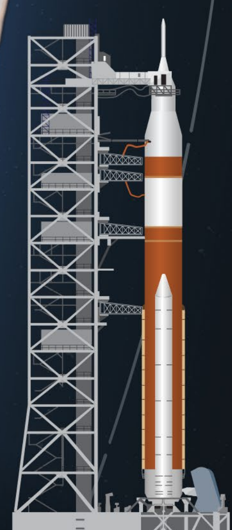
ARTEMIS V

PROGRAMS

SLS Block 1B
Orion
EGS: ML2
HLS – SLD
EHP: xEVA, LTV
Gateway: PPE, HALO, DSL, I-HAB, ESPRIT-RM, GERS
LTV

The Artemis V mission adds two internationally-contributed modules to the Gateway—ESPRIT-RM and GERS—and is a lunar landing mission.

This mission may also use a sustainable version of a human landing system from a new provider to take crew to the lunar surface. NASA plans to deliver the LTV to the lunar surface for crew use during lunar exploration activities.



Legend:
Deep Space Logistics **(DSL)**
European System Providing Refueling, Infrastructure, and Telecommunications Refueler Module **(ESPRIT-RM)**
Exploration Extravehicular Activity **(xEVA)**
Exploration Ground Systems **(EGS)**
Extravehicular Activity and Human Surface Mobility Program **(EHP)**
Gateway External Robotic System **(GERS)**
Habitation and Logistics Outpost **(HALO)**
Human Landing System **(HLS)**
International Habitat **(I-HAB)**
Lunar Terrain Vehicle **(LTV)**
Mobile Launcher 2 **(ML2)**
Orion Multi-Purpose Crew Vehicle **(Orion)**
Power and Propulsion Element **(PPE)**
Solar Electric Propulsion **(SEP)**
Space Launch System **(SLS)**
Sustaining Lunar Development **(SLD)**

Source: GAO analysis of NASA documentation (data and images); manuelhuss/stock.adobe.com (moon image). | GAO-23-106021

Source: NASA. | GAO-23-106021

Extravehicular Activity and Human Surface Mobility Program (EHP)

The EHP oversees the development of space suits and associated tools to support activities on the International Space Station (ISS), and modernized space suits and human surface mobility systems for lunar exploration activities during Artemis missions. The program is comprised of three major projects: Exploration Extravehicular Activity (xEVA), Lunar Terrain Vehicle (LTV), and a Pressurized Rover. NASA plans to award contracts for vendors to develop and provide the modernized space suits and LTV systems as a service.

Project Information

NASA-developed EHP projects:

- **xEVA**
- **LTV**
- **Pressurized Rover**

Lead Mission Directorates: **Space Operations and Exploration Systems Development**

NASA Lead Center: **Johnson Space Center**

International Partners: **To be determined**

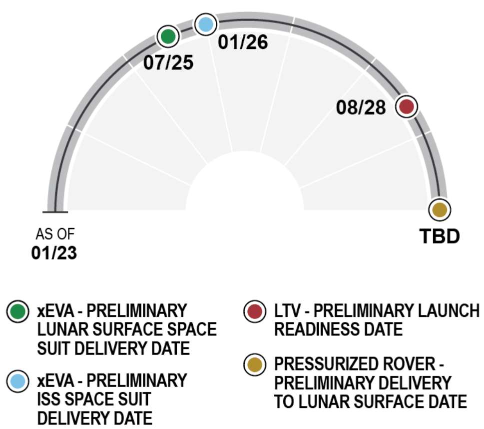
Current Status

NASA established the EHP in December 2021 to oversee several related projects at one NASA center. According to NASA, this reorganization provides program-level authority, consistent leadership, and integration across the space suit and human surface mobility elements, and leverages existing programmatic expertise.

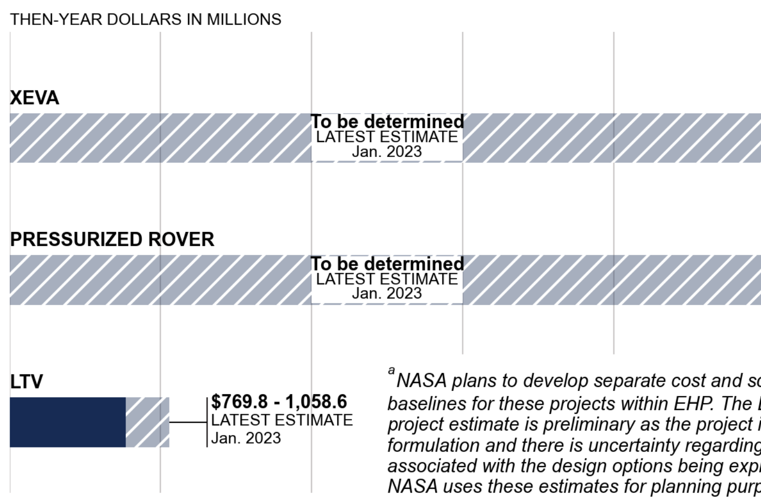
NASA is acquiring the space suits and associated tools for the xEVA project as a commercial service. In September 2022, NASA awarded a task order to Axiom Space to develop and provide space suits for the Artemis III mission. In December 2022, NASA awarded a task order to Collins Aerospace to develop and provide space suits for the ISS. It intends to follow a similar approach for the LTV, with plans to issue a request for proposals in spring 2023.

The Artemis space suits are required for the Artemis III mission, which is planned for no earlier than 2025 and will land humans on the moon for the first time since 1972. The LTV is required for the Artemis V mission, currently planned for 2029, and will provide crewed and uncrewed transport on the lunar surface to enhance exploration. The pressurized rover is currently in early planning stages. It will provide a pressurized mobility system on the lunar surface to support crewed exploration for a long duration and distance from the Human Landing System. NASA plans to hold a review for the project to enter the concept and technology development phase in spring 2023.

Preliminary Schedule



Preliminary Cost[a]



[a] *NASA plans to develop separate cost and schedule baselines for these projects within EHP. The LTV project estimate is preliminary as the project is in formulation and there is uncertainty regarding costs associated with the design options being explored. NASA uses these estimates for planning purposes.*

Project Office Comments

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

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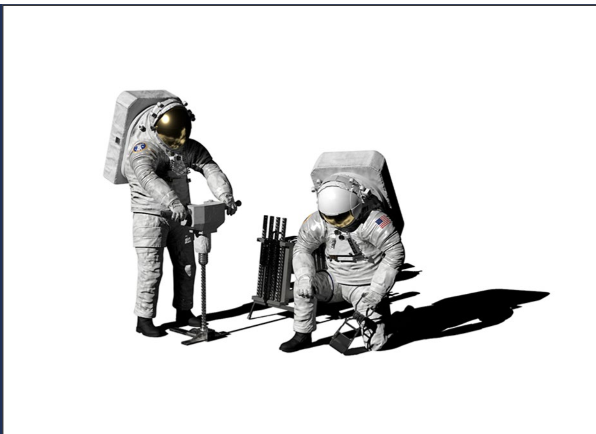


Source: NASA. | GAO-23-106021

Extravehicular Activity and Human Surface Mobility Program (EHP) – Exploration Extravehicular Activity (xEVA)

The xEVA project is responsible for providing space suits and other hardware to support astronaut activities, referred to as EVAs, on the International Space Station (ISS) and the lunar surface for Artemis missions. The project office is overseeing contractors that will demonstrate, certify, and deliver: (1) tools the crew will use for lunar science and maintenance tasks; (2) interfaces 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 astronauts. The EHP manages the xEVA project.

Timeline

Formulation

- **07/19** Formulation start
- **09/21** System requirements review
- **05/22** Contract awards
- **12/22** Axiom mission concept review
- **01/23** GAO review
- **02/23** Collins mission concept review
- **06/23** Collins preliminary design review
- **11/23** Axiom preliminary design review
- **Fall 2023 (under review)** Key decision point C

Implementation

- **01/24** Collins critical design review
- **08/24** Axiom critical design review
- **07/25** Lunar surface space suit delivery
- **01/26** ISS space suit delivery

Project Information

NASA Lead Mission Directorate: **Exploration Systems Development**

NASA Lead Center: **Johnson Space Center**

International Partners: **None**

Launch Location: **N/A**

Launch Vehicle: **N/A**

Mission Duration: **5 years**

Requirement Derived from: **NASA Strategic Plan**

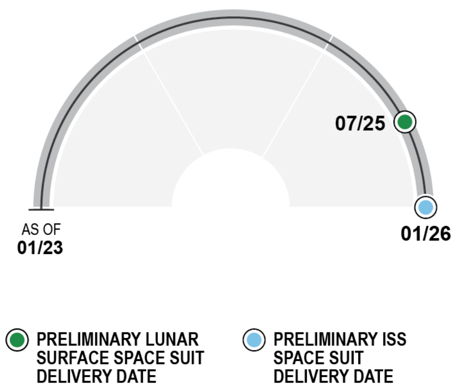
Project Summary

In May 2022, the project awarded firm-fixed-price indefinite-delivery, indefinite-quantity contracts to Axiom Space and Collins Aerospace, the scope of which includes the development and delivery of modernized space suits for the first lunar landing mission—Artemis III—and the ISS, respectively. The contracts set a minimum combined value of services to be ordered at nearly $1.3 billion and a maximum amount of $3.1 billion.

Prior to awarding contracts, the project developed a government reference design and test unit for companies to leverage if they choose. Project officials said that Axiom Space plans to leverage several aspects of the reference design for the Artemis III mission space suit and expects that approach to increase the speed of development.

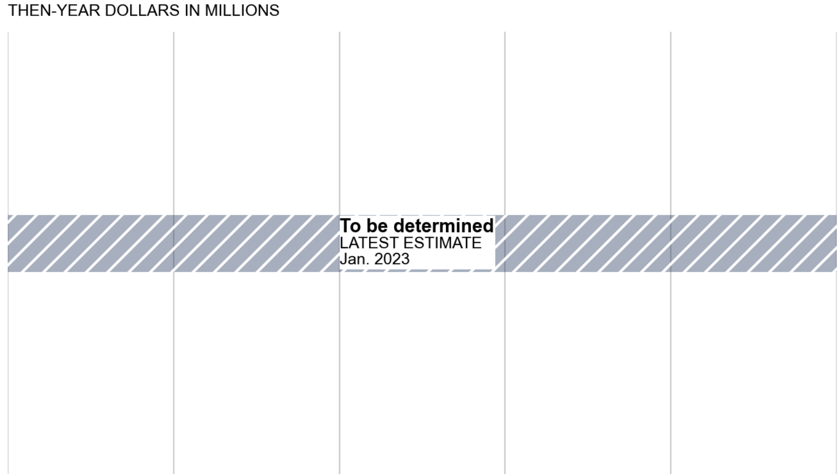
The project's top risks are associated with integrating the Artemis III space suits with the HLS, which will deliver crew to the lunar surface. The HLS is also in development. To mitigate this risk, NASA is tracking technical performance requirements and interfaces between the EHP and the HLS program.

Preliminary Schedule



Preliminary Cost

THEN-YEAR DOLLARS IN MILLIONS



Cost and Schedule Status

In fall 2021, the project changed its strategy for acquiring space suits and associated tools from a government-led development to contracting with commercial industry for a service. NASA is pursuing this approach to develop a modernized space suit capability more quickly and affordably while enabling industry to develop a commercial market for space suits. Prior to changing the acquisition strategy and reorganizing the project office, NASA invested about $420 million between 2007 and 2021 to develop and build a new space suit. The agency tentatively plans to establish a cost and schedule baseline for the project in fall 2023, but project officials said the date is yet to be determined.

In May 2022, the project awarded firm-fixed-price indefinite-delivery, indefinite-quantity contracts to Axiom and Collins to provide safe and reliable commercial extra vehicular activity services in micro-gravity and partial gravity environments for the Artemis missions and the ISS. The contracts set a minimum amount of services to be ordered at a combined value of approximately $1.3 billion and a maximum amount of $3.1 billion for each vendor.

In September 2022, the project ordered the development and demonstration of a suit for lunar surface activities from Axiom for $229 million. Axiom is required to successfully perform exploration and science missions on the lunar surface during the Artemis III mission, currently planned for late 2025.

In December 2022, the project ordered the first suit demonstration to perform mechanical and maintenance tasks on the ISS from Collins. The task order has a base value of $97.2 million for work through critical design review.

Technology and Design

Prior to changing the project's acquisition strategy, NASA developed a government reference design of a modernized space suit, including building a test unit of the suit. When the project determined it would use a commercial approach, the project took steps to complete most of the reference design and made the design publicly available for potential awardees to leverage in their proposals. According to project officials, Axiom is leveraging many aspects of the government reference design to expedite the development of the Artemis III space suits.

Axiom completed a mission concept review for the Artemis space suits in December 2022. During this review, Axiom was required to present key management plans and tools needed for successfully developing the suit and its components. Axiom plans to hold a preliminary design review in November 2023.

For the ISS suits, project officials said that Collins completed a mission concept review in February 2023, and plans to hold a preliminary design review in June 2023. In announcing the award, NASA stated that Collins will complete a critical design review and a demonstration in a simulated space environment by January 2024.

Other Issues to Be Monitored

The project stated that its top risks are associated with integration with the HLS. In order for a lunar landing demonstration to be successful, the Artemis III space suits must interface with the HLS. To manage integration, the project developed program-to-program agreements that document and define data to be exchanged between the xEVA project and the HLS program. Additionally, NASA is tracking technical performance requirements and interfaces between EHP—the program that oversees the xEVA project—and the HLS program.

The project is also currently working to mitigate risks associated with limited lunar surface communication range and insufficient lunar surface lighting for the crew. The project is working with the EHP and HLS program to reevaluate the lunar communication and lighting architectures to better meet the needs of the surface crew.

Project Office Comments

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

Source: Analytical Mechanics Associates. | GAO-23-106021

Extravehicular Activity and Human Surface Mobility Program (EHP) – Lunar Terrain Vehicle (LTV)

The LTV is a transportation system that will enable crew members to explore the lunar surface and allow NASA to conduct remote science operations. The LTV will be available for Artemis V—planned for 2029—and future missions. In addition to serving as a mode of transportation, the LTV will: (1) transport and deploy small payloads; (2) conduct science with its robotic arm; (3) produce multimedia content of landings, points of interest, and crew activities; and (4) support science activities between crewed missions. Developing and demonstrating these technologies will support increased capabilities for future lunar surface and Mars missions. The EHP manages the project.

Project Information

NASA Lead Mission Directorate: **Exploration Systems Development**

NASA Lead Center: **Johnson Space Center**

International Partners: **N/A**

Launch Location: **To be determined**

Launch Vehicle: **To be determined**

Mission Duration: **10 years**

Requirement Derived from: **Space Policy Directive 1, 2022 and NASA Strategic Plan**

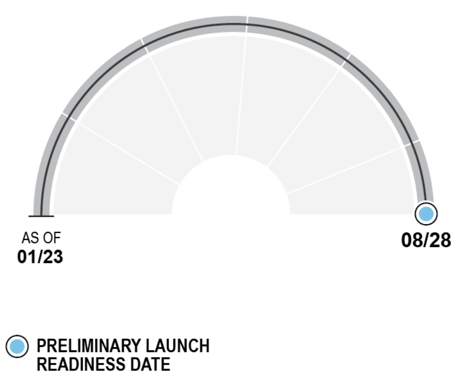
Next Major Project Event: **Release request for proposals (May to June 2023)**

Current Status

In November 2022, the LTV project established a preliminary cost estimate range of $770 million to $1.1 billion and a preliminary launch readiness date of August 2028. The preliminary costs cover contractor design, development and production of the LTV, and launch and delivery to the lunar surface. After studying delivery approaches, the project determined that awardees would be responsible for obtaining a launch vehicle and lunar lander to afford the awardee flexibility for how it integrates the LTV into the launch vehicle.

The project plans to release a request for proposal in spring 2023 and make multiple awards under an indefinite-delivery, indefinite-quantity contract in fall 2023. The project plans to proceed with the procurement using firm-fixed price orders in two phases: (1) all contract awardees will conduct a feasibility assessment to refine concepts, requirements, and standards; and (2) NASA will competitively select one or more vendors that will execute a crewed and uncrewed demonstration mission. The number of awardees in each phase is dependent on funding availability. The program has released requests for information to solicit industry feedback and is developing a physical prototype and created a digital prototype to inform requirements, designs, and cost estimates. The prototype will also serve as a testing stand-in until the contractor provides testing and training hardware.

Preliminary Schedule



Preliminary Cost[a]

[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.*

Project Office Comments

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

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Source: NASA. | GAO-23-106021

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 future missions to Mars. It comprises multiple projects and is developing the outpost in two phases—initial and sustained. The initial capability includes the Power and Propulsion Element (PPE) and the Habitation and Logistics Outpost (HALO) to support the early Artemis missions using Gateway. The sustained configuration adds additional NASA-led and international partner elements to support later missions (see illustration on next page for the Gateway sustained configuration).

Project Information

NASA-developed Gateway elements
- **Habitation and Logistics Outpost (HALO)**
- **Power and Propulsion Element (PPE)**
- **Deep Space Logistics (DSL)**

International partner contributions
- **International Habitat (I-HAB)**
- **European System Providing Refueling,**
- **Infrastructure, and Telecommunications Refueler Module (ESPRIT-RM)**
- **Gateway External Robotic System (GERS)**
- **H-II Transfer Vehicle-XG**
- **Airlock***

*Not yet a confirmed contribution.

Lead Mission Directorate: **Exploration Systems Development**

NASA Lead Center: **Johnson Space Center**

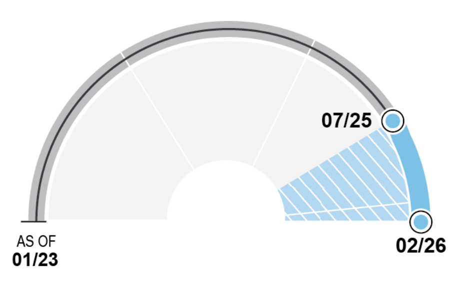
Current Status

The Gateway program is planning to establish cost and schedule baselines for its PPE and HALO elements—which will launch together—in June 2023. The PPE will provide power and propulsion and the HALO will provide living space for crew. The cost baseline will also include the costs of the launch vehicle and program support for integration and launch. The program previously planned to complete a preliminary design synchronization review to assess the maturity of the integrated design of the two elements and hold a review to establish these baselines in 2022. However, the program delayed the reviews primarily to finalize major updates to the PPE contract and the HALO project schedule. Program officials said that they needed both updates for their joint cost and schedule confidence level analysis, which informs the program's cost and schedule baselines.

The program's baseline will not include the DSL project. The program plans to establish separate cost and schedule baselines for this project. The DSL project is responsible for the execution of commercial services to deliver logistics vehicles that will provide Gateway with cargo and supplies prior to crew arrival.

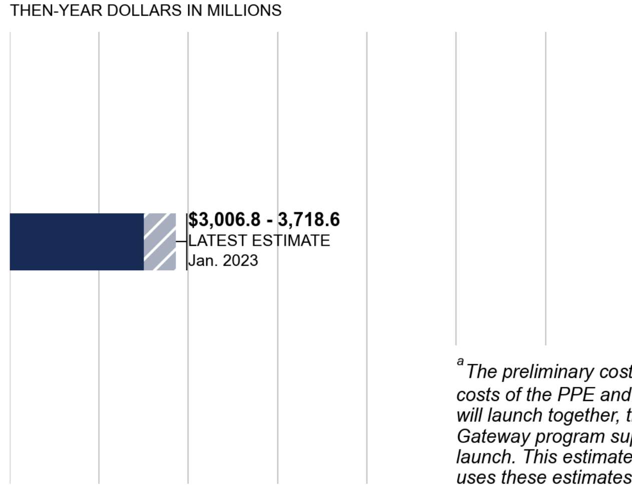
NASA previously planned to authorize the DSL contractor to start work on a logistics vehicle to support the Artemis V mission, but now plans to do so earlier to support the Artemis IV mission. Having a logistics delivery for Artemis IV could help address mass concerns for the PPE, HALO, and I-HAB because the logistics vehicle could deliver cargo and equipment to Gateway that would have previously needed to be launched on the other elements.

Preliminary Schedule



Preliminary Cost[a]

THEN-YEAR DOLLARS IN MILLIONS



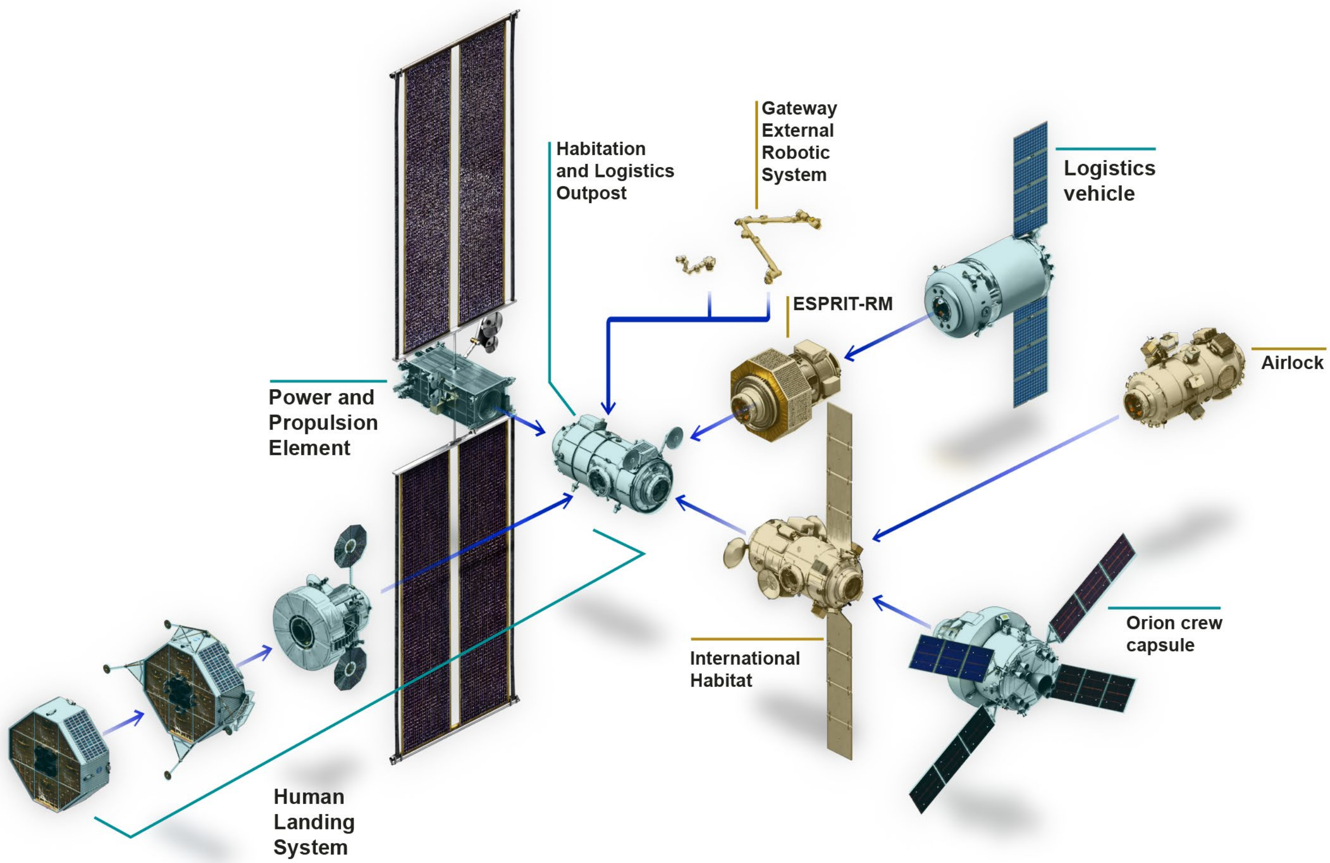
[a] *The preliminary cost range includes the costs of the PPE and HALO projects, which will launch together, the launch vehicle, and Gateway program support for integration and launch. This estimate is preliminary and NASA uses these estimates for planning purposes.*

Gateway Initial and Sustained Configurations

The Gateway initial configuration includes the PPE and HALO elements. NASA plans to launch the PPE and the HALO in time to support the Artemis IV mission. During this mission, astronauts will arrive at Gateway on the Orion Multi-Purpose Crew Vehicle (Orion) and will help integrate the I-HAB with the HALO and also conduct a lunar landing. The I-HAB will provide additional living space to crew on Gateway.

The Gateway sustained configuration includes three U.S.-developed elements and four elements contributed by international partners. The illustration below shows the Orion crew capsule and Human Landing System docked with the Gateway sustained configuration to support human lunar landing missions. The Orion crew capsule will transport crew from Earth to Gateway, where they will transfer into a Human Landing System for transport to the lunar surface and back. After returning to Gateway, the crew will return to Earth aboard the Orion crew capsule.

Illustration of the Orion Multi-Purpose Crew Vehicle and Human Landing System Docked with the Gateway Sustained Configuration



NASA-developed hardware

International contributions for sustained configuration

ESPRIT-RM = European System Providing Refueling, Infrastructure, and Telecommunications Refueler Module

Source: GAO analysis of Gateway Program documentation (data); NASA (image). | GAO-23-106021

Project Office Comments

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

Source: NASA. | GAO-23-106021

Gateway – Habitation and Logistics Outpost (HALO)

The HALO will be the initial crew module for the Gateway. It will provide living quarters, as well as communication functions to the lunar surface and for visiting vehicles. It will also augment life support systems in conjunction with NASA's Orion Multi-Purpose Crew Vehicle. The HALO will also have docking ports to connect with other components. NASA plans to integrate the HALO and the Power and Propulsion Element (PPE) on the ground and launch them together, known as comanifesting. The HALO project is responsible for managing the integration, test, and launch of the comanifested PPE and HALO.

Timeline

Formulation

- **04/19** Formulation start
- **02/20** System definition review
- **05/21** Preliminary design review
- **01/23** GAO review
- **04/23** Critical design review
- **06/23** Key decision point 1

Implementation

- **Under review** System integration review
- **07/25-02/26** Preliminary launch readiness date

Project Information

NASA Lead Mission Directorate: **Exploration Systems Development**

NASA Lead Center: **Johnson Space Center**

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

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

Launch Vehicle: **Falcon Heavy**

Mission Duration: **15 years**

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

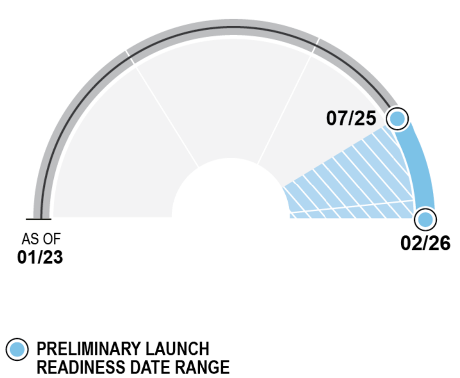
Project Summary

The Gateway program delayed setting the baselines for its PPE and HALO elements—which will launch together—from July 2022 to June 2023 to finalize major updates to the PPE contract and the HALO project's schedule. HALO project officials explained that they updated the project schedule to include updates to the timing of the HALO and PPE integration and capture prior delays. The project is now working to a later launch readiness date than previously planned, largely due to coordinating with the PPE project on the timing of integration.

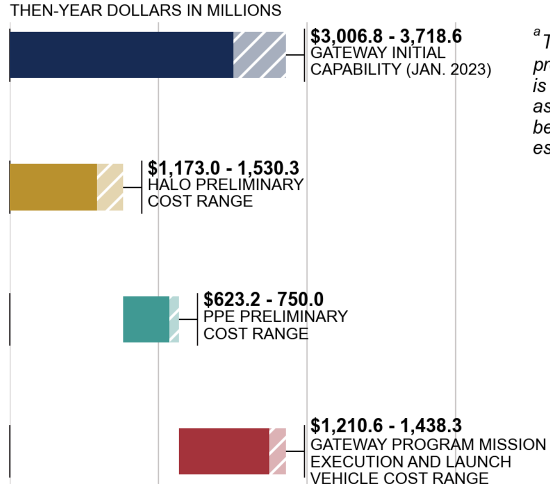
The HALO project began its critical design review in August 2022, but needs to hold lower-level reviews for two subsystems that were not ready for the review due to design issues. The project plans to hold those reviews in early 2023 and then close out its project-level review.

The comanifested launch vehicle continues to experience mass challenges. The project is considering off-loading some HALO components for the launch and as a potential way to reduce mass. If the Gateway program decides to off-load components, it would use a logistics vehicle to deliver these components to the Gateway for crew to install on-orbit.

Preliminary Schedule



Preliminary Cost[a]



[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 Gateway program delayed establishing cost and schedule baselines for its PPE and HALO elements—which will launch together—from July 2022 to June 2023. The program delayed setting the baselines to finalize major updates to the PPE contract and the HALO project's schedule. The cost baseline will also include the costs of the launch vehicle and program support for integration and launch.

The HALO project updated its schedule and is now working to an October 2025 launch readiness date. The project was previously working to an earlier launch date of November 2024. HALO project officials explained that this change is largely due to coordinating with the PPE project on the timing of the HALO and PPE integration. The officials also said that the updated schedule captures prior HALO project schedule delays, such as delays to completing welding on the HALO's primary structure. This new schedule will inform the baseline set at the Gateway program's key decision point review.

Officials reported that COVID-19 has had a major effect on lead times for parts. This has been particularly challenging for the HALO project. For example, officials explained that one key component that usually took about 14 weeks to order and arrive currently has a lead time of 72 weeks. The project is tracking a risk that it may not have parts in time to support the launch need date, which could lead to a significant schedule delay. According to officials, the project has been monitoring parts shortages for over a year and is considering using alternate vendors to find components.

Technology and Design

The HALO project began its critical design review in August 2022, where it reviewed 15 out of 17 subsystems. Project officials explained that two subsystems that handle thermal control and life support systems were not ready for the review because they needed more time to resolve design issues. The project plans to have these subsystems complete their subsystem-level reviews in early 2023, which would allow the project to complete its project critical design review in spring 2023. Prior to August 2022, the project reported that all of its critical technologies were mature.

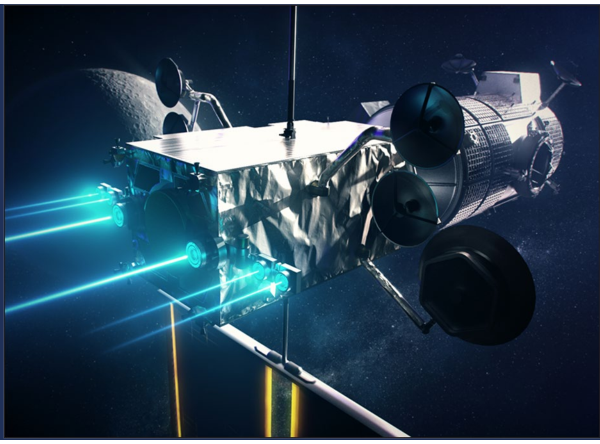
Project officials told us that the HALO design has matured since last year. To assess the maturity of the project's design, project officials said they use the number of approved computer models, but do not have benchmarks for the percentages of models approved to assess design maturity. This measurement differs from our best practice, which recommends releasing 90 percent of drawings by critical design review to lower the risk of projects experiencing design changes and subsequent cost growth and schedule delays.

The comanifested vehicle continues to experience mass challenges since NASA decided in February 2020 to launch the HALO and the PPE together. Specifically, the comanifested vehicle continues to be too heavy. Although the project took steps to reduce mass, it is still approximately 480 kilograms over its allocation. If the combined mass of the comanifested vehicle is too high, it could affect the vehicle's ability to reach the correct lunar orbit.

As a result of the mass challenges, the project is considering off-loading some HALO components for the launch. The project is working with contractors to identify potential opportunities for off-loading components and reducing mass. The project already identified approximately 300 kilograms of components to potentially off-load. If the Gateway program decides to off-load some HALO components for the initial launch, it would use a logistics vehicle to separately deliver these components to the Gateway for the crew to install on-orbit. Adding a logistics mission in late 2027—prior to the Artemis IV mission, which is when Gateway is required—could enable the project to remove 100 kilograms of the identified components from the HALO. However, even with these mass reduction efforts, the project will need to identify additional opportunities to further reduce mass.

Project Office Comments

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



Source: NASA. | GAO-23-106021

Gateway – Power and Propulsion Element (PPE)

The PPE will be a spacecraft that provides power, communications, and the ability to change orbits, among other things to the Gateway—a sustainable outpost planned for lunar orbit. The Gateway's 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 Gateway's Habitation and Logistics Outpost (HALO) on the ground and launch them together, known as comanifesting. After NASA integrates the HALO and PPE together, it creates one vehicle for launch known as a comanifested vehicle.

Timeline

Formulation
- **09/17** Formulation start
- **09/19** System requirements review
- **11/21** Preliminary design review
- **01/23** GAO review
- **06/23** Key decision point 1

Implementation
- **10/23** Critical design review
- **09/25** PPE delivery for integration with HALO
- **07/25-02/26** Preliminary launch readiness date

Project Information

NASA Lead Mission Directorate: **Exploration Systems Development**

NASA Lead Center: **Glenn Research Center**

International Partners: **Canadian Space Agency**

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

Launch Vehicle: **Falcon Heavy**

Mission Duration: **15 years**

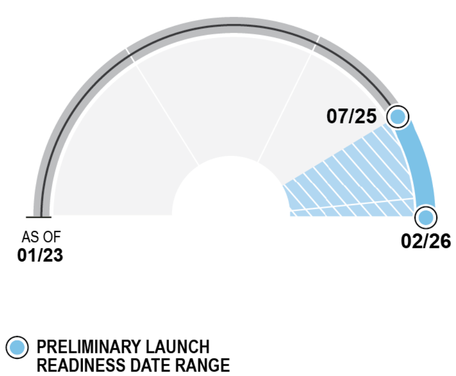
Requirement Derived from: **Space Policy Directive-1 and 2018 NASA Strategic Plan**

Project Summary

The Gateway program delayed establishing cost and schedule baselines for its PPE and HALO elements—which launch together—from July 2022 to June 2023. This is a result of finalizing major updates to the PPE contract and the HALO project's schedule. NASA modified the PPE project's contract with Maxar twice in late 2022 and plans to modify the contract again in April 2023 to incorporate requirements changes. According to the project, these modifications incorporate over 700 new requirements from the Gateway program and changes to the PPE because of the decision to comanifest the PPE and HALO.

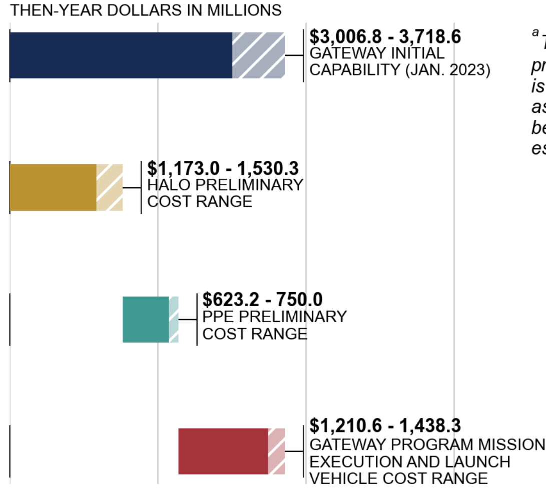
The project is planning to deliver the PPE for integration with the HALO in September 2025, which is about a year later than previously planned. This new date is informed by schedule changes as a result of the contract modifications and the delivery time frames for the high-powered SEP thrusters.

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 Gateway program delayed establishing cost and schedule baselines for its PPE and HALO elements—which will launch together—from July 2022 to June 2023. The program delayed setting the baselines to finalize major updates to the PPE contract and the HALO project's schedule. The cost baseline will also include the costs of the launch vehicle and program support for integration and launch.

The PPE project continues to experience contract cost growth as a result of requirements changes. Project officials said these changes include incorporating new and updated requirements to ensure that the PPE could successfully integrate with the HALO for launch, transit to the near rectilinear halo orbit, and reliably fulfill Gateway's capability and operational needs for a minimum of 15 years. NASA modified the PPE project's contract with Maxar twice in late 2022 to incorporate requirements changes, and plans to modify the contract again in April 2023. The combined value of the two finalized modifications is about $87 million. As a result of the finalized and prior modifications, the contract now exceeds its total value at the time of award by 95 percent, with more cost growth expected as a result of the pending modification. According to the project, the three most recent contract modifications incorporate over 700 new requirements from the Gateway program and from changes to the PPE as a result of the decision to comanifest. For example, NASA added requirements for mission performance, communication, and refueling. Project officials said that the contract updates have resulted in deviations from the commercially derived approach initially planned for PPE.

The PPE project is currently planning to deliver the PPE for integration with the HALO in September 2025, which is about a year later than previously planned. This new date is informed by schedule changes as a result of the contract modifications and the delayed delivery of the high-powered SEP thrusters. Program officials told us that the biggest changes to the project's schedule are due to the new requirements recently incorporated by the contract modifications. For example, the change to launching as a comanifested vehicle required the PPE project to increase the power in its SEP system. PPE also redesigned its propellant tank because it will now be launched in a different configuration. Officials explained that the pending contract modification to address new requirements is key to the project being able to finalize its design and hold its critical design review. Officials said that Maxar delayed its critical design review, which is planned for October 2023, in order to incorporate the high volume of requirements into the design and construction of the PPE.

The project continues to track a schedule risk related to the delayed delivery of its high-powered SEP thrusters. The effort to develop and produce these thrusters—which NASA's SEP project manages—is significantly behind schedule. As of February 2023, Aerojet Rocketdyne, the contractor that will develop the thrusters for the SEP project, planned to deliver the flight thrusters 5 months later than the PPE project needs them for integration. PPE project officials said they are working with the SEP project and thruster contractor to understand available mitigation options.

Technology and Design

As of January 2023, the project reported that six of its nine critical technologies are mature. When the project held its preliminary design review in November 2021, none of the critical technologies were mature. Our best practice for technology maturity states that critical technologies should achieve technology readiness level 6 by preliminary design review to minimize risks for further product development.

One of the three technologies that is not mature is the high-powered SEP thrusters. The SEP project, which is responsible for maturing the thruster technology for the PPE project, expects to mature the technology in late summer 2023 after completing acceptance testing on one of its qualification thrusters. This is before Aerojet Rocketdyne plans to complete final assembly and deliver the first of three flight thrusters to the PPE project in January 2024, but after the contractor started production on them in 2022. In addition, the SEP project will not complete full wear testing of the qualification thrusters before the PPE launches. SEP project officials said that this wear testing is intended to reduce uncertainty in and inform on-orbit operations. The officials also said they mitigated this risk by ensuring that they will complete the first 4,500 hours of this testing ahead of the PPE flight thruster operations. If the SEP project identifies issues with the thrusters during acceptance or wear testing, it could result in design changes to the flight thrusters and delays to the PPE project's schedule. The PPE project expects to mature one of its other two remaining technologies in summer 2023 and does not yet have an expected date to mature the other.

As of February 2023, the PPE's mass is anticipated to be above its allocation on the comanifested vehicle by approximately 155 kilograms. This excess persists in spite of the project's efforts to reduce some of its mass. For example, the PPE is no longer launching with the plasma diagnostics package, which the SEP project was developing to describe the performance of the electric propulsion system while in space. The PPE project plans to update the mass estimate after Maxar incorporates the requirements changes in the contract modification nearing award. If the PPE project has to make late design changes to reduce mass, it could result in cost growth and schedule delays. Not achieving the target mass may result in a reduction of spacecraft capabilities, which could affect the comanifested missions' success and other elements of the Gateway.

Project Office Comments

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

Source: SpaceX. | GAO-23-106021

Human Landing System (HLS) – Initial Capability

The HLS will provide crew access to the lunar surface and demonstrate initial capabilities required for deep space missions. NASA plans to use the HLS initial capability for the Artemis III mission to the moon, planned for no earlier than 2025. The HLS will deliver a crew from lunar orbit to the lunar surface, provide capabilities for lunar surface extravehicular activities, and then return the crew and materials to lunar orbit to enable their return to Earth. The HLS will dock with the Orion Multi-Purpose Crew Vehicle (Orion) for Artemis III. The design, development, testing, and evaluation of the HLS will be contractor-led. NASA will certify its design and flight readiness.

Timeline

Formulation
- 05/19 Formulation start
- 05/20 Base period contractor selections
- 12/20 Continuation review
- 07/21 Exercise of Option A
- **01/23** GAO review
- **06/23** Key decision point C

Implementation
- Critical design review
- Uncrewed lunar landing flight test
- Design certification review
- **12/25** Launch of HLS lander Starship
- **12/25** Crewed landing

Project Information

NASA Lead Mission Directorate: **Exploration Systems Development**

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

Launch Location: **Multiple launch locations including Kennedy Space Center and Boca, Chica, TX**

Launch Vehicle: **SpaceX Super Heavy Booster**

Crewed Mission Duration: **6.5 days**

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

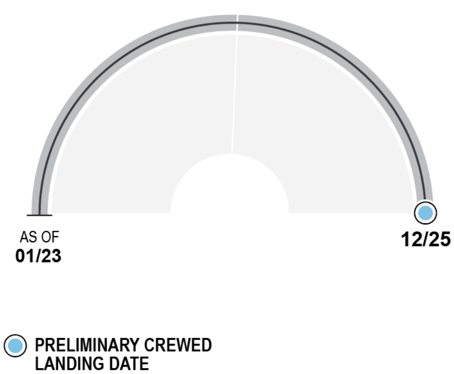
Project Summary

The HLS program delayed setting cost and schedule baselines for its initial capability from August 2022 to June 2023. Program officials stated that they delayed establishing these baselines to incorporate data from SpaceX's incremental design update, which marked the end of preliminary design. The program and SpaceX are adjusting several milestones, as they continue to work toward a December 2025 crewed landing.

SpaceX's HLS mission concept requires three variants of SpaceX's Starship vehicle—HLS Starship, a propellant tanker, and an on-orbit propellant depot—to support on-orbit propellant transfer and land astronauts on the lunar surface.

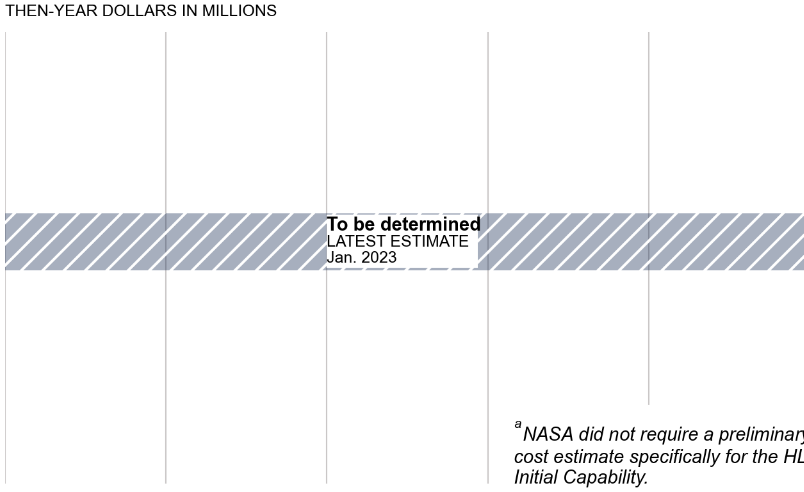
The program's top risks relate to maturing the Raptor main engine and propellant technologies, essential capabilities for realizing the mission concept. The program is mitigating these risks by monitoring planned critical events to mature these technologies.

Preliminary Schedule



Preliminary Cost[a]

THEN-YEAR DOLLARS IN MILLIONS



[a] *NASA did not require a preliminary cost estimate specifically for the HLS Initial Capability.*

Cost and Schedule Status

In July 2021, the program exercised a $2.9 billion option (referred to as Option A) on the firm-fixed-price indefinite-delivery, indefinite-quantity contract first awarded to SpaceX in May 2020. The scope of work includes the design, development, testing, and evaluation of the HLS Starship, an uncrewed lunar landing test, and Artemis III, a crewed lunar landing demonstration mission planned for December 2025.

The HLS program delayed its key decision point C review, the point at which it will set its cost and schedule baselines for the initial capability, from August 2022 to June 2023. This is 10 months later than originally planned. According to the program, this delay allowed for more time to incorporate data from SpaceX's incremental design update. Program officials stated that this design update marked the end of the program's preliminary design review phase. NASA did not require the program to establish preliminary cost estimates specifically for the HLS initial capability.

Technology and Design

SpaceX's mission profile is complex and includes multiple systems and on-orbit propellant transfers to deliver astronauts to the lunar surface. The HLS Starship variant is based on a common architecture and shares many of the same critical systems including propulsion, structures, and avionics. According to SpaceX officials, these commonalities are intended to improve overall reliability.

The fully integrated HLS Starship system is comprised of the Super Heavy booster (first stage) and Starship (second stage). Both stages are powered by Raptor engines that require liquid methane and liquid oxygen propellant (collectively referred to as propellant). Prior to the launch of the HLS Starship, a depot Starship will be launched to low Earth orbit, followed by multiple tanker Starships which will rendezvous with, dock to, and transfer propellant to the depot.

Once sufficient propellant is on-orbit, an uncrewed HLS Starship will launch into low-Earth orbit, then rendezvous with and dock to the depot Starship. The depot Starship will transfer its propellant to the HLS Starship. The HLS Starship will then perform a rapid transfer into near rectilinear halo orbit (NRHO) where it will loiter for up to 90 days to confirm vehicle health and await the launch and arrival of Orion. After docking with Orion, two astronauts will transfer from Orion into the HLS Starship, which will descend to the lunar surface for a 6.5-day stay. Once crewed surface operations are complete, the HLS Starship will ascend back to NRHO where the crew will transfer back to Orion for their return to Earth. According to program officials, this concludes NASA's requirements for the HLS Starship.

SpaceX's Raptor engine and propellant transfer and storage are critical technologies required to execute a lunar landing mission. SpaceX has and is planning to conduct a significant number of early tests, for example commercial Starlink launches, to reduce risk and mature these technologies.

The development of SpaceX's Raptor engines is one of the program's top risks. SpaceX continues to refine the Raptor engine design to improve reliability and to conduct HLS-mission specific testing to meet HLS mission requirements. SpaceX officials report that they have built over 200 engines to date, demonstrating their ability to build engines to meet HLS mission needs.

The program plans to continue monitoring critical events related to Raptor engine development. For example, SpaceX completed cold-start testing of the sea level Raptor engine and is planning a similar cold-start demonstration of the vacuum Raptor engine. SpaceX is also planning for Starship's first orbital flight test in 2023. While the test is not a contract milestone, the post-test data review is one. The test will demonstrate flight capabilities of the Super Heavy booster and Starship, including Raptor engine performance. One of the key test objectives is to gather data to verify and refine the design of the stages.

The program is also tracking a risk related to several propellant technologies, including: ship-to-ship propellant transfer, long-term propellant storage, and accurately estimating propellant mass in space. To address this risk, SpaceX completed multiple ground test events related to propellant transfer technologies and is working toward on-orbit testing which would demonstrate rendezvous and docking of two Starships and propellant transfer between tanks.

If SpaceX experiences challenges during these early test events, it could result in delays to other test events and to the program's schedule. For example, program officials have said that SpaceX's ability to perform these propellant transfer demonstrations depends on the company successfully completing Starship's first orbital flight test. The HLS Starship is inherently more complex than other space flight programs because it supports human spaceflight, and the program is working to an aggressive schedule. Because the HLS Starship is a key component of the Artemis III mission, delays to the program's schedule could also delay the mission.

Project Office Comments

HLS program and SpaceX officials provided technical comments on a draft of this assessment, which were incorporated as appropriate.

Source: NASA. | GAO-23-106021

Human Landing System – Sustaining Lunar Development (HLS SLD)

The HLS program's SLD effort will demonstrate expanded capabilities beyond Artemis III to support a lasting crewed presence on the moon. These capabilities include transporting additional crew, docking with the Gateway—a sustainable outpost in lunar orbit—and operating near the lunar south pole for extended durations. SpaceX and a second provider will develop lunar landers to deliver these expanded capabilities. NASA will certify that the providers' lunar lander designs meet NASA requirements and are safe for crew.

Project Information

NASA Lead Mission Directorate: **Exploration Systems Development**

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

International Partners: **None**

Launch Location: **To be determined**

Launch Vehicle: **To be determined**

Surface Mission Duration: **6-33 days**

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

Next Major Project Event: **Second provider contract award (June 2023)**

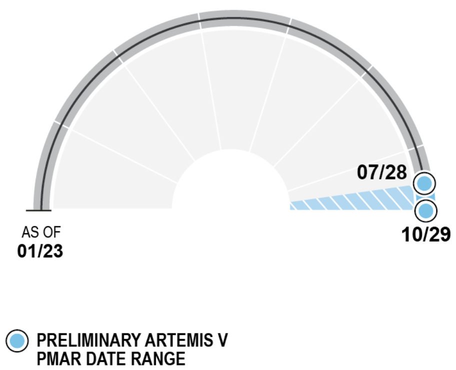
Current Status

The HLS program's SLD effort entered the preliminary design phase and technology completion phase in July 2022, with a preliminary cost range of $8 billion to $12 billion. This cost estimate assumes that two providers will develop lunar landers that meet NASA's requirements for SLD's expanded capabilities. NASA officials said the two providers' lunar landers will support different Artemis missions—Artemis IV planned for September 2028, and Artemis V planned for September 2029. The effort's schedule is tied to the Artemis V post-mission assessment review (PMAR), which occurs after crew return to Earth. When NASA approved the effort's preliminary cost and schedule in September 2022, the agency estimated the PMAR would occur between July 2028 and October 2029.

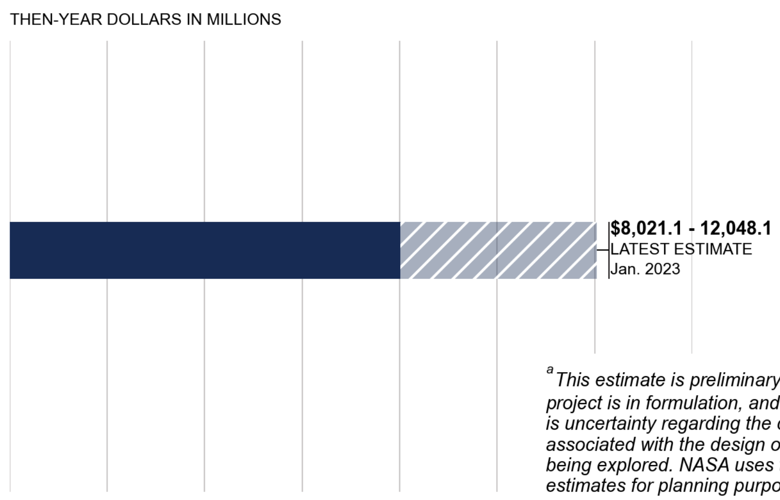
NASA's plans for two providers are underway. In November 2022, NASA awarded a modification to its existing HLS contract with SpaceX to develop a sustaining human landing system for the Artemis IV mission.

Additionally, in September 2022, NASA released a request for proposals for a second provider to develop a sustaining human landing system for the Artemis V mission. According to NASA, the second provider will be required to complete an uncrewed landing demonstration prior to Artemis V. NASA anticipates awarding a contract to a second provider in June 2023.

Preliminary Schedule



Preliminary Cost[a]



[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.

Project Office Comments

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

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Source: NASA. | GAO-23-106021

Mobile Launcher 2 (ML2)

ML2 is a project within the Exploration Ground Systems (EGS) program. It will provide a new 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 SLS vehicle and Orion Multi-Purpose Crew Vehicle (Orion) spacecraft 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.

Timeline

Formulation

- **Continued from EGS program** Formulation start
- **03/20** System requirements review
- **03/21 and 12/21** Preliminary design review steps 1 and 2
- **01/23** GAO review
- **Summer 2023 (under review)** Key decision point C

Implementation

- **09/23 (under review)** Critical design review
- **06-12/26 (under review)** Multi-element verification and validation
- **12/26** Completion of ML2 hardware build

Project Information

NASA Lead Mission Directorate: **Exploration Systems Development**

NASA Lead Center: **Kennedy Space Center**

International Partners: **None**

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

Project Summary

The ML2 project has not set cost and schedule baselines, but plans to do so in the summer of 2023. As of January 2023, NASA's preliminary estimate is that ML2's hardware will be complete in December 2026 at a cost of about $1.4 billion. This estimate represents a $450 million increase in development funding compared to the estimate in the fiscal year 2023 budget request.

Bechtel and NASA made a number of changes to the ML2 design to reduce its overall weight and preserve some margin. Steel fabrication was put on hold during the redesign and is now underway. Construction of the ML2 primary structure is planned to begin in the summer of 2023. In addition, Bechtel plans to hold its internal critical design review in March 2023. The project is targeting the government-led critical design review in September 2023, but this date is under review.

The program is tracking risks on material and labor costs and availability, as well as potentially inadequate schedule for verification and validation tests.

Preliminary Schedule

Preliminary Performance[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 ML2 project is still in the process of setting its cost and schedule baselines and is negotiating contract changes with the prime contractor, Bechtel. NASA is targeting summer 2023 to set project cost and schedule baselines. As of January 2023, NASA is estimating ML2's hardware will be complete in December 2026 at a cost of about $1.4 billion. This cost estimate—generated using Bechtel cost inputs—is $450 million more than the estimate in the fiscal year 2023 budget request. The project's notional schedule continues to slip. Further, after the ML2 hardware is delivered by Bechtel, NASA plans for 6 months of integrated testing with ground systems and another 12 months to support first-time processing and integration of the SLS Block 1B and ML2, leading up to the Artemis IV launch planned for September 2028.

Based on updated cost and schedule estimates from Bechtel, NASA estimates completing construction on the ML2 by December 2026. According to NASA documentation, the schedule estimate provided by the contractor does not meet NASA's requirements, but the two parties are working to come to an agreement on cost and schedule. Project officials stated that cost and schedule changes did not require an independent cost or schedule assessment. Instead, the NASA project team assessed the estimates.

NASA project officials stated that Bechtel initially underestimated the complexity of the effort necessary to design and build the ML2. Bechtel officials stated that early on, they were not expecting the volume and complexity of design change requests received from NASA. According to Bechtel officials, that led the contractor to reassess its project organizational structure to better address design changes. Since that point, the project and Bechtel have been working together more closely. NASA project officials said that they are having more frequent meetings and discussions with Bechtel and attending contractor-led quarterly management meetings.

Technology and Design

The ML2 design is under its weight limit due to a combined effort of NASA and Bechtel. The ML2 design was estimated to be overweight by 500,000 pounds in 2021. The parties met, discussed options, and selected 32 weight reduction actions for implementation. Those actions led to a redesign effort that, according to officials, affected one-third of the project's subsystems and reduced the ML2 weight. Also, NASA released additional weight margin, and the current design has about 443,000 pounds of that margin remaining. Bechtel officials stated that though they would like to have additional margin at this point, they are confident in the design as they have modeled more than 90 percent of it as of November 2022.

Constructing the ML2 structure requires steel design and fabrication, which has been on hold due to design changes and market influences. Bechtel has been working on finalizing steel fabrication drawings for vendors and has reported that all of the steel fabrication work has been placed on purchase orders. According to officials, the vendors have begun work on portions of the steelwork and are arranging additional fabricators for other portions. Once fabrication is complete, those pieces will be delivered to Bechtel. ML2 construction is currently scheduled to begin in August 2023.

Bechtel is planning to hold its internal critical design review—including contractor design information, not government design information—in March 2023. As of February 2023, NASA officials stated that Bechtel completed 37 of 47 subsystem design reviews leading up to this review. The subsequent government critical design review date is under review with a target date of September 2023.

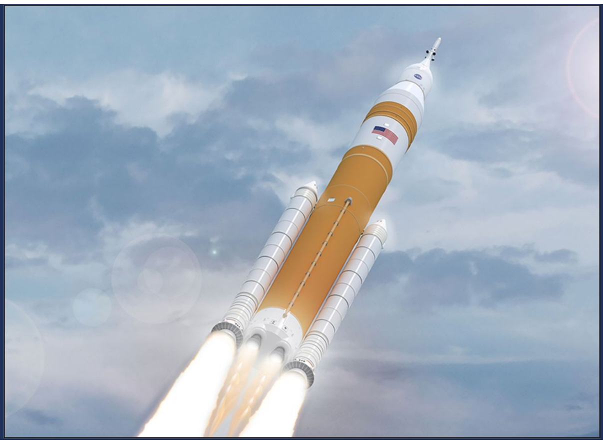
Other Issues to Be Monitored

The project is tracking a number of risks. The near-term risks revolve around contract performance, as described above, and market volatility. According to project officials, the market volatility risk includes concerns about material and labor pricing as well as availability fluctuations. Project officials are looking at mitigation options such as purchasing materials in advance, as well as finding alternative components for unavailable items.

The project continues to track a long-term risk that there is not enough time to complete stand-alone and multi-element verification and validation testing. Project officials stated that this will remain a risk even after the schedule replan. According to NASA, the contractor's recently updated schedule estimate may actually increase this testing risk, as the estimated construction completion date does not include enough time for the multi-element verification and validation testing and launch vehicle processing. Because the contractor and NASA are still negotiating delivery dates, there is still an opportunity to mitigate this risk by including additional schedule margin when NASA sets the project's baseline.

Project Office Comments

In commenting on a draft of this assessment, ML2 project officials said Bechtel's internal critical design review was completed in March 2023. ML2 project and Bechtel officials also provided technical comments on a draft of this assessment, which were incorporated as appropriate.



Source: NASA. | GAO-23-106021

Space Launch System (SLS) Block 1B

The SLS Block 1B is a planned evolution of the SLS Block 1. The SLS Block 1 is intended to be NASA's first human-rated, heavy-lift vehicle since the Saturn V and to enable deep-space Artemis and Mars missions. The SLS Block 1B will retain the core stage, RS-25 engines, and solid rocket boosters from Block 1, but replace the interim cryogenic propulsion stage (ICPS) with the more powerful Exploration Upper Stage (EUS) and adapters for payloads. The EUS 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.

Timeline

Project Information

NASA Lead Mission Directorate: **Exploration Systems Development**

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

International Partners: **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**

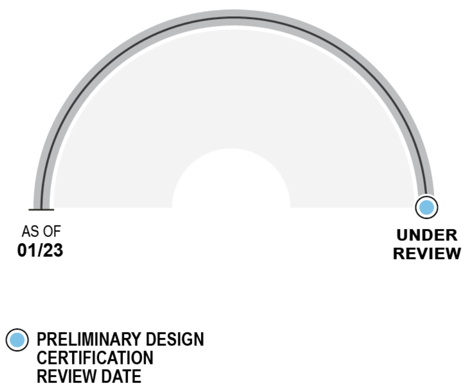
Project Summary

NASA has not yet established preliminary cost estimates or formal cost and schedule baselines for the SLS Block 1B program. NASA plans to fly the SLS Block 1B for the first time on Artemis IV, a crewed lunar mission, which NASA now plans to occur in September 2028.

NASA initiated a SLS Block 1B critical design review (CDR) in late 2022. NASA expects to resolve most review and action items from the CDR and close out the review by April 2023. The review did not include the flight software CDR, which is planned for September 2023. The program's flight software is on its critical path; therefore, any delays are likely to affect the program's launch readiness date.

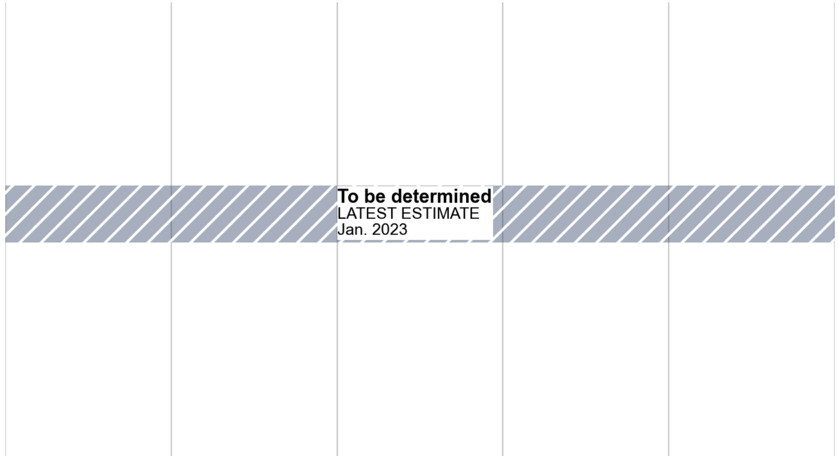
The program is also working toward a green run test—that is, a full power test—of the EUS in 2024 or 2025. However, the program is tracking a risk related to the availability of parts for the required test equipment.

Preliminary Schedule



Preliminary Cost

THEN-YEAR DOLLARS IN MILLIONS



Cost and Schedule Status

NASA has not yet established preliminary cost estimates or formal cost and schedule baselines for the SLS Block 1B program. NASA plans to fly the SLS Block 1B for the first time to support the Artemis IV mission, a crewed lunar mission, in September 2028. NASA's Agency Program Management Council, which is responsible for assessing programs and their respective baselines, has reviewed the SLS Block 1B program's proposed baselines twice. On the first occasion, in December 2021, NASA leadership decided to withhold releasing the SLS Block 1B baselines until the baseline cost and schedule commitments for Mobile Launcher 2 were approved and released. Mobile Launcher 2 is required to transport SLS Block 1B from the vehicle assembly building to the launch pad. On the second occasion—in June 2022, after the agency had decoupled these two baselines, according to officials—the Agency Program Management Council deferred establishment of formal baselines again until the levels of NASA's planned future funding requests were better defined. NASA officials said that the agency tentatively plans to establish cost and schedule baselines for the program in August 2023.

NASA reported finalizing the Stages Production and Evolution Contract with Boeing in December 2022 by reaching an agreement on certain outstanding terms and conditions of the contract. According to officials, the contract includes materials and production of SLS for the Artemis III and Artemis IV missions and SLS core stage materials and the EUS for the Artemis V and Artemis VI missions. SLS Block 1B production and operations costs beyond Artemis IV will remain uncertain until NASA is able to complete negotiations on the Explorations Production and Operations Contract, which officials do not plan to award earlier than in December 2023.

Technology and Design

NASA initiated a vehicle-level SLS Block 1B CDR in November 2022. At the time of the initial review, the program released about 63 percent of its design drawings specifically for the capability upgrade elements of the vehicle. Program officials stated that this is, in part, due to design configuration changes due to changes in the mission—from an SLS cargo-only mission to a crewed mission. They also noted that the design drawings released at the CDR are only the Block 1B-specific elements as most of the SLS design remains the same as the configuration flown on Artemis I. Program officials said that, at the vehicle level, they released 97 percent of the drawings. NASA expects to resolve most review and action items from the CDR and close out the review by April 2023. We plan to follow up on the percentage of drawings released at the time of the review close out to determine whether the program met our best practice of releasing 90 percent of design drawings by CDR, which lowers the risk of design changes that can lead to cost and schedule growth.

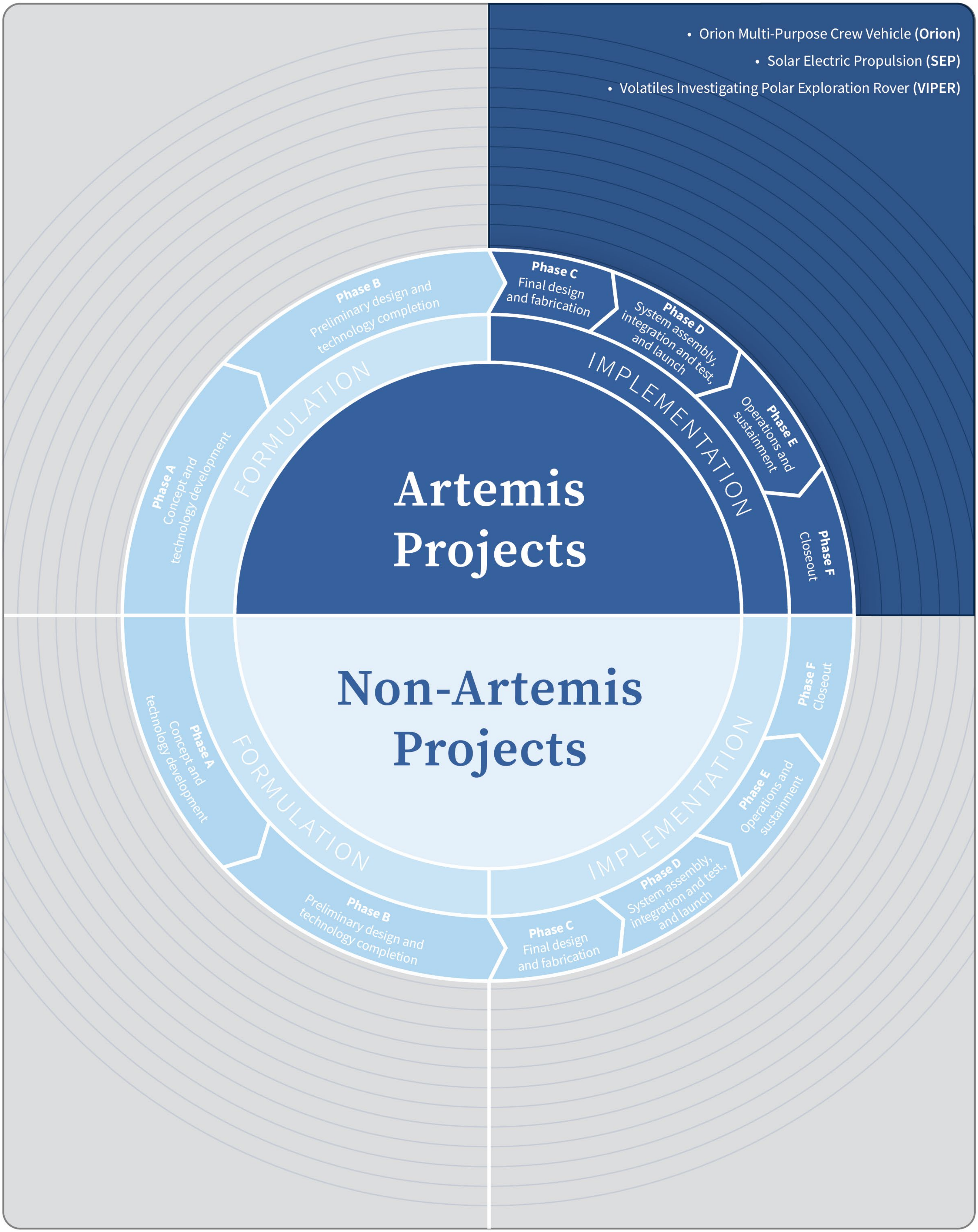
However, the program deferred CDR for the SLS Block 1B flight software until September 2023. The idea behind this deferral is to allow additional time to develop hardware to provide a more mature base for the software design review. According to program officials, it is not unusual for software development to lag hardware development. However, software development is already one of the program's critical paths—the portion of the program with the least amount of schedule reserve available. Consequently, deferring the flight software CDR until later in the development cycle increases the likelihood that any software delays could affect the Artemis IV launch date. In addition, the program is considering adding a risk that the software schedule may be delayed due to Artemis I and II efforts that negatively affected SLS Block 1B program and contractor resources, as well as data delivery delays.

Other Issues to Be Monitored

Development of the stage controller hardware and software is the program's third critical path. NASA needs the stage controller to support the green run, or first full power test of the EUS, which NASA may hold in late 2024 or early 2025. The exact date will be unknown until NASA releases the schedule. According to program officials, the stage controller will provide simulated flight instructions to the EUS during green run testing. These officials indicated that the stage controller for the EUS green run is 90 percent common with the stage controller used for the SLS core stage green run. However, officials stated that the program is tracking a risk that parts needed to manufacture the EUS green run controller may not be available. Program officials indicated that because of the design commonality, they do not consider this to be a significant risk, and that it will be ready for the EUS green run.

Project Office Comments

SLS Block 1B program officials provided technical comments on a draft of this assessment, which were incorporated as appropriate.



Source: GAO analysis of NASA data. | GAO-23-106021

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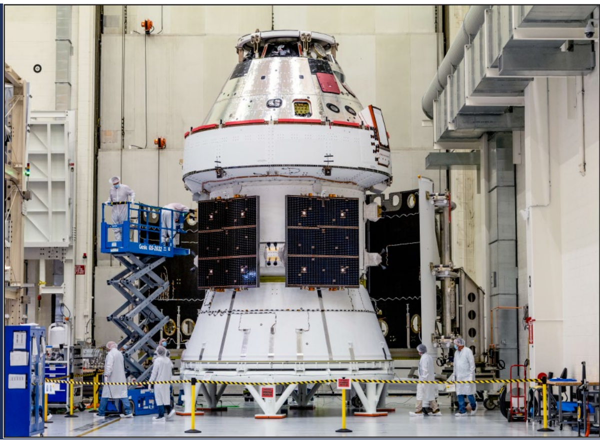


Orion Multi-Purpose Crew Vehicle (Orion)

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, launch abort system, and rendezvous proximity operations and docking capability (RPOD). The project had one uncrewed mission (Artemis I) in 2022, and plans for the first crewed mission (Artemis II). NASA plans to produce additional Orion capsules to transport crew for a planned 2025 lunar landing mission, called Artemis III, and later missions. The Orion program is continuing to advance the development of the vehicle started under the canceled Constellation program.

Source: NASA. | GAO-23-106021

Timeline

- **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** Key decision point C
- *Implementation*
- **10/15** Critical design review
- **11/22** First uncrewed flight
- **01/23** GAO review
- **11/24 (under review)** First crewed flight launch readiness date

Project Information

NASA Lead Mission Directorate: **Exploration Systems Development**

NASA Lead Center: **Johnson Space Center**

International Partners: **European Space Agency**

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

Launch Vehicle: **Space Launch System**

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

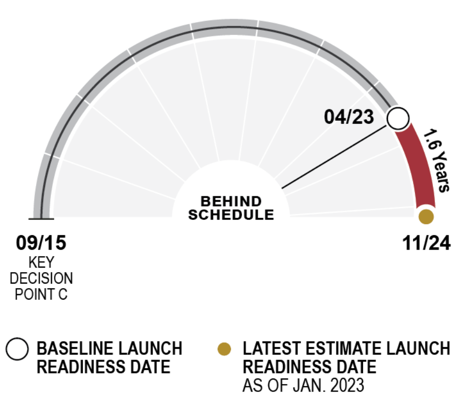
Requirement Derived from: **NASA Authorization Act of 2010**

Project Summary

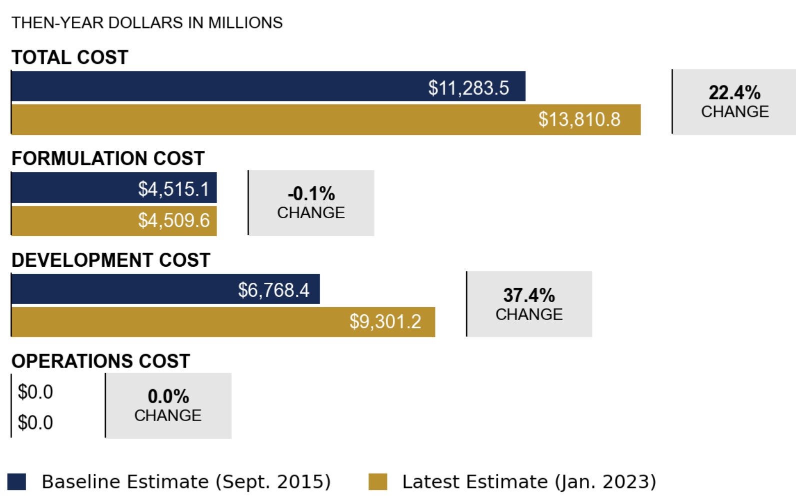
NASA successfully conducted the Artemis I mission—the first test of an uncrewed Orion crew capsule—in November 2022. The program's most recent cost and schedule baselines assumed an April 2022 Artemis I launch date. As a result of the launch slipping to November 2022, the program is reviewing cost and schedule. The program is currently working to a November 2024 launch readiness date for the Artemis II mission, a 6-month delay from the prior May 2024 date. Program officials said they plan to have a new cost estimate in summer 2023 and expect cost growth to be above the rebaselined life-cycle cost estimate, which assumed a May 2024 launch readiness date.

Artemis II integration and testing is ongoing, beginning with service module environmental control life support system and propulsion integration in April 2022. The program also completed component-level testing on the Orion docking capability, RPOD, for some systems, such as the docking camera and light detection and ranging system. The Orion docking capability will have limited testing and demonstration for Artemis II, and will be fully incorporated for Artemis III to allow for docking with the Human Landing System (HLS).

Schedule Performance – Under Review



Cost Performance – Under Review



Cost and Schedule Status

In November 2022, NASA conducted the Artemis I mission—the first test of an uncrewed Orion vehicle using the Space Launch System—after a further 6-month delay from May 2022. NASA recovered the vehicle in December 2022 after a successful visit to the moon and return to Earth. The capsule splashed down in the Pacific Ocean and was then transported back to the Kennedy Space Center where technicians removed payloads and are analyzing elements like the vehicle heat shield.

Artemis II—a crewed test flight—will be the next major flight test for the program. Previously, in June 2022, NASA approved shifting the Artemis II launch date by 6 months from May 2024 to November 2024. The Orion program is working to that new milestone.

As we reported in June 2022 (GAO-22-105212), the Orion program rebaselined in 2021. One of the major underlying cost assumptions at that time was that Artemis I would launch no later than April 2022. Program officials said they could not determine the program's cost implications from the launch delay until after the return of the Artemis I Orion capsule. This is because the program plans to reuse nine non-core avionics components from the Artemis I Orion capsule for the Artemis II capsule. The program also plans to reevaluate its cost and schedule estimates based on the results of an Artemis II schedule risk assessment—a tool that helps NASA identify a realistic, risk-informed launch date for the mission—and the program's review of post-Artemis I flight data.

As of January 2023, program officials are reviewing the program's cost and schedule estimates and the program expects to have new estimates in summer 2023. Program officials said that they expect some development cost growth beyond the current estimate, which assumed a May 2024 launch readiness date, due to the Artemis I launch delay; the delay to the Artemis II launch readiness date; and incorporating risk mitigations and first-time hardware development and integration for Artemis II into the program's schedule. The officials said they expected the cost growth to remain below the level required for congressional notification.

The program is tracking risks related to completing Artemis II software development and testing the software when integrated with hardware. Program officials said they were monitoring these risks for multiple reasons, one being that the integration needs between hardware and software are more complex because Artemis II will have a crew on board Orion.

Integration and Test

Integration and testing for the Orion Artemis II capsule is ongoing. The crew module conducted initial power on testing in May 2022, with the service module following in August 2022. The service module began environmental control life support system and propulsion integration in April 2022 and is currently undergoing functional testing.

According to program officials, the project team is taking three main lessons learned from the Artemis I mission and applying them to Artemis II and Artemis III assembly, integration, test, and processing. First, the team modified the design of some Orion components to improve manufacturing efficiency, which program officials said reduced the total number of parts they will need to integrate. Second, the program upgraded certain operations facilities and changed processes—including performing some tasks in parallel instead of sequentially—to improve the assembly process flow. Third, the program incorporated new technologies such as additive manufacturing.

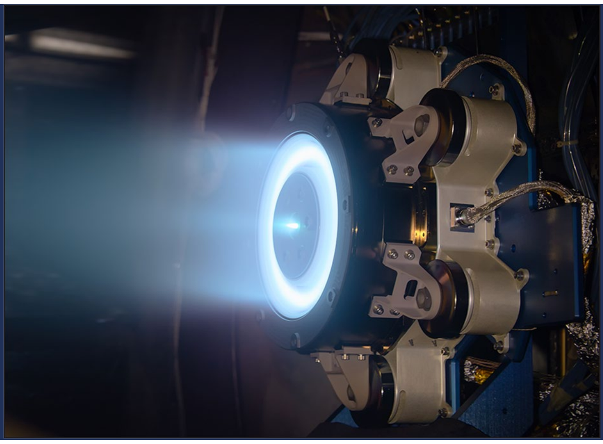
Rendezvous Proximity Operations and Docking

NASA's plans for RPOD for Artemis II and Artemis III remain the same from last year. For Artemis II, NASA plans to conduct a limited RPOD demonstration capability on the Orion crew capsule. The crew will perform proximity tests to demonstrate the ability of the docking system to line up with a target. The full RPOD capability will be used to dock Orion with the HLS as part of the Artemis III mission.

The program held an RPOD subsystem critical design review in May 2021. Program officials said that, since that time, various RPOD suppliers completed component-level development tests. Officials said that the docking camera, docking lights, docking light controller, and light detection and ranging systems have completed these tests. The program began assembling the docking module jettison system test article for qualification testing in September 2022.

Project Office Comments

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



Solar Electric Propulsion (SEP)

The SEP project is a technology demonstration that aims to develop high power electric propulsion technologies for NASA exploration and to empower the U.S. space industry. Solar electric propulsion uses energy from the sun to ionize and accelerate gas, resulting in higher fuel efficiency. This reduces the mass of propellant needed for spaceflight missions beyond low-Earth orbit compared to conventional chemical propulsion systems. The SEP project is developing an Advanced Electric Propulsion System (AEPS) that will fly on the Gateway's Power and Propulsion Element (PPE).

Source: NASA. | GAO-23-106021

Timeline

Formulation

- **03/15** Formulation start
- **05/16** AEPS system requirements review
- **08/17** AEPS preliminary design review
- **02/20** Key decision point C

Implementation

- **03/22** AEPS critical design review
- **01/23** GAO review
- **07/24** Complete delivery of three AEPS flight thrusters to the PPE
- **10/28** AEPS life qualification test report complete

Project Information

NASA Lead Mission Directorate: **Space Technology**

NASA Lead Center: **Glenn Research Center**

International Partners: **None**

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

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

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

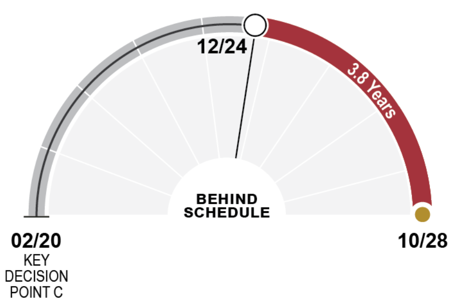
Requirement Derived from: **2018 Strategic Objectives 2.2, 3.1, 4.2**

Project Summary

The SEP project is operating within its 2022 rebaselined cost and schedule. However, since the rebaseline, the project reports that the thruster contractor experienced cost overruns and schedule delays against its new contract baseline. Requirements changes also drove about 2 months of contractor delays to the delivery date of the first of two qualification units, according to project documentation. As a result of cost increases for the thruster and in consideration of Gateway's PPE mass reduction efforts, the Space Technology Mission Directorate canceled one of its two subprojects in May 2022.

As of January 2023, the project's highest technical risk was finishing the cathode, which produces electrons for the thruster. The project was working to address issues with the cathode that had the potential to result in a redesign. Aerojet Rocketdyne and NASA conducted a risk assessment to determine if they needed to redesign the cathode and agreed to proceed with the existing design. The SEP project plans to mature the thruster technology after the first qualification unit completes acceptance testing by the end of summer 2023. This is prior to the PPE project's critical design review and final assembly and delivery of the flight thrusters.

Schedule Performance

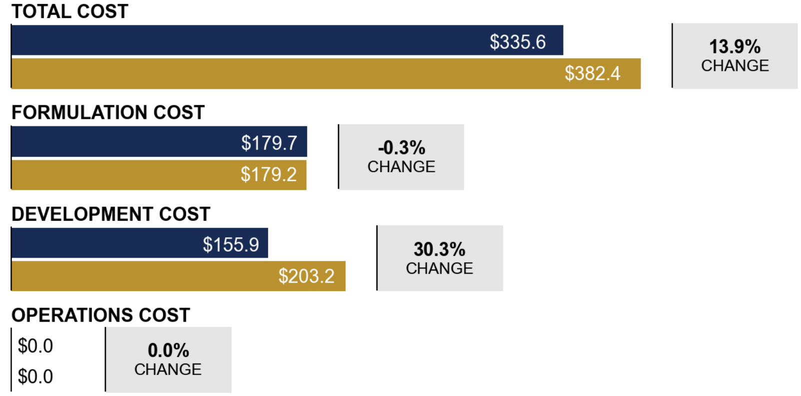


BASELINE AEPS LIFE QUALIFICATION TEST REPORT COMPLETE DATE

LATEST ESTIMATE AEPS LIFE QUALIFICATION TEST REPORT COMPLETE AS OF JAN. 2023

Cost Performance

THEN-YEAR DOLLARS IN MILLIONS



Baseline Estimate (Feb. 2020) Latest Estimate (Jan. 2023)

Cost and Schedule Status

The SEP project is operating within its 2022 rebaselined cost and schedule. The project rebaselined in March 2022 after exceeding its cost baseline by $46.8 million and delaying its completion date by 46 months.

The project reports that within a couple of months of updating its contract with Aerojet Rocketdyne for the AEPS thrusters in February 2022, the contractor began to experience cost overruns and schedule delays against the new contract baseline, as well as other challenges. For example, the project identified differences between the master schedule and contractor's production schedule, a lack of details in a contractor's schedule risk assessment, and overly optimistic contractor cost estimates. However, in August 2022, project officials reported positive changes from the contractor such as increased communication and transparency.

As a result of the increased costs of the AEPS subproject and in consideration of PPE mass reduction efforts, the Space Technology Mission Directorate decided to cancel the Plasma Diagnostics Package (PDP) subproject and removed it from project's cost baseline in May 2022. The SEP project was developing PDP to describe the performance of the electric propulsion system while in space. SEP project officials stated the cancelation of PDP will not affect SEP's ability to meet requirements, but the PPE project will no longer have the data from PDP. The same officials explained that descoping PDP allowed the SEP project to reallocate about $3.5 million from the PDP subproject to the AEPS subproject. Officials added that without moving this funding to the AEPS subproject, the project may have needed to increase its overall life-cycle cost baseline if there had been additional cost growth and schedule delays.

Additionally, according to project documentation, changes to PPE requirements drove contractor delays of about 2 months to the planned delivery date of the first of two qualification thrusters, from January to March 2023. SEP officials explained this delay had a ripple effect on other project milestones—it pushed back the delivery date of the second qualification thruster and the start of the 4,500 hour wear test.

Technology and Design

As of January 2023, the highest technical risk to completing the delivery of qualification and flight thrusters was finishing the cathode. The cathode produces electrons for the thruster. During this process, the temperature changes from hot to cold and can cause stress to the cathode's joints.

The project was working to address remaining issues with the cathode. For example, officials explained that an analysis completed prior to the project's critical design review indicated that some joints may not meet requirements for the number of thermal cycles that the joints can go through without breaking, which put the cathode design at risk. Aerojet Rocketdyne and NASA conducted a risk assessment to determine if they needed to redesign the cathode and agreed to proceed with the existing design. Project officials said that NASA and Aerojet Rocketdyne are revisiting their qualification processes in early 2023 and may add additional cathode subcomponent testing.

SEP is a technology demonstration project where the main objective is to mature a new technology. The project will mature 12 kW thruster technologies for the PPE project. The project will also assemble and test two qualification thrusters and manage the assembly of three flight thrusters for the PPE project. Our best practice for technology maturity states that critical technologies should achieve technology readiness level (TRL) 6 by preliminary design review to minimize risks for further product development. Achieving a TRL 6 involves demonstrating a representative prototype of the technology in a relevant environment that simulates the harsh conditions of space. However, because the project is a technology demonstration, NASA does not apply this best practice. The SEP project planned to mature its technologies to a TRL 6 by critical design review. However, officials explained the project did not do so because of cathode development delays, which prevented the cathode from being integrated with the thruster before relevant environmental testing. As a result, the project had to complete separate testing for the cathode.

The project plans to mature the thruster technology to a TRL 6 by the end of summer 2023, which is before the PPE project's critical design review and final assembly and delivery of the flight thrusters. SEP project officials said the technology will achieve a TRL 6 when the first of two qualification thrusters completes acceptance testing, which includes limited vibration, thermal-cycling, and performance testing. At that point, officials said they will have tested a prototype in a relevant environment.

According to project documentation, the project will subsequently begin 23,000 hours of long-duration wear testing on its second qualification thruster. The first 4,500 hours, which the project plans to complete in September 2025, is expected to reduce uncertainty in and inform on-orbit thruster operations. When the thrusters launch on the PPE—currently planned for July 2025 at the earliest—the thruster may not have finished the 4,500 hours of qualification testing. The thruster will undergo an additional 18,500 hours of life testing, which officials explained will test the amount of expected wear, plus a contingency margin, against the 15-year PPE mission thruster requirement.

Project Office Comments

SEP project officials provided technical comments on a draft of this assessment, which were incorporated as appropriate. Project officials also stated that as of March 2023, they had mitigated major risks associated with the cathode and completed installation of the cathode into the qualification thruster.

Source: NASA. | GAO-23-106021

Volatiles Investigating Polar Exploration Rover (VIPER)

VIPER will be a lunar rover that aims to understand how much water is on the moon and where the water 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 the Artemis III lunar landing site decisions. The VIPER project is continuing to develop the rover started under the canceled Resource Prospector project.

Timeline

Project Information

NASA Lead Mission Directorate: **Science**

NASA Lead Center: **Ames Research Center**

International Partners: **N/A**

Launch Location: **To be determined**

Launch Vehicle: **Commercial Lunar Payload Services (CLPS) Provided SpaceX Falcon Heavy**

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

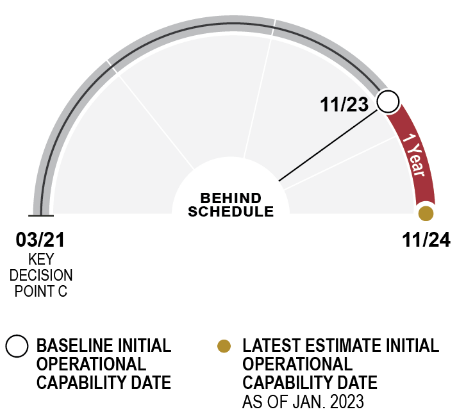
Requirement Derived from: **2011 Planetary Science Decadal Survey**

Project Summary

In July 2022, NASA announced it delayed VIPER's launch readiness date by 1 year from November 2023 to November 2024. As a result of the launch delay, the project's costs increased by $64 million. NASA delayed the launch readiness date to allow Astrobotic—the Commercial Lunar Payload Services (CLPS) provider delivering VIPER from Earth to the moon—additional time to test the propulsion systems on Astrobotic's Griffin lander. Now that the project has an additional year, it is reevaluating its system integration and test schedule to reduce project schedule and technical risks. For example, the project may add testing back into its schedule that it had previously removed to meet the prior November 2023 launch readiness date.

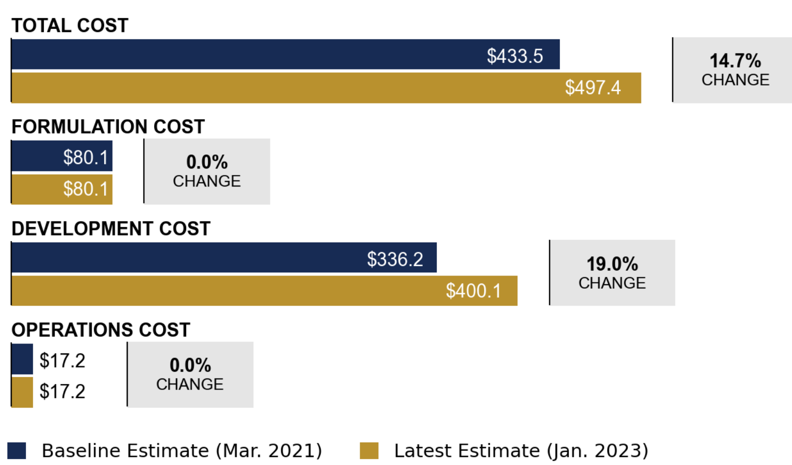
The project continues to experience challenges resulting from COVID-19 and parts delivery delays due to supply chain issues. Project officials are trying to mitigate supply chain issues by using multiple vendors. The project has seen mass growth in the last year, but has been taking action to find additional mass reductions.

Schedule Performance



Cost Performance

THEN-YEAR DOLLARS IN MILLIONS



Cost and Schedule Status

In July 2022, NASA announced that it delayed VIPER's launch readiness date by 1 year, from November 2023 to November 2024, to allow for additional testing of the lander that will deliver the rover to the lunar surface. As a result of this schedule change, the VIPER project's life cycle costs increased by $64 million.

The VIPER lunar delivery date was rescheduled because NASA wanted Astrobotic—the CLPS contractor providing end-to-end commercial payload services between Earth and the moon—to conduct additional testing on the company's Griffin lander's propulsion system. The lander's propulsion system is a new design and has not flown before. NASA was concerned that Astrobotic had not adequately demonstrated in its testing plan that the VIPER lunar delivery would occur within an acceptable level of risk. Project officials said that because of the importance of VIPER and the amount of resources the agency has invested in it, NASA wanted to add testing to reduce the risk of mission failure. Further, NASA officials also had concerns that vendor delays for the lander engines and the reliance on using lessons learned from Astrobotic's Peregrine lander mission, which has been delayed, would mean that Astrobotic might not have enough time for testing and analysis.

In July 2022, NASA modified the Astrobotic CLPS task order for VIPER delivery to add lander testing requirements and to include the later launch date. This modification increased the value of the contract by $67.8 million, from $252.6 million to $320.4 million. VIPER's cost baseline does not include funding for CLPS task order costs, or for prior development work under the Resource Prospector project. In May 2021 (GAO-21-330), we recommended that NASA include these cost as relevant in the VIPER baseline. NASA did not concur with this recommendation, stating that Resource Prospector's mission was significantly different and that CLPS costs differ from other launch services procured for NASA missions.

COVID-19-related and supply chain issues continue to pose challenges for the project. The project is tracking these issues as cost and schedule threats. As of September 2022, the project experienced an estimated $21.9 million in COVID-19-related cost increases, which the project covered using its cost reserves. The project has continued to see delivery delays from vendors and is trying to mitigate the effect of these supply chain issues on the project's overall schedule. For example, project officials said they are using multiple vendors to purchase the same item in hopes that one will be able to deliver.

According to project officials, they have also seen a decline in parts quality, even with on-time deliveries. For example, officials said the VIPER navigational camera's lens and imager produced by a vendor did not satisfy quality requirements and required additional work. The project is evaluating other lens options and hiring a consultant to provide support to the vendor to address the issue.

Integration and Test

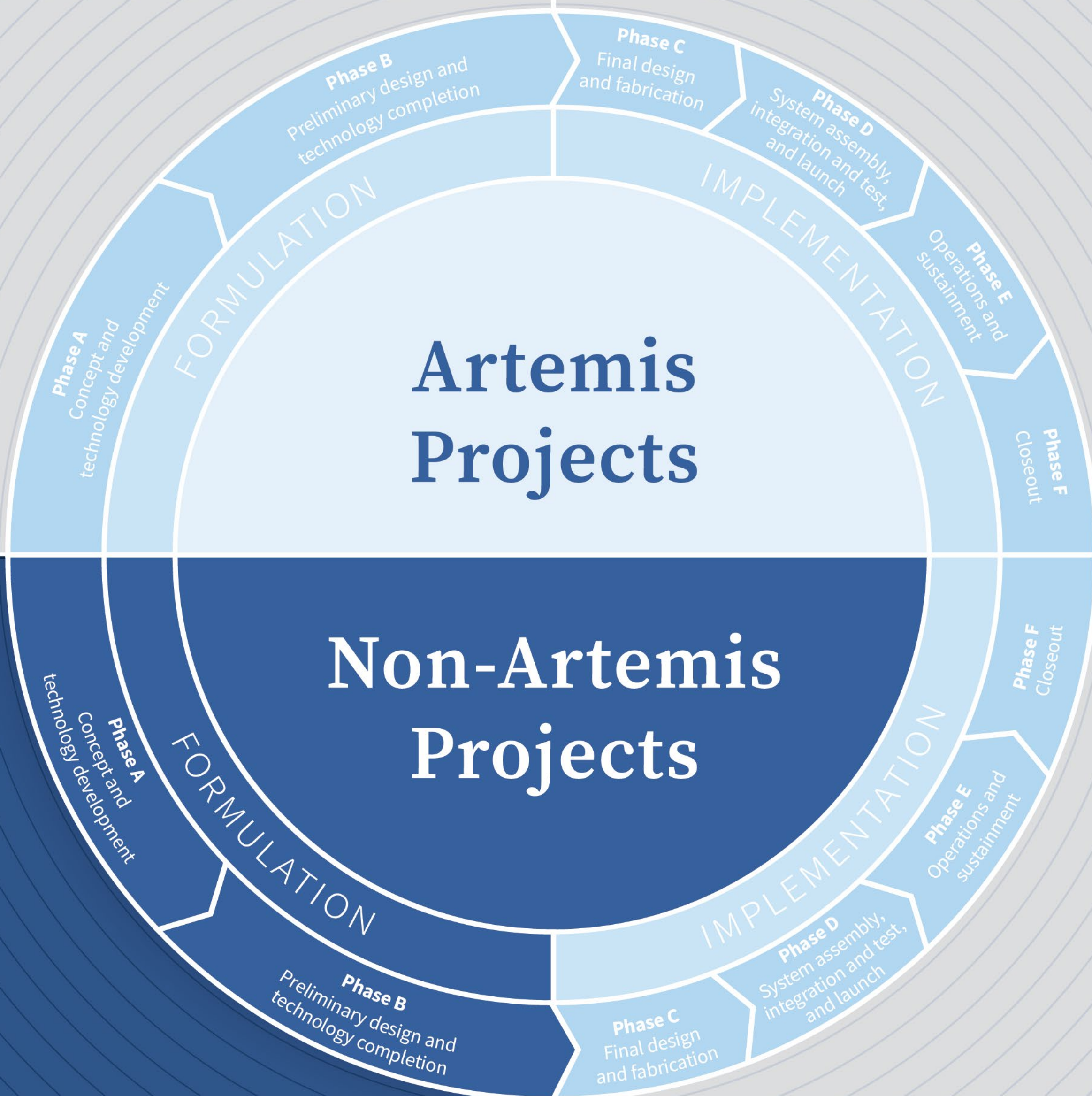
The VIPER project is reassessing its system integration and test schedule to reduce technical risk. Prior to NASA delaying the project's launch readiness date, the project modified its integration and test schedule to address schedule risk. Now, because of the later launch readiness date, project officials said they were looking at what testing they could add back into the schedule. Officials said, for example, that they previously reduced the number of thermal vacuum cycle tests, but now they could do them all. Project officials said this should help reduce the project's risk posture. The project held its system integration review in December 2022 and plans to begin system integration and test in early 2023.

Design

The project is tracking a risk and is closely monitoring the rover's mass. While the project is currently still within project's mass allocation for delivery and launch, further mass growth could require tradeoffs that may affect rover performance. The project previously experienced mass growth as it balanced CLPS launch vehicle mass constraints with changes to mission requirements resulting from the evolution of Resource Prospector to VIPER. For example, VIPER's requirements include ensuring the rover can survive a 100-plus-day mission, including extended periods of darkness. According to project officials, additional mass increases in the last year were not the result of design changes, but rather the project obtaining more accurate knowledge of parts mass. The project appointed a systems engineer to find ways to reduce mass. The systems engineer helped identify potential mass reductions of 16 kilograms, which is equal to 3 percent of VIPER's mass margin. The project is evaluating additional mass reduction options, such as removal of one of the four battery units on the rover.

Project Office Comments

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



- Dragonfly
- Electrified Powertrain Flight Demonstration (**EPFD**)
- Mars Sample Return (**MSR**)

Source: GAO analysis of NASA data. | GAO-23-106021

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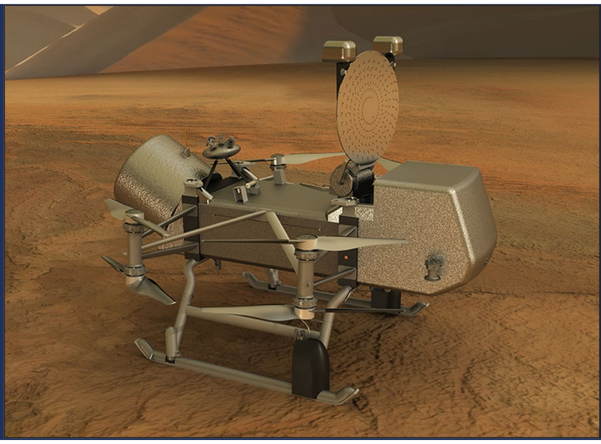


Source: Johns Hopkins University Applied Physics Laboratory. | GAO-23-106021

Dragonfly

Dragonfly is an eight-bladed rotorcraft that will visit Titan—Saturn's largest moon—and fly like a drone to sample and examine dozens of sites and search for the building blocks of life. It will explore organic dunes and the deposits of an impact crater where liquid water and complex organic materials key to life that once existed together for possibly tens of thousands of years. It will also investigate how far prebiotic chemistry has progressed. This mission is the first time that NASA will fly an eight-bladed rotorcraft and take advantage of Titan's dense atmosphere—four times denser than Earth's—to gather science on another planetary body and fly its entire science payload to new places for repeated and targeted access to surface materials.

Timeline

Formulation

- **06/19** Formulation start
- **08/20** Internal system requirements review
- **01/23** GAO review
- **02/23** Preliminary design review
- **06/23** Key decision point C

Implementation

- **03/24** Critical design review
- **05/26** System integration review
- **06/27** Preliminary launch readiness date

Project Information

NASA Lead Mission Directorate: **Science**

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

International Partners: **Centre National d'Etudes Spatiales (France), Japan Aerospace Exploration Agency, German Aerospace Center**

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

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

Mission Duration: **11 years**

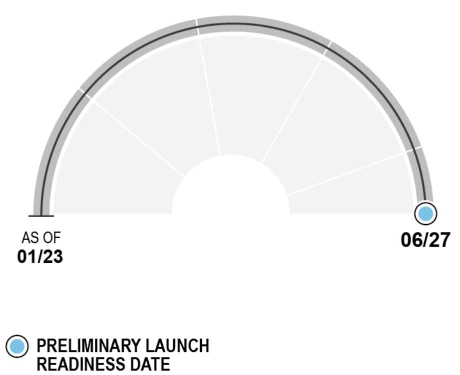
Requirement Derived from: **2011 Planetary Science Decadal Survey**

Project Summary

The Dragonfly project continues to proceed through the preliminary design and technology completion phase. It plans to set its cost and schedule baselines and enter the final design and fabrication phase when it holds its key decision point C review in June 2023.

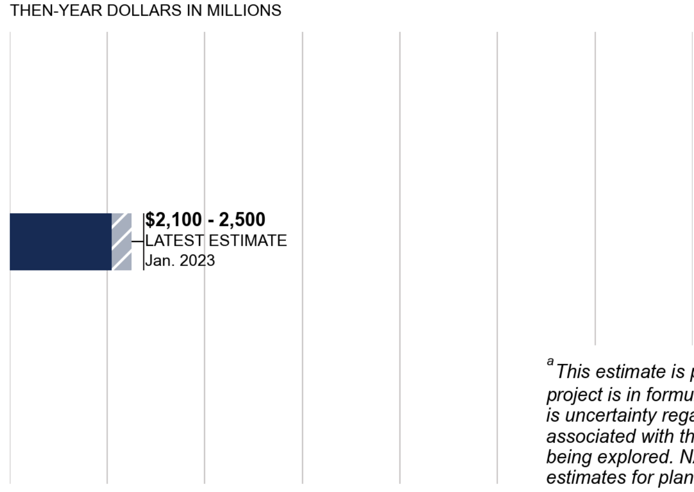
The project made progress on the rotorcraft lander and its instrument designs. The project faces challenges such as limited funding which, among other things, resulted in the project deferring planned work to fiscal years 2023 and 2024. The project is tracking a risk that if funding is not available to support its planned spending profile, further delays are likely. In addition, to address system mass concerns, the project identified a number of items to descope, which project officials said removed redundancy and would not affect the project's ability to meet its level-1 science requirements. The project delayed its preliminary design review from October 2022 to February 2023 to incorporate these descopes into its overall system design.

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 Dragonfly project entered the preliminary design and technology completion phase in June 2019. The project plans to establish its cost and schedule baselines and enter the final design and fabrication phase when it holds its key decision point C review in June 2023. In January 2022, NASA increased the project's preliminary life-cycle cost estimate to a range of $2.1 billion to $2.5 billion and set a preliminary launch date of June 2027.

A lack of cost reserves, supply-chain delays, staffing challenges, facility unavailability, and COVID-19 issues have hampered the project's efforts to complete its preliminary design. According to officials, the project has not received optimal funding levels during the preliminary design phase, and as a result, has not had sufficient reserves to address all issues as they arise. For example, the project is experiencing supply-chain delays, which have caused increases in cost and lead times for parts. Project officials are working to understand which parts are affected and procure them as early as possible to accommodate the long turn-around times. However, with limited funding and cost reserves in fiscal year 2022, the project is tracking a risk that it may experience more schedule delays if it cannot order parts further in advance.

The project is also tracking a risk on the availability of resources to support deferred work as a result of 3 years of cost constraints. The project repeatedly deferred work in order to not overspend available resources. As a result, the project expects an increase in planned work in fiscal years 2023 and 2024 and to have limited funding for procurements at that time. According to the project, if funding is not available to support its planned spending profile, further delays are likely.

Technology and Design

The Dragonfly project rescheduled its preliminary design review from October 2022 to February 2023 in order to incorporate descopes into its overall system design to address mass concerns and to complete its integrated master schedule. If the system is too heavy, then the range of the rotorcraft is affected. The lander mass margin was too low for the project's current phase, so the project identified a list of items it could descope from the system and material changes to improve this margin. For example, the project decided to use magnesium instead of aluminum for the mechanical enclosure designs to reduce mass. Project officials said that most of the descopes removed redundancy and would not affect the project's ability to meet its level-1 science requirements. For example, the project reduced mass by removing one of the navigation cameras. In January 2023, the project reported that Dragonfly's mass margin had increased to an acceptable level and is stable. However, the project is continuing to identify mass savings and catalog mass threats. In addition to mass concerns, the project determined that it needed more time to improve the maturity of its schedule. For example, project officials said that the integrated master schedule lacked adequate detail for the mechanical and thermal development.

Project officials reported that they matured Dragonfly's three critical technologies to a technology readiness level 6 in advance of preliminary design review. This aligns with our best practice for technology maturity to minimize risks for further product development.

The project continues to make progress on the preliminary designs of its rotorcraft lander and instruments, including incorporating the descopes. For example, the project removed a drill, blower, and the inner carousel ring from the Drill for Acquisition of Complex Organics (DrACO). DrACO will deliver surface material for analysis to the Dragonfly Mass Spectrometer (DraMS), which is an instrument that will study the chemical complexity and diversity of Titan's solid surface. The project also reduced the number of cups on DrACO's carousel from 58 to 40. These cups are where material collected from the drill is placed for testing. The changes to DrACO do not affect DraMS's ability to meet its science requirements, but the project is evaluating the optimal distribution of cups between two DraMS measurement test modes—Laser Desorption Mass Spectrometry and Gas Chromatography Mass Spectrometry—if both are to be used. The project is evaluating whether it should also descope the Laser Desorption Mass Spectrometer to reduce mass. The international contributor responsible for providing the Gas Chromatograph is experiencing schedule delays of about 6 months that will affect DraMS delivery. The project is working closely with the international contributor to identify mitigation steps to reduce further delays.

The project continues to refine the design of its Dragonfly Camera Suite, which are the cameras that will image Titan's terrain and help Dragonfly navigate and determine landing areas of scientific interest. For example, the project recently moved the Panoramic Cameras from the High Gain Antenna location to the nose of the lander to meet camera thermal requirements. The project is resolving mechanical and thermal interfaces between the camera suite and the lander.

The project also made progress testing sensors on the Dragonfly Geophysics and Meteorology Package (DraGMet). DraGMet is a suite of geophysical and meteorological sensors, including a seismometer to detect Titanquakes and understand the moon's interior and liquid subsurface ocean. The project completed prototype development of all 12 sensor types and is in the process of designing, building, and testing the sensor boards that interface to the sensors.

Project Office Comments

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

Source: NASA. | GAO-23-106021

Electrified Powertrain Flight Demonstration (EPFD)

EPFD is a technology demonstration project overseeing the commercial development of hybrid electric-powered aircraft. The program is working with GE Aviation (GE) and magniX to mature Electrified Aircraft Propulsion (EAP) technologies for commercial aircraft through ground and flight demonstrations. The use of EAP technologies can lead to lower operating costs and benefits, such as higher fuel efficiency and reduced noise emissions. GE is developing a megawatt-class powertrain system for single-aisle aircraft carrying approximately 150 passengers, while magniX is developing a hybrid commuter aircraft for transporting approximately 45 passengers.

Timeline

Formulation

- **06/20** Formulation start
- **09/21** Contract awards
- **2022** GE system requirements review
- **2022** GE preliminary design review
- **01/23** GAO review
- **2023** magniX system requirements review
- **08/23** Key decision point C

Implementation

- **2023** GE critical design review
- **2023** magniX preliminary design review
- **2024** magniX critical design review
- **10/24-06/25 (under review)** First flight for concept 1 and 2

Project Information

NASA Lead Mission Directorate: **Aeronautics Research**

NASA Lead Center: **Virtual Project Office**

International Partners: **None**

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

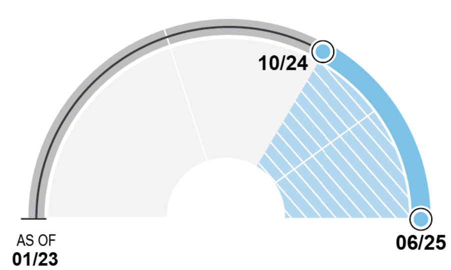
Project Summary

The EPFD project expects to stay within its preliminary cost range but not within its preliminary schedule range when it establishes cost and schedule baselines in summer 2023. The project has experienced delays in part due to supply chain and workforce availability issues caused by COVID-19. The project and its two industry partners are tracking risks that a constrained supply base for critical components could further affect the project's schedule. Despite the delays, the project does not anticipate that its cost baseline will exceed $469.4 million because of its firm-fixed-price contracting approach.

GE completed its preliminary design review (PDR) last year while magniX plans to do so after the project sets its baselines. In place of PDR data, project officials said they will use information from magniX's integrated baseline review (IBR), planned to occur prior to key decision point C (KDP C), to help inform the project's baselines.

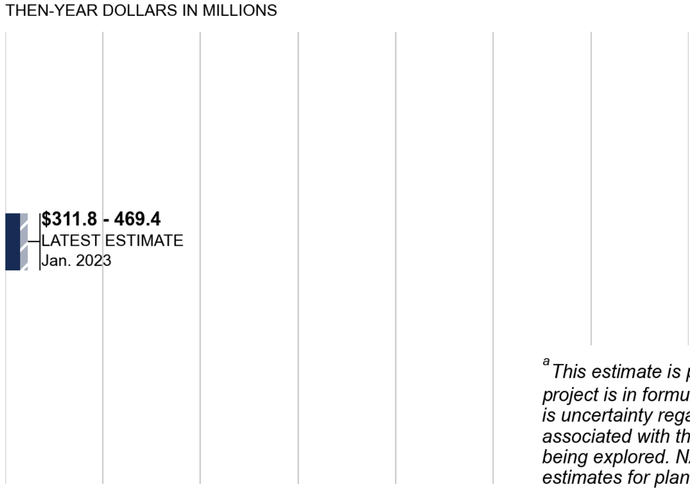
EPFD does not apply NASA's best practice of technology readiness level 6 by PDR due to its status as a technology demonstration. One of its objectives is for both industry partners to demonstrate technology maturity through ground and flight demonstrations for their individual integrated powertrain systems at the project's conclusion.

Preliminary Schedule – Under Review



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 expects to stay within its preliminary cost range but not within its preliminary schedule range when it establishes cost and schedule baselines at KDP C in summer 2023. The project set its preliminary schedule estimates in November 2020 for first flights between December 2023 and August 2024. It now expects first flights to occur about 10 months later, between October 2024 and June 2025. According to project documentation, the project's industry partners will attempt to achieve first flight by September 2025.

The project has experienced delays that are due, in part, to supply chain and workforce availability issues caused by COVID-19. The project and its two industry partners are tracking risks that a constrained supply base for critical components could further affect the project's schedule due to COVID-19, the technical complexity of these unique parts, and raw material shortages, among other reasons. Despite these delays, officials said they do not expect to set a cost baseline above $469.4 million, the top of their preliminary cost estimate range, because they are using firm-fixed-price contracts.

NASA is moving forward with two hybrid firm-fixed-price, cost-share contracts with GE and magniX awarded in 2021. The contracts are firm-fixed-price until critical design reviews. NASA and the industry partners will each fund 50 percent of the total contract costs from critical design review through contract closeout, which includes flight demonstration.

GE Aviation. GE's next milestone is its critical design which it plans to hold in 2023, ahead of the project's KDP C.

magniX. magniX's next milestone is its system requirements review (SRR), which it plans to complete in 2023. Project officials said that although magniX has prior experience flying lower power electric propulsion units on existing aircraft, it required additional time to achieve some of its early milestones in part because it needed further time to expand its workforce. In addition, officials noted that magniX experienced challenges awarding a new contract for an aircraft integration subcontractor, which resulted in the award taking 4 months longer than originally planned.

magniX also plans to hold its PDR in 2023, after the project's KDP C, when it sets its baselines. Although NASA's best practices include holding PDR before setting baselines, EPFD project officials said they are comfortable setting baselines earlier if they are informed by a robust SRR and an IBR with a credible schedule and because of the industry partner's prior experience. The IBR process is used to verify technical content and the realism of related performance budgets, resources, and schedules. magniX plans to complete its IBR prior to KDP C.

Technology and Design

Because the EPFD project is categorized as a technology demonstration project, NASA does not apply its best practice of technology readiness level 6 by PDR. EPFD uses technology readiness data to assess the maturity of critical technologies at various points in their life cycles, but has additional flexibilities to determine when it will mature technologies. One of the project's objectives is for both industry partners to demonstrate a technology readiness level 6 through ground and flight demonstrations for their individual integrated powertrain systems at the conclusion of the project.

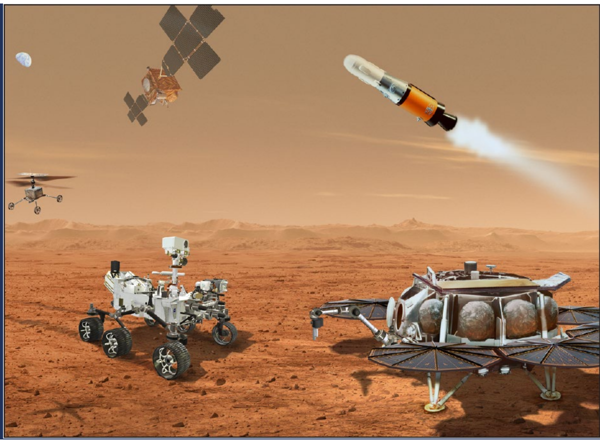
GE Aviation. GE successfully held its PDR in 2022 and is responding to several key action items from the review. During the review, the industry partner provided the project with insight into its system engineering processes, such as plans to reduce risk by iteratively integrating and testing modified components of its hybrid electric powertrain together in increasingly complex configurations. In response to the action items, GE will provide further details into some of its subsystem designs, including its battery system, to better illustrate how it will meet system performance objectives. Additionally, officials said that GE's IBR, currently schedule in 2023 prior to KDP C, should help address another open action item to provide more details on its cost and schedule.

GE is tracking several risks, including a risk that electromagnetic interference from power electronics may interfere with aircraft or propulsion systems operations. To mitigate this risk, the industry partner is pursuing a strategy that includes progressive component, system, and ground testing.

magniX. magniX is conducting studies to support system trades and risk reduction ahead of its system requirements review. The industry partner is performing scans of its chosen engine casing, which will then be used to support ongoing trade studies related to engine configuration, battery placement location, and energy storage selection. Officials said that as part of this effort, magniX is also determining if it can meet mission goals at a lower cost and quicker by incorporating some of the existing aircraft engines into its designs instead of upgrading to larger engines as originally planned. Using existing engines would mitigate a risk that incorporating larger engines would require modification of the existing aircraft systems.

Project Office Comments

In commenting on a draft of this project assessment, EPFD officials agreed with the findings. They also provided technical comments on a draft of this assessment, which were incorporated as appropriate.



Source: Cal Tech / NASA Jet Propulsion Laboratory. | GAO-23-106021

Mars Sample Return (MSR)

The MSR program is a joint endeavor between NASA and the European Space Agency (ESA). It will collect Martian samples gathered by the Mars Perseverance Rover and bring them safely back to Earth for study and analysis. NASA contributions include the Sample Retrieval Lander, the Mars Ascent Vehicle, and the sample Capture Containment and Return System. ESA contributions include the Earth Return Orbiter and Sample Transfer Arm (see illustration on next page for other NASA and ESA contributions). This mission will include the first launch from the surface of another planet and the first international, interplanetary relay effort.

Project Information

NASA Lead Mission Directorate: **Science**

NASA Lead Center: **Jet Propulsion Laboratory**

International Partners: **European Space Agency**

Launch Location: **Eastern Range, Florida (Sample Retrieval Lander) and French Guiana (Earth Return Orbiter)**

Launch Vehicle: **TBD**

Mission Duration: **5 years**

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

Next Major Project Event: **Preliminary Design Review (late 2023)**

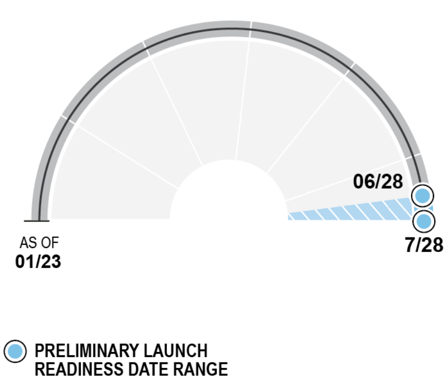
Current Status

In September 2022, the MSR program entered the preliminary design and technology completion phase with a preliminary cost estimate range of $5.9 billion to $6.2 billion and a launch readiness date range for the Sample Retrieval Lander of June to July 2028. The preliminary costs include NASA-managed or NASA-contributed elements. As part of the review to enter this phase, NASA determined that a 2026 preliminary launch readiness date was no longer feasible, and would use the later 2028 date to reduce technical and schedule risks to the program.

The program changed its architecture from a dual lander approach to one that uses Perseverance—a rover currently collecting samples on Mars—as the primary means for sample delivery. Early in the concept and technology development phase, the program identified significant mass and volume issues, which required it to consider alternative mission architectures. The dual lander architecture would have included a lander containing the Mars Ascent Vehicle—a rocket that will transport the samples into Martian orbit—as well as a second lander containing a sample fetch rover. The program determined that using Perseverance rather than a second rover for sample recovery reduced mass and the complexity of the mission. The program plans to include one or more helicopters to augment the sample recovery capability. As part of the Perseverance mission, the proposed helicopter technology has been successfully demonstrated in the Martian environment.

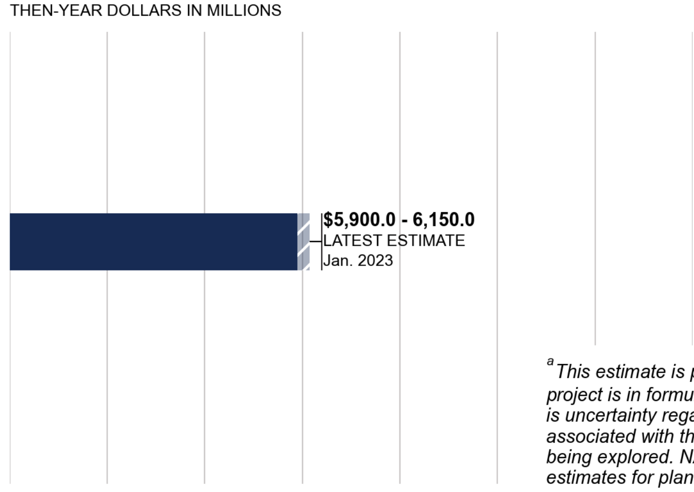
The program is working toward holding its preliminary design review and key decision point C in late 2023, at which point the program will establish its cost and schedule baselines.

Preliminary Schedule



Preliminary Cost[a]

THEN-YEAR DOLLARS IN MILLIONS

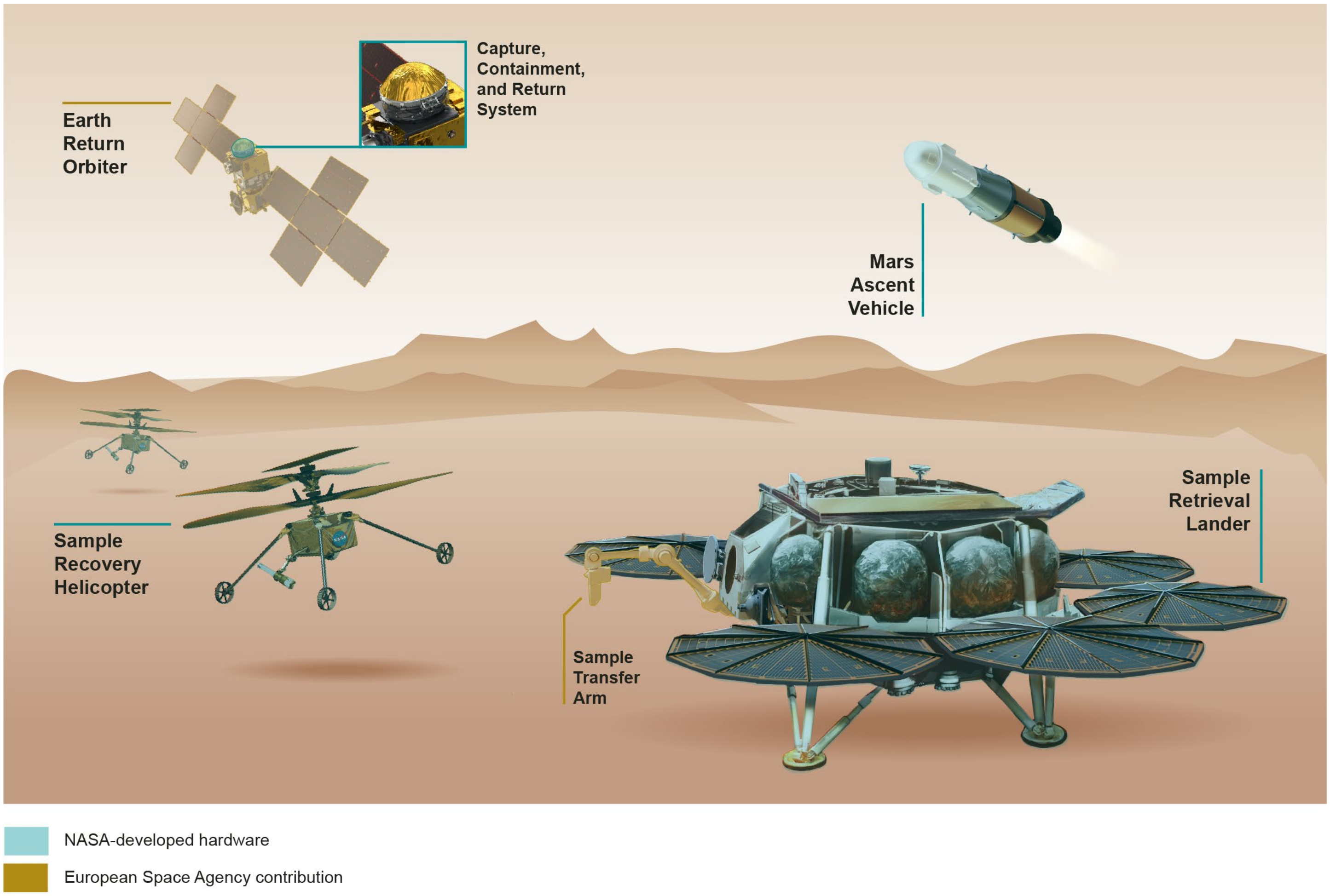


[a] *This estimate is preliminary as the project is in formulation, and there is uncertainty regarding the costs associated with the design options being explored. NASA uses these estimates for planning purposes.*

MSR Mission Architecture

The MSR program consists of two major components—a Sample Retrieval Lander and the Earth Return Orbiter. NASA will use Perserverence—a rover currently collecting samples on Mars—to deliver the samples it acquires to NASA's Sample Retrieval Lander. After Perserverence delivers the samples to the lander, the ESA-contributed Sample Transfer Arm on the lander will transfer the samples to the Mars Ascent Vechicle, which will launch the samples into Martian orbit. NASA also plans to stow one or more Sample Recovery Helicopters on the lander, which will supplement the sample retrieval capabilities of Perseverence and serve as a backup in the event of a catastrophic failure of Perseverence. Once the samples are in orbit, the ESA-contributed Earth Return Orbiter—which includes the NASA-developed Capture, Containment, and Return System—will capture, contain, and safely store the samples for transit of the samples to Earth.

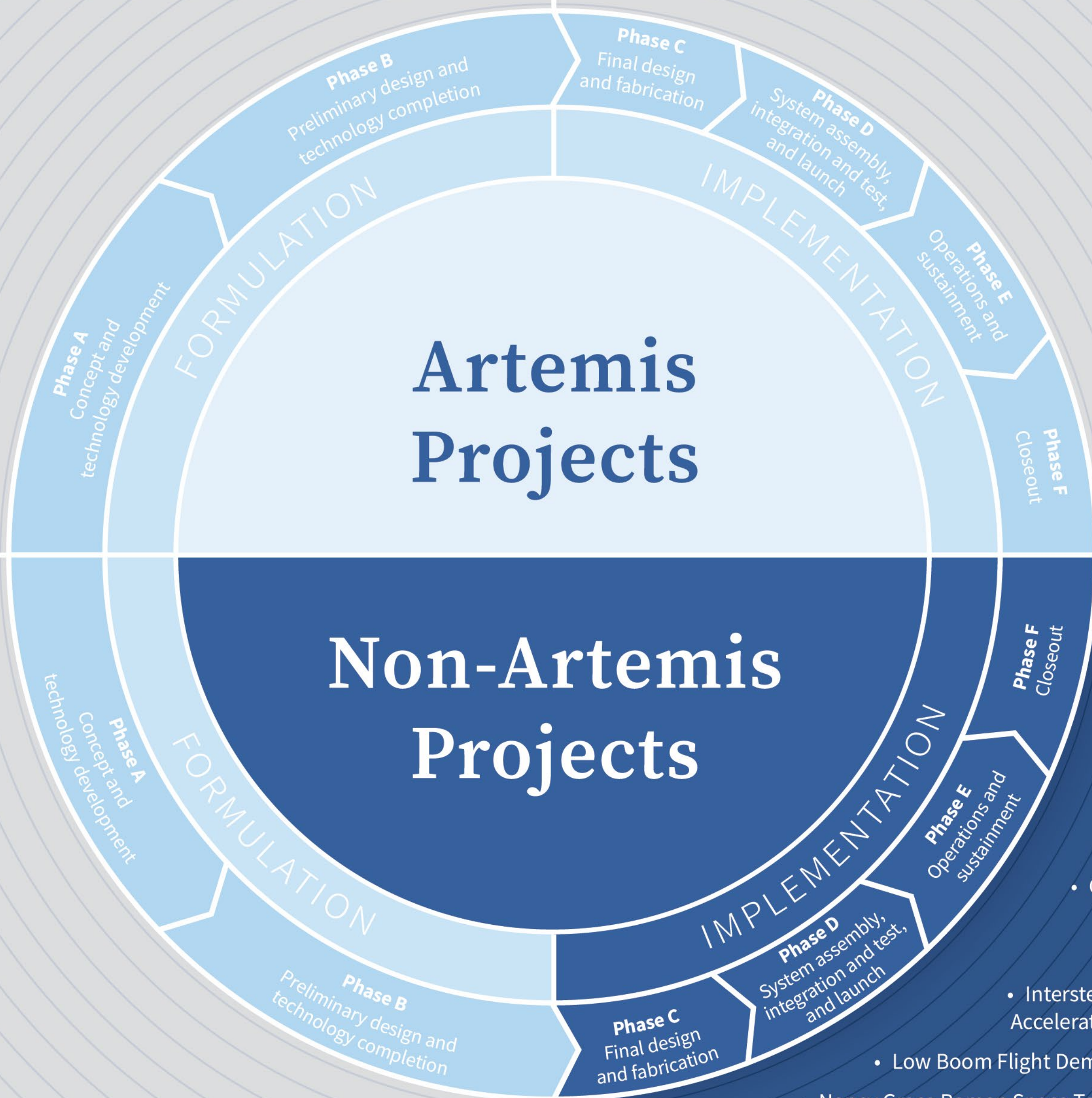
Illustration of the MSR Program Architecture



Source: GAO analysis of MSR project documentation (data); National Aeronautics and Space Administration Jet Propulsion Laboratory (images); GAO (image background). | GAO-23-106021

Project Office Comments

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



- Commercial Crew Program **(CCP)**
- Europa Clipper
- Interstellar Mapping and Acceleration Probe **(IMAP)**
- Low Boom Flight Demonstrator **(LBFD)**
- Nancy Grace Roman Space Telescope **(Roman)**
- NASA Indian Space Research Organisation - Synthetic Aperture Radar **(NISAR)**
- Near Earth Object Surveyor **(NEO Surveyor)**
- On-Orbit Servicing, Assembly, and Manufacturing 1 **(OSAM-1)**
- Plankton, Aerosol, Cloud, ocean Ecosystem **(PACE)**
- Psyche
- Spectro-Photometer for the History of the Universe, Epoch of Re-ionization and Ices Explorer **(SPHEREx)**

Source: GAO analysis of NASA data. | GAO-23-106021

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Commercial Crew Program (CCP)

CCP oversees the development of crew transportation systems by commercial companies to carry NASA astronauts to and from the International Space Station (ISS). In earlier phases of the program, CCP provided technical support or funding to eight companies to develop and demonstrate crew transportation capabilities. In the current phase, the program is working with Boeing and SpaceX to design, develop, test, and operate crew transportation systems. NASA must certify that these crew transportation systems meet its standards for human spaceflight before the companies can fly crewed missions to and from the ISS. NASA certified SpaceX in November 2020.

Source: Produced by KIAC with spacecraft imagery provided by Boeing and SpaceX. | GAO-23-106021

Timeline

Project Information

NASA Lead Mission Directorate: **Space Operations**

NASA Lead Center: **Kennedy Space Center**

Commercial Partners: **Boeing and SpaceX**

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

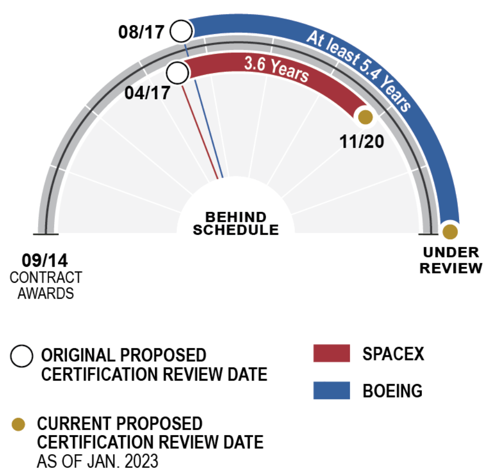
Launch Vehicle: **Boeing - Atlas V; SpaceX – Falcon 9**

Requirement Derived from: **NASA Strategic Plan**

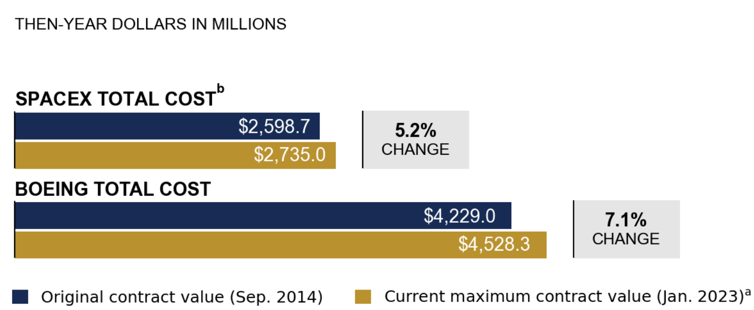
Project Summary

CCP and Boeing continue to progress toward certifying Boeing's crew transportation system to transport crew to and from the ISS. Boeing completed its second uncrewed flight test in May 2022. The dates of Boeing's certification review—which has been delayed over 5 years—and the first post-certification, or service, mission are under review. CCP officials said that the timing of these two events will be driven by multiple factors, including time needed to address any issues from the crewed flight test and ISS availability. Boeing's schedule for the crewed flight test is driven by certification work that must be complete before the test. Boeing and CCP have also taken steps to reduce risks associated with the flight software, which previously contributed to Boeing's spacecraft failing to reach orbit during the first uncrewed flight test. CCP continues to rely on SpaceX to provide uninterrupted access to the ISS; CCP reported that it awarded SpaceX five additional service missions.

Schedule Performance



Cost Performance[a]



[a] *As reported by NASA as of January 2023 and includes contract cost for development, operations, and special studies*

[b] *SpaceX completed development and began post-certification missions to the ISS in November 2020*

Cost and Schedule Status

CCP and Boeing continue to progress toward certifying Boeing's crew transportation system to transport crew to and from the ISS. Boeing completed its second uncrewed flight test in May 2022 and, as of January 2023, was working toward a crewed flight test in April 2023. The test has since slipped to July 2023. The dates of Boeing's certification review—which has been delayed at least 5 years—and the first service mission are under review. CCP officials said that the timing of these two events will be driven by multiple factors, including time needed to address any issues from the crewed flight test, to review new aspects of Boeing's system that will be flown on the first service mission, such as new space suits, and ISS availability.

CCP's planned timing of the first Boeing service mission was one of the CCP Chief Safety Officer's concerns to NASA's Aerospace Safety and Advisory Panel (ASAP). Specifically, the Chief Safety Officer noted that schedule pressure was driving Boeing and CCP to accept increased risk. CCP officials explained that this concern was due to the amount of remaining certification work and the planned 6-10 months between the crewed flight test and first service mission. To mitigate this concern, CCP officials said CCP and Boeing are holding recurring meetings to discuss certification issues to manage the CCP Chief Safety Officer's concern to an acceptable level of risk.

Integration and Test

Boeing's schedule for the crewed flight test is driven by certification work that must be complete before the test. As of December 2022, Boeing has approximately 4 weeks of schedule margin for the crewed flight test and both CCP and Boeing officials expressed concerns about each other's ability to complete the remaining certification products for the crewed flight test. Both parties were particularly concerned about the remaining work to certify the parachute system, which allows Boeing's spacecraft to safely land on the ground. Boeing's project manager said the certification work for the parachute system was extensive. According to NASA documentation, certification approval of the parachute system was deferred from the uncrewed test flights to crewed flight test due to differences in the types of information needed to meet requirements. In March 2023, Boeing officials said they completed the majority of the parachute certification work.

CCP and Boeing have made process improvements in preparation for the crewed flight test and in light of the software issues that contributed to Boeing's spacecraft failing to reach orbit during the first uncrewed flight test. Boeing and CCP completed 12 mitigations to reduce a risk that flight software errors have not been effectively detected and removed. For example, Boeing executed a new high-fidelity, end-to-end validation test for the second uncrewed flight test and CCP increased staff dedicated to reviewing software. As a result, CCP accepted a risk about Boeing's software workmanship under the condition that there continues to be effective software testing and verification. Further, CCP developed a series of stress tests to examine how Boeing's software performs under operational failure scenarios. These stress tests resulted in significant learning for CCP and Boeing.

However, CCP and Boeing have work remaining with the flight software. For example:

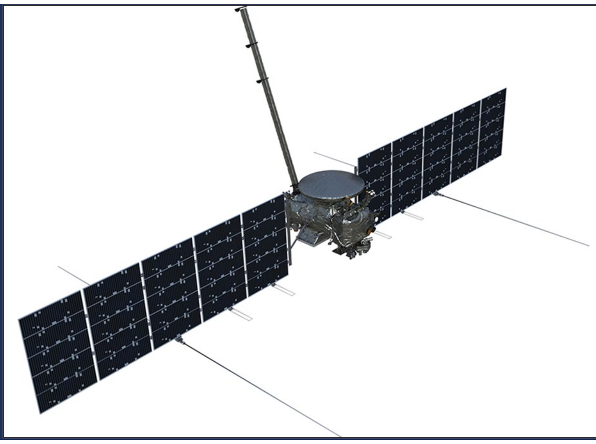
- Boeing's project manager said the company was updating its flight software to include lessons learned from the second uncrewed flight test, known issues that were deferred until the crewed flight test, and issues discovered during the software stress tests. For example, Boeing made software updates so that the software does not turn off functioning reaction control system thrusters.
- Boeing's crew displays reboot randomly due to unknown causes. In October 2022, CCP reported to ASAP that the flight operations directorate and crew would not agree to proceed with the crewed flight test due to this issue. However, in December 2022, CCP reported that it planned to accept this risk and Boeing's project manager told us that the crewed flight test astronauts were involved in developing the flight rationale for flying the spacecraft as-is and accepting this risk. CCP's program manager said they accepted this risk because the chance of the crew displays failing is low and Boeing intends to continue testing the crew displays in its software integration lab. Since implementing all of the software mitigations and running over 10 million iterations, no reboots have occurred. If a cause is identified, Boeing and CCP plan to determine whether to fly with a new mitigation or fly as-is with the accepted flight rationale.

Other Issues to Be Monitored

CCP continues to rely on SpaceX to provide uninterrupted access to the ISS. The CCP program manager said the program did not identify additional providers that could transport crew. CCP reported that it awarded SpaceX five additional service missions to the ISS; in total, SpaceX is expected to provide 14 service missions. CCP is monitoring SpaceX's non-CCP ground and launch operations at Kennedy Space Center to ensure that SpaceX can continue to support crew launches to the ISS.

Project Office Comments

CCP program officials provided technical comments on a draft of this assessment, which were incorporated as appropriate. Boeing officials told us that, as of March 2023, the company had completed all of its certification products, including for the parachute system, and the products were being reviewed by NASA.



Source: NASA/ Jet Propulsion Laboratory-California Institute of Technology. | GAO-23-106021

Europa Clipper

The Europa Clipper mission aims to investigate whether Europa—a Jupiter moon—could harbor conditions suitable for life. The project plans to place a spacecraft in orbit around Jupiter and conduct a series of investigatory flybys of Europa. The mission will use its nine instruments to characterize Europa's ice shell and any subsurface water, analyze the composition and chemistry of its surface and atmosphere, and gain an understanding of the formation of its surface features.

Timeline

Formulation
- 06/15 Formulation start
- 01/17 System requirements/ mission definition review
- 08/18 Preliminary design review
- 06/19 Delta preliminary design review
- 08/19 Key decision point C

Implementation
- 12/20 Critical design review
- 11/21 System integration review
- **01/23** GAO review
- **10/24** Latest launch readiness date

Project Information

NASA Lead Mission Directorate: **Science**

NASA Lead Center: **Jet Propulsion Laboratory**

International Partners: **None**

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

Launch Vehicle: **Falcon Heavy**

Mission Duration: **4-year science mission**

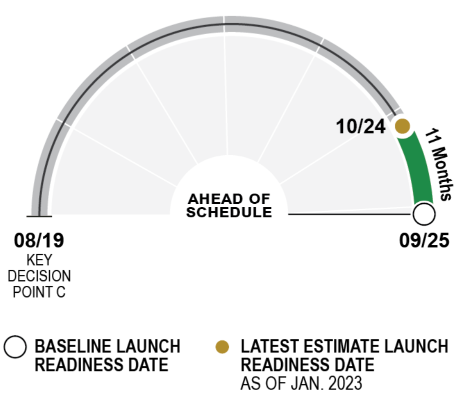
Requirement Derived from: **2011 Planetary Science Decadal Survey**

Project Summary

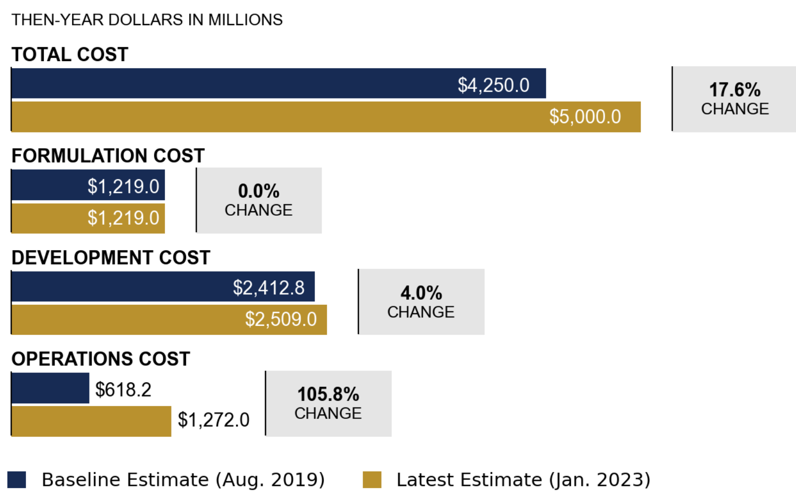
The Europa Clipper project continues to operate within its updated cost and schedule estimates, which NASA finalized in April 2022. The project is tracking a risk to its launch date as a result of staffing shortages at the Jet Propulsion Laboratory (JPL) following the Psyche project's launch delay. The Europa Clipper project undertook several mitigation efforts to preserve schedule, such as descoping an environmental test. However, the project exhausted its options to compress schedule and may have to accept increased cost or risk to accommodate further delays.

Previously, the project planned to close and then reopen a radiation-protected vault that stores many of the spacecraft's and instruments' electronics, which created a risk of damaging the already-integrated hardware. In response to concerns from the project's standing review board, the project is now closing the vault 6 months later. Project officials said this will help the project maintain schedule by accommodating late deliveries without adding significant technical risk. In addition, this will allow the project to reduce the complexity of integration.

Schedule Performance



Cost Performance



Cost and Schedule Status

The Europa Clipper project continues to operate within its updated cost and schedule estimates, which NASA finalized in April 2022. However, cost and schedule remains a concern for the project due to COVID-19 inefficiencies, late hardware deliveries, staffing challenges, and the scope of the remaining work. For example, staff availability limitations at JPL are worsening one of the project's top risks that late deliveries or problems discovered during integration will affect the project's assembly, test, and launch operations (ATLO) schedule. The project has exhausted its options to compress its schedule and may have to accept increased cost or risk to accommodate further delays.

Further, the project is tracking a risk to its launch date as a result of the Psyche project's launch delay. Both the Europa Clipper and Psyche projects are managed out of JPL, which provides workforce and facilities for both projects. The Psyche launch delay resulted in some Psyche project staff being unavailable to transition to other projects at the center, including the Europa Clipper project. As a result, the Europa Clipper project is tracking a risk that it may miss its launch date if it is not able to add necessary staff.

If the project misses its October 2024 launch date, then the project's next launch opportunity is in October 2025, which has a slightly longer cruise time. As a result, Europa Clipper would not reach Jupiter's orbit until July 2031, 5.8 years after the 2025 launch opportunity, instead of April 2030, 5.5 years after the 2024 launch opportunity.

Integration and Test

The project has taken various steps to improve the ATLO schedule such as descoping an environmental test, changing the flow of activities, and adding staff to support second shift work starting in January 2023. For example, the project descoped one of two thermal vacuum tests in order to mitigate potential delays. Project officials said all the objectives could be met in a single test.

In response to concerns raised by the project's standing review board and to preserve the ATLO schedule, the project delayed the closure of the radiation-protected vault that stores many of the spacecraft's and instruments' sensitive electronics. Previously, the project was concerned that the timing of the vault closure would require the project to reopen the vault later in the ATLO process when late hardware was delivered. This plan posed a risk of damaging the already-integrated hardware. The project is now closing the vault 6 months later than originally planned. Project officials said that this will help the project maintain schedule by accommodating late deliveries without adding significant technical risk.

In addition to the delayed vault closure, the project plans to delay stacking the spacecraft by 5 months to accommodate late hardware deliveries. The project previously planned to close the vault and stack the spacecraft earlier, which project officials said allowed for an earlier system-level test of electromagnetic compatibility in the stacked position. However, with the delayed vault closure and stacking, project officials said the project will test electromagnetic compatibility at the system level later, leaving less time for the project to address any potential issues. According to officials, remaining in the unstacked configuration longer reduces the complexity of remaining work because the stacked position would require scaffolding to continue integration.

During the system integration review in November 2021, the project's standing review board recommended the addition of two status update meetings to help address the project's risks. The first meeting was in May 2022 and focused on the status of issues raised at the system integration review, such as concerns about the integration and closure of the vault. The review board found that the project made noteworthy progress in addressing these issues. The second update is planned for February 2023 and will focus on programmatic performance in addition to any other technical issues.

Project Office Comments

In commenting on a draft of this assessment, Europa Clipper project officials stated that they continue to actively manage hardware deliveries and identify schedule flexibilities to maintain the appropriate risk balance as the project proceeds through the system assembly, integration, test, and launch phase. The officials did not provide any technical comments.

Interstellar Mapping and Acceleration Probe (IMAP)

IMAP is a spinning spacecraft that will help researchers better understand the boundary where the heliosphere collides with interstellar medium, or material from the rest of the galaxy. The heliosphere is the bubble created by the solar wind—a constant flow of particles from our sun—and the 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 Earth, where it will collect and analyze particles that make it through the boundary.

Source: IMAP Mission, Princeton University, Johns Hopkins University/Applied Physics Laboratory. | GAO-23-106021

Timeline

Formulation
- 05/18 Formulation start
- 12/19 System requirements/ mission definition review
- 05/21 Preliminary design review
- 07/21 Key decision point C

Implementation
- 01/23 GAO review
- 01/23 Critical design review
- 07/23 System integration review
- 12/25 Latest launch readiness date

Project Information

NASA Lead Mission Directorate: **Science**

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

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

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

Launch Vehicle: **Falcon 9**

Mission Duration: **2 years**

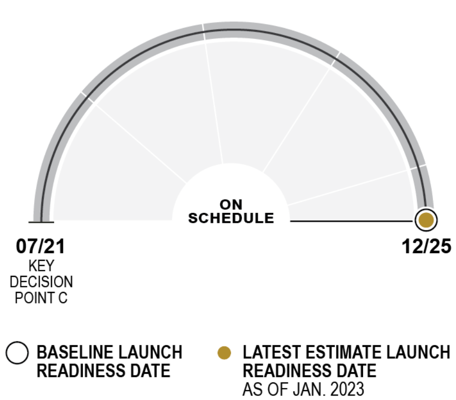
Requirement Derived from: **2013 Heliophysics Decadal Survey**

Project Summary

The IMAP project is operating within its cost and schedule baselines, which NASA established in July 2021. The project is using schedule reserves to cover ongoing delays with the spacecraft's primary structure, such as the structure's radial panels. Program officials said they received the redesigned spacecraft panels from the vendor in January 2023 and completed primary structure assembly. However, the project continues to track schedule risks related to its primary structure and propulsion system integration schedule, which if are not mitigated, could lead to a launch readiness date slip.

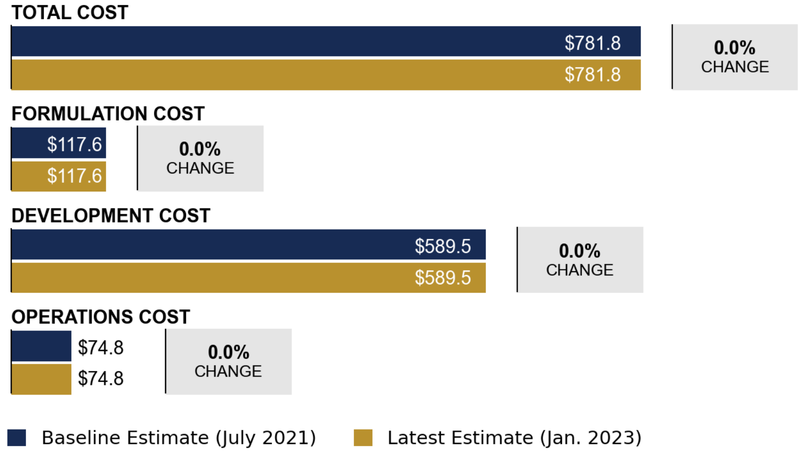
The project held its critical design review in January 2023 after a 6-month delay to allow additional time to mitigate issues with various instruments and subsystems, including the Compact Dual Ion Composition Experiment (CoDICE) and IMAP-Lo instruments. The project is also tracking several risks related to the launch vehicle and the project's secondary payloads, including concerns related to the contamination of IMAP's instruments. The project is working with the launch vehicle contractor to design the launch vehicle encapsulation process and ground operations to mitigate the risk of potential contamination.

Schedule Performance



Cost Performance

THEN-YEAR DOLLARS IN MILLIONS



Cost and Schedule Status

The IMAP project is operating within the cost and schedule baselines that NASA established in July 2021. The project continues to use schedule reserves to cover ongoing delivery delays with the spacecraft's primary structure. For example, the project recently redesigned the structure's radial panels after discovering that clips on the panels did not meet strength requirements. In addition, a project official said that the structure contractor had experienced delays due to machining issues and delivery lead times on certain parts.

According to program officials, they received the redesigned spacecraft panels from the vendor in January 2023, and completed primary structure assembly. The assembled structure is expected to be delivered to the contractor responsible for the propulsion system integration in March 2023 after modal testing is complete. Officials said they are negotiating a shorter integration period for the propulsion system with the contractor to save schedule. However, the project is tracking a risk that delivery of the structure could be further delayed and a separate risk that the propulsion system contractor may not be able to compress the schedule to accommodate the later delivery, which could lead to a launch readiness date slip.

Technology and Design

The project held its critical design review in January 2023 after a delay of about 6 months to complete design work on several instruments and subsystems. For example, the CoDICE instrument received a partial pass at its instrument critical design review in August 2022. The project held a follow-up review for CoDICE in December 2022 to assess the test results of the instrument's engineering model and ensure that concerns about the instrument's sensors were fully addressed. The project is tracking a risk that redesigns may be necessary if the project cannot address these issues. Two of the project's instruments will hold follow-up critical design reviews in spring 2023 due to outstanding action items from the initial review. The project expects to release 90 percent of its design drawings—our best practice to lower the risk of design changes that can lead to cost and schedule growth—by May 2023.

Staffing, organizational, and technical challenges with IMAP-Lo and its pivot platform delayed the instrument critical design review by about 2 months. For example, the locking mechanism malfunctioned during vibration testing. The project implemented design changes and is also assessing a different type of hard lock mechanism as a contingency. However, IMAP's schedule is at risk if the locking mechanism needs further design changes. In addition, due to IMAP-Lo's complexity, there is a risk that additional time or personnel may be needed to deliver the full system. If realized, this will increase the project's costs and also delay the delivery of IMAP-Lo to integration and testing, which could further strain the project's schedule.

Launch Vehicle

The project has several risks related to the Falcon 9 launch vehicle, including risks that Falcon 9 cannot meet IMAP's separation and environmental requirements. For example IMAP may need to use more fuel—which could shorten the life of the mission—if Falcon 9 cannot meet the separation requirements, which relate to how the launch vehicle releases the spacecraft after launch. The IMAP spacecraft uses a spinning motion to stabilize its orbit. However, the Falcon 9 has never attempted a separation from a spinning spacecraft.

In addition, the project is tracking a risk regarding the need for IMAP personnel to maintain access to the instruments to mitigate potential contamination concerns while inside the launch vehicle fairing, which is the nose cone of the rocket used to protect the payload during launch. According to project officials, Falcon 9 processing occurs in a horizontal rather than a vertical position, which creates unique concerns related to airflow and potential contamination of IMAP's instruments. The project is working with SpaceX to design the launch vehicle encapsulation process and ground operations to mitigate these concerns.

Other Issues to Be Monitored

The project is tracking two risks related to its secondary payloads. First, if the payloads require too much of the Deep Space Network's time during early post launch operations, then IMAP might not have sufficient dedicated access to the network to complete initial trajectory correction maneuvers, which could affect mission success. IMAP requires continuous contact with the Network in the first week after launch to prepare for the trajectory correction maneuvers and commission the spacecraft. The project created a working group to better understand IMAP's Network needs, particularly in the first 2 days after launch.

The other risk is that potential contamination from the secondary payloads could negatively affect IMAP's mission performance. According to a project official, two of the four secondary payloads were removed from the IMAP launch due to scheduling issues, which alleviated some of the secondary payload-related risks. However, the official stated that the project intends to keep the contamination risk open until the two remaining payloads are delivered.

Project Office Comments

In commenting on a draft of this assessment, IMAP project officials said that they are considering delaying system integration review from July to October 2023 after receiving an advisory from the project's standing review board. The officials also provided technical comments, which were incorporated as appropriate.

Low Boom Flight Demonstrator (LBFD)

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 eventual commercial use in overland 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 the aircraft transfer review, the project plans to transfer the flight demonstration aircraft to NASA's Commercial Supersonic Technology project and the Flight Demonstration and Capability project. This will provide an opportunity to gather community responses to the flights and create a database to support development of international noise standards for supersonic flight.

Source: NASA. | GAO-23-106021

Timeline

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** Key decision point C

Implementation
- **09/19** Critical design review
- **01/23** GAO review
- **Under review** Latest first flight date
- **Under review** Systems acceptance review
- **Under review** Aircraft transfer review

Project Information

NASA Lead Mission Directorate: **Aeronautics Research**

NASA Lead Center: **Virtual project office**

International Partners: **None**

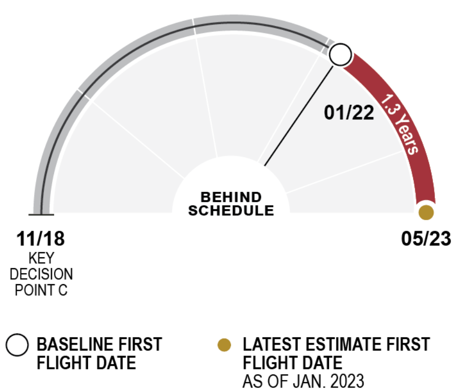
Requirement Derived from: **Aeronautics Research Mission Directorate Strategic Implementation Plan**

Project Summary

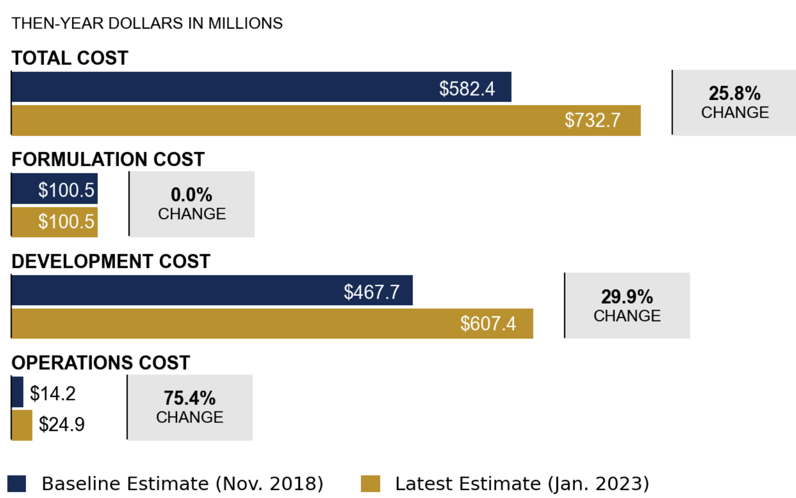
The LBFD project increased its life-cycle costs by $35.7 million and delayed its first flight date by at least 5 months beyond the December 2021 replan. NASA reported the additional funds were needed to address ongoing performance issues at Lockheed Martin, the contractor responsible for building the aircraft. According to project officials, additional delays beyond the 5 months are expected as these issues persist. NASA also reported that Lockheed Martin agreed to complete some work using its own investment funds. The project is at risk of a rebaseline if development costs continue to grow.

The project's integration and testing schedule continues to deteriorate as a result of more deferred work than expected, workmanship quality issues, and necessary rework. For example, the scope of the work deferred before ground testing in Fort Worth was larger than anticipated. According to the contractor, the nature of building a one-of-a-kind aircraft has also contributed significantly to delays.

Schedule Performance – Under Review



Cost Performance



Cost and Schedule Status

The LBFD project increased its life-cycle costs by $35.7 million and delayed its first flight date by at least 5 months beyond the project's December 2021 replan. According to NASA documentation, NASA reported providing these additional funds to mitigate ongoing contractor performance issues at Lockheed Martin, which is responsible for building the aircraft, and to cover potential future issues. With 29.9 percent development cost growth, the project is now close to a rebaseline, which is triggered by 30 percent development cost growth.

NASA reported that Lockheed Martin agreed to complete some work associated with the first flight delay using its own investment funds. According to NASA documentation, Lockheed Martin will need to absorb costs in order for NASA to avoid a rebaseline.

The latest cost increase was intended to support a May 2023 first flight date, but this date is under review. The project estimates that the first flight date will slip at least another 2 months. According to NASA documentation, poor contractor performance led to ongoing schedule delays because of the large amounts of deferred work, discoveries during integration and testing, and resulting rework. According to NASA, Lockheed Martin's issues are caused by ongoing workforce challenges, such as inexperienced staff and insufficient staffing levels throughout the project's development. The project office attributed the rework during integration largely to decisions inexperienced staff made earlier in the design phase. Lockheed Martin officials said their issues were primarily due to industry-wide workforce challenges related to the availability of experienced staff. According to contractor officials, they also received more work than expected at the time the LBFD project began, which resulted in large demand on the workforce.

In addition, the project's schedule is at further risk because Lockheed Martin did not include some aircraft simulations as part of its testing plan. Project officials felt strongly that the additional tests were necessary. The project is tracking a risk of system failure if the simulations are not conducted to verify the project's models. According to NASA and contractor officials, NASA modified the contract to require the tests, but they are not yet included in the current schedule. NASA officials said this will likely cause further delays.

Integration and Test

Delays during integration and testing were the result of decisions to defer some work in favor of short-term progress in other areas. For example, the LBFD project deferred work in late 2021 in order to ship the aircraft to Fort Worth, Texas for ground system testing before the end of the year. The project and Lockheed Martin used the time the aircraft was in Texas to plan out the deferred work. However, the scope of the deferred work was larger than originally anticipated, leading to further delays.

In addition, the project experienced other delays during integration and testing due to rework that resulted from workmanship quality issues. For example, Lockheed Martin added staff to support wiring the aircraft, which was critical to maintaining the schedule. However, project officials said the schedule was not maintained because a number of the wires were too short and were unable to reach the desired location when routed through the aircraft. As a result, project officials said that Lockheed Martin had to replace the short wires on the aircraft.

Contractor officials also said the nature of building a one-of-a-kind aircraft, such as having a more limited stock of parts, significantly contributed to schedule delays. According to Lockheed Martin, the learning curve when building a single one-off aircraft does not provide a schedule benefit because only one aircraft is produced. When multiple aircraft are manufactured then there may be efficiencies gained as a result of discoveries and corrections made earlier in the process. In addition, there is no other aircraft in production from which to borrow parts, so officials said parts issues are more likely to affect cost and schedule.

Other Issues to Be Monitored

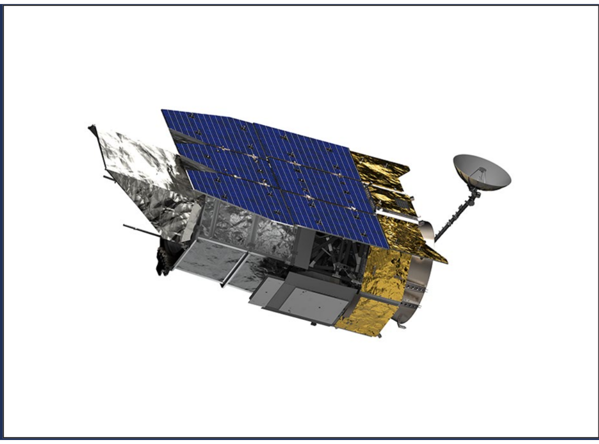
The LBFD project is one of three projects in the Quesst mission. The mission has two goals: (1) develop an aircraft with technology to reduce the loudness of a sonic boom, and (2) fly the aircraft over five communities and gather data on public response to the noise. The LBFD project is responsible for the first phase of the mission and the remaining two projects will conduct the work on community responses.

The results from this mission will support the Committee on Aviation Environmental Protection, an international group that meets every 3 years. If LBFD's first flight date slips past July 2023, then the Quesst mission may not be able to support the committee's meeting with five community tests as planned.

The other two projects in the Quesst mission adjusted their schedules to accommodate the first flight slip to May 2023 and still achieve full success for the mission. For example, officials said the LBFD project may need to collect early data with a shock sensing probe during initial flight tests to reduce the time needed to validate the aircraft's sonic boom. There is a risk that initial flight tests could take longer than planned, which would further strain the ability of the projects to meet the Quesst mission.

Project Office Comments

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



Source: NASA/Goddard Space Flight Center. | GAO-23-106021

Nancy Grace Roman Space Telescope (Roman)

Roman, formerly known as the Wide-Field Infrared Survey Telescope, is an observatory designed to perform wide-field imaging and survey of the near-infrared sky. The Roman project plans to answer questions about the structure and evolution of the universe and expand our knowledge of planets beyond our solar system. The telescope has a primary mirror that is 2.4 meters in diameter and its primary instrument will have a field of view that is 100 times greater than the Hubble Space Telescope's infrared instrument. The project plans to launch Roman to an orbit about 1 million miles from Earth. The project is also planning a guest observer program that may provide observation time to academic and other institutions.

Timeline

Formulation
- 02/16 Formulation start
- 03/18 System requirements/ mission definition review
- 10/19 Preliminary design review
- 02/20 Key decision point C

Implementation
- 09/21 Critical design review
- 01/23 GAO review
- 06/24 System integration review
- 05/27 Latest launch readiness date

Project Information

NASA Lead Mission Directorate: **Science**

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

International Partners: **European Space Agency, Centre National d'Etudes Spatiales (France), Japan Aerospace Exploration Agency, Max Planck Institute (Germany)**

Launch Location: **Kennedy Space Center / Eastern Range, FL**

Launch Vehicle: **Falcon Heavy**

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

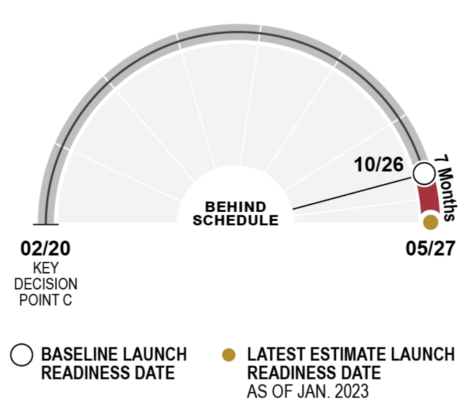
Requirement Derived from: **2010 Astrophysics Decadal Survey**

Project Summary

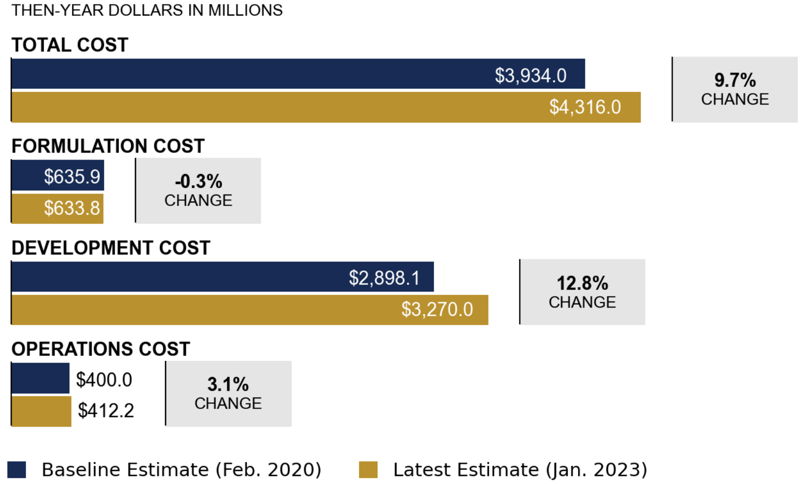
The Roman project continues to operate within its replanned life-cycle cost of $4.3 billion and launch readiness date of May 2027 despite operating at reduced efficiency due to COVID-19 and supplier issues. The project is working to an earlier launch readiness date of October 2026 and experienced a number of issues over the last year that resulted in more than planned consumption of project-held schedule reserve to this earlier date. Hardware delivery schedules were delayed due to contractor workforce retention, COVID-19, supply chain, and other issues. The project replanned its integration and test schedule to mitigate the schedule delays. Despite these delays, the project continues to make progress. For example, the project completed the Primary Mirror Assembly of the Optical Telescope Assembly and successfully completed a strength regression test of a bonding gap.

The Roman Coronagraph Instrument (CGI) also experienced challenges due to COVID-19 and other issues. In August 2022, NASA approved the release of $12.4 million of headquarters-held reserves to the CGI project, but reserves remain low. The project made technical progress on the instrument, but at a slower pace than planned.

Schedule Performance



Cost Performance



Cost and Schedule Status

The Roman project continues to operate within its replanned cost and schedule baselines. In June 2021, NASA approved the replan that set a new life-cycle cost of $4.3 billion, and a launch readiness date of May 2027.

The project is working to an earlier launch readiness date of October 2026 and experienced a number of issues over the last year that resulted in more consumption of project-held schedule reserve than planned to this earlier date. For example, the Optical Telescope Assembly contractor experienced an issue with workforce retention in addition to COVID-19 and supply chain issues, which affected the delivery schedule. To mitigate the schedule reserve issue, the project replanned its integration and test schedule. According to project officials, the revised schedule creates schedule savings and simplifies integration. The officials said, for example, they combined thermal vacuum testing for the spacecraft bus and integrated payload. These changes moved the start of system integration and test earlier and improved project-held funded schedule reserve levels. NASA is also holding additional reserves at the headquarters level that the project could request if needed.

Integration and Test

The project is tracking multiple risks of hardware deliveries due to technical, supplier, and COVID-19 issues, which threaten the project's revised integration and test schedule. For example, the project is continuing to experience delays in the delivery of the instrument carrier due to delays manufacturing its structure. The machining of the carrier's titanium nodes was also more difficult than anticipated and a subcontractor delayed work due to prioritizing other work, among other issues.

Despite the delays, the project continues to make progress building, assembling, and testing key system subcomponents. The contractor responsible for the Wide Field Instrument integrated and aligned components of the element wheel assembly and delivered it to begin assembly integration and test. The contractor responsible for the Optical Telescope Assembly completed the Primary Mirror Assembly and successfully completed a strength regression test of a bond on the assembly after discovering a bonding gap and refilling it.

Coronagraph Instrument

The CGI continues to make progress, but experienced schedule delays due to COVID-19-related issues and technical challenges. CGI is a technology demonstration designed to perform high contrast imaging and spectroscopy of nearby exoplanets. It is managed separately from the Roman observatory, and places no science requirements on Roman. CGI received all of its flight hardware from its domestic vendors and international partners with the exception of the warm radiator, which is being painted and is on schedule.

According to NASA, CGI experienced workforce inefficiencies, late deliveries, and other issues, which resulted in the unexpected use of cost reserves. For example, the continuation of COVID-19 illnesses and associated work restrictions at the Jet Propulsion Laboratory continues to pose challenges to CGI's development. In addition, some of its international contributions did not arrive as planned and CGI expended reserves to address the delayed deliveries.

In August 2022, NASA approved the release of $12.4 million of headquarters-held reserves to the CGI project to replenish its reserves. However, in December 2022, a project official said that technical and other issues resulted in the CGI cost reserves falling to 8 percent, which is below the 20 percent recommended by Jet Propulsion Laboratory Flight Projects standards.

CGI technical progress continues, but slower than planned due to technical issues. The project developed a solution for replacing resistors in the Deformable Mirror (DM) electronics. All of the resistors were screened before installation, but the combination of latent failures that did not appear during screening and technical evaluations indicated that the entire lot of resistors had failed and needed to be replaced. As a result, the CGI project plans to replace all 14,392 resistors with screened automotive grade parts and expects the repaired DM electronics to be delivered by May 2023.

In addition, the focus of the flight DMs drifted to a greater extent than in the past. DMs are used to correct errors in the rest of the optical system and help with starlight suppression. The characterization showed that the flight DMs had focus drift and astigmatism that was larger than expected, but still met requirements with some margin. The CGI project used a third flight DM to verify a solution, which has been incorporated into CGI plans. However, the project is still concerned about the ability to handle unforeseen errors from CGI optics in orbit.

Launch Vehicle

In July 2022, NASA reported that it awarded a contract valued at $255 million to SpaceX to provide launch services for Roman on a Falcon Heavy launch vehicle. The contract value is $16 million more than the project budgeted for the launch vehicle. The project is working with NASA headquarters to release reserves to cover the additional cost and aligning fiscal year funding to match the launch vehicle contract.

Project Office Comments

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

NASA Indian Space Research Organisation (ISRO) – Synthetic Aperture Radar (NISAR)

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 a satellite with the first dual frequency synthetic aperture radar instrument, which includes one radar provided by NASA and one provided by ISRO. The two radars each use a different frequency and will use advanced radar imaging to construct large-scale data sets of Earth's movements. ISRO will also provide NISAR's spacecraft and launch vehicle. NISAR represents the most complex science mission development undertaken jointly by NASA and ISRO.

Source: © 2017 California Institute of Technology/Jet Propulsion Laboratory. | GAO-23-106021

Timeline

Formulation
- **03/14** Formulation start
- **12/14** System requirements/mission definition review
- **06/16** Preliminary design review
- **08/16** Key decision point C

Implementation
- **10/18** Critical design review
- **10/20** System integration review
- **01/23** GAO review
- **10/24** Latest launch readiness date

Project Information

NASA Lead Mission Directorate: **Science**

NASA Lead Center: **Jet Propulsion Laboratory**

International Partners: **Indian Space Research Organisation**

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

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

Mission Duration: **3 years**

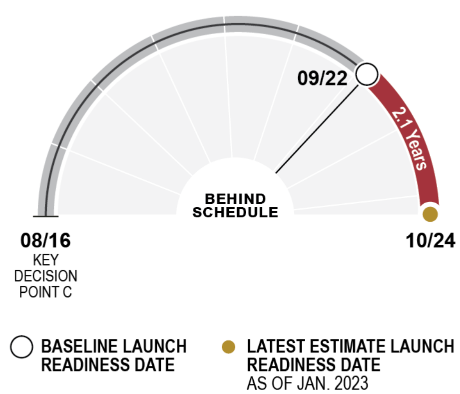
Requirement Derived from: **2007 Earth Science Decadal Survey**

Project Summary

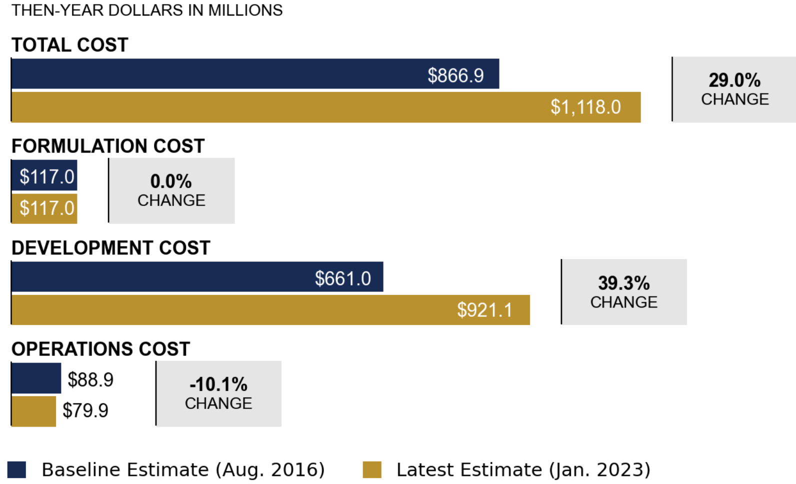
In August 2022, the NISAR project rebaselined its cost and schedule. The project has now exceeded its original cost baseline by 29 percent and delayed its original launch readiness date by over 2 years. The August 2022 rebaseline further increased the project's life-cycle cost by $146.8 million and delayed the project's launch readiness date by 13 months from September 2023 to October 2024. The NISAR project attributed the latest cost increase and schedule delays primarily to technical issues at the Jet Propulsion Laboratory (JPL) and ISRO. Project officials also said that ISRO delays due to COVID-19-related shutdowns in India contributed to the cost increases, among other things.

The NISAR project plans to begin the fourth phase of system-level integration and test in March 2023. During this final phase of integration and test, project staff will be on-site in India to assist with hardware integration onto the ISRO-provided spacecraft and continue NISAR's test campaign. One of the project's top risks is the retention of key technical staff in India. JPL and the project team developed a strategy for backup technical support to help mitigate this risk.

Schedule Performance



Cost Performance



Cost and Schedule Status

In August 2022, NASA approved a rebaseline for the NISAR project, which further increased the project's life-cycle cost by $146.8 million and delayed the project's launch readiness date by 13 months from September 2023 to October 2024. This is the second time in 16 months that the project revised its cost and schedule baselines. NASA also approved a replan of the project's cost and schedule estimates in April 2021. The project's overall cost growth is $251.1 million beyond its original baseline, or 29 percent higher, and the new launch readiness estimate is more than 2 years later than the original launch readiness date of September 2022.

The project attributed the cost growth and schedule delays since the April 2021 replan primarily to technical issues that the project experienced after it integrated the NASA- and ISRO-provided radars. For example, after integration, the ISRO-provided radar experienced electromagnetic interference leading to the need to replace the radar's electronics box. Project officials also said that ISRO delays due to COVID-19-related shutdowns and lengthening the schedule for the final phase of system, integration, and test in India contributed to the cost increases. The project also experienced hardware delivery delays and other technical challenges during the NASA-provided radar testing that resulted in cost growth and schedule delays. Project officials stated that all of the technical issues driving the rebaseline have been resolved or are being mitigated by the project.

Integration and Test

As of January 2023, the NISAR project is in the final stages of System Integration and Test Level 3 (SIT-3). During this phase, the project integrated its two radars and is in the final stage of testing the radars. The project is also integrating and testing other NISAR hardware, such as the boom and reflectors. The build of the ISRO-provided spacecraft is progressing and officials expect it to be complete in January 2023.

The NISAR project is planning to begin its System Integration and Test Level 4 (SIT-4) in India in March 2023. SIT-4 is the phase of the project where all operations will transfer to India. Project officials said that the radars and other hardware, such as the boom and reflectors, will be integrated with the ISRO-provided spacecraft during this phase. Project officials said that they are preparing for the beginning of SIT-4 by coordinating with ISRO on logistics, scheduling, and agreed-upon integration and test processes.

One of the NISAR project's top risks is that if it cannot retain key technical staff throughout SIT-4 in India, then it could experience delays or other problems during system integration and test. According to project officials, NISAR project staff will be traveling between California and India, in about 3-week increments, during the 10.5 months that NISAR will be in SIT-4. JPL and the project team are working on a mitigation plan to have staff backup support ready to step in if a key staff member cannot support SIT-4 for any reason. The plan for backup support consists of four tiers: (1) NISAR staff cross trained in disciplines, (2) ISRO staff, (3) JPL staff from other projects, and (4) Goddard Space Flight Center and contractor support from Europe.

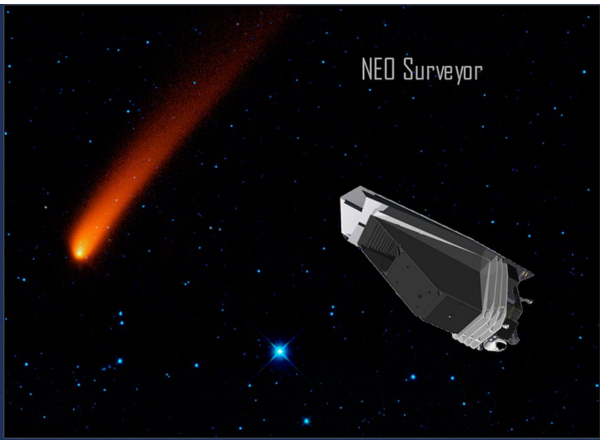
Launch Vehicle

The ISRO-provided launch vehicle—the Geosynchronous Satellite Launch Vehicle Mark II (GSLV)—remains a risk for the project. ISRO and NASA agreed to a set of five criteria that the ISRO-provided launch vehicle must meet before NISAR's launch. The launch vehicle has already met three of the criteria.

During an August 2021 launch, the GSLV upper stage did not ignite and the launch vehicle failed to accomplish its mission. Despite the failure, NASA officials said this mission satisfied a criterion regarding successful deployment of a 4-meter fairing, which is the nose cone of the rocket used to protect the payload during launch. According to project officials, ISRO has one GSLV launch planned for summer 2023 that could satisfy the remaining criteria prior to NISAR's launch. Project officials said that if a successful GSLV upper stage requalification flight does not happen ahead of the planned NISAR launch period, the project's launch readiness date may be delayed beyond October 2024.

Project Office Comments

When commenting on a draft of this assessment, NISAR project officials said that they had completed SIT-3 testing and prepared the payload flight system for the first of two shipments to India, planned for early March 2023. The officials also provided technical comments, which were incorporated as appropriate.



Near Earth Object (NEO) Surveyor

NEO Surveyor is a space-based telescope designed to search for NEOs such as asteroids and comets that are 140 meters or larger in diameter. By accomplishing this survey, the telescope will detect, track, catalog, and characterize NEOs to identify objects that could impact Earth and pose a danger to life and property. The project aims to obtain detailed physical characterization data for individual objects that are likely to pose an impact hazard, and to characterize the entire population of potentially hazardous NEOs to inform mitigation strategies. The NEO Surveyor continues work previously done under the NEO Camera (NEOCam) project.

Source: University of Arizona. | GAO-23-106021

Timeline

Formulation

- 06/20 Formulation start
- 09/20 System requirements/ mission definition review
- 09/22 Preliminary design review
- 12/22 Key decision point C

Implementation

- 01/23 GAO review
- 02/25 Critical design review
- 07/26 System integration review
- 06/28 Latest launch readiness date

Project Information

NASA Lead Mission Directorate: **Science**

NASA Lead Center: **Jet Propulsion Laboratory**

International Partners: **None**

Launch Location: **To be determined**

Launch Vehicle: **To be determined**

Mission Duration: **5 years**

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

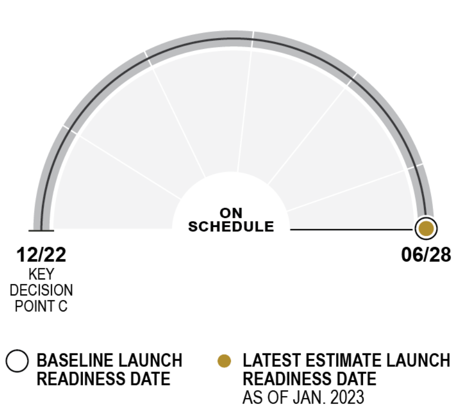
Project Summary

NEO Surveyor entered the implementation phase in December 2022 and established cost and schedule baselines of $1.6 billion and June 2028, respectively. These estimates are $604 million more than the project's preliminary cost estimate and 2 years later than its preliminary schedule estimate. The project attributes this change to NASA constraining the project's budget in prior and future fiscal years.

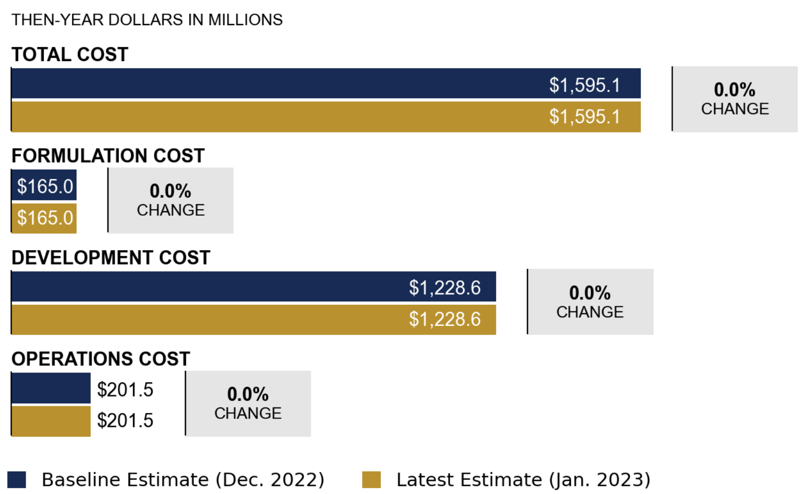
The NEO Surveyor project held its preliminary design review in September 2022 with all critical technologies meeting our best practice of achieving a technology readiness level 6 by this review, which can minimize risk. The project plans to hold its critical design review in February 2025.

The project is facing several challenges in developing, testing, and integrating the observatory. The project has not yet tested NEO Surveyor's triplet design—part of the instrument needed for the telescope—for flight. The project plans to test different cables needed for the design and use the one that tests best. The project is facing delays in detector manufacturing and is carrying a risk regarding the contractor's ability to deliver flight detectors on time.

Schedule Performance



Cost Performance



Cost and Schedule Status

The NEO Surveyor project entered the implementation phase and established its cost and schedule baselines in December 2022. NASA set a baseline life-cycle cost estimate of $1.6 billion and a June 2028 launch readiness date. This is $604 million more than the project's preliminary cost estimate and 2 years later than its preliminary schedule estimate. The project attributes this change to NASA constraining the project's budget in prior and future fiscal years. For example, in August 2022, NASA informed the project that it would only receive $80 million to $90 million for fiscal year 2023 instead of the $170 million in the project's budget plans.

As a result of these budget constraints, the project underwent a replan to match the work to be performed to the available funding prior to entering the implementation phase. Project officials said they changed the timing of the work to be performed, but not the project's scope. Also due to budget constraints, the project will not have any NASA Science Mission Directorate cost reserves in fiscal years 2023 and 2024. However, the project still has project-held reserves that it can use in those fiscal years. One of the project's top concerns that may require the use of these reserves is cost growth resulting from supply chain issues and wage inflation. For example, project officials said that they continue to see cost growth and schedule elongation and expect to see significant increases in labor costs across the project over the next several years.

According to project officials, part of their replan strategy was to reduce risk as much as possible in fiscal year 2023 by deprioritizing lower-risk areas and prioritizing areas with the most technical and schedule risk. For example, the project disbanded the spacecraft team, which the project viewed as an acceptable risk because the spacecraft is based on hardware previously used in space. An official said that they will reconstitute the spacecraft team when funding is available in fiscal year 2024. The project is prioritizing testing instead to reduce risk. For example, the project wants to conduct the external thermal balance test as early as possible to guide decision-making on the integrated instrument. The results of the thermal test will reduce risk because it will allow the project to assess the effectiveness of the passive cooling system.

Technology and Design

The NEO Surveyor project passed its preliminary design review in September 2022, with all three critical technologies meeting our technology maturity best practice of achieving technology readiness level 6 by preliminary design review. Our best practices work has shown that maturing technologies by this review can minimize risks for systems entering product development.

The project is working to resolve a few issues identified during the preliminary design review prior to critical design review, which is planned for February 2025. For example, the project has not yet qualified NEO Surveyor's triplet design (Focal Plane Module + Interconnect Cable + Sensor Chip Electronics)—part of the instrument needed for the telescope—for flight. A project official said that they are working on how to perform the testing. The interconnect cable is segmented and longer than used in previous missions. As a result, the project is looking at building a few types and configurations of cables and plans to use whichever one tests best. The project also has concerns over electromagnetic interference and electromagnetic compatibility issues. The project wants to qualify the cable in a flight-like environment as soon as possible, including at the pre-instrument and instrument levels.

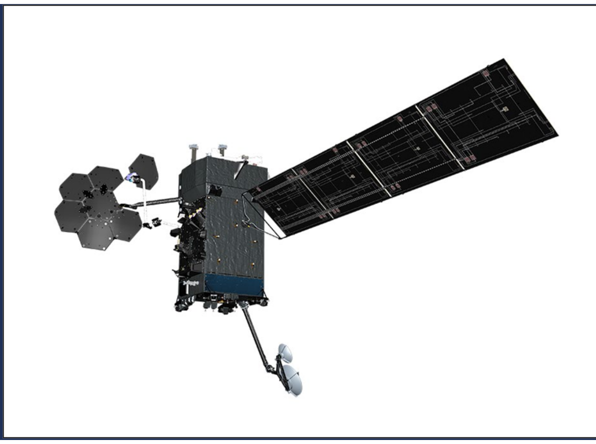
Another issue is the use of molybdenum on a component that is close to the sensors near the detectors. Molybdenum is prone to cosmic ray behavior, which was previously seen in data from the James Webb Space Telescope. According to a project official, the detector may get some radiation hits on the image, which could obscure the target. There is no option to replace molybdenum, but there are ways to mitigate the issue. The project plans to use a data processing technique used by other projects that would remove the effects of the cosmic rays on science data. The project simulated the issue in an image simulator and found that it does not cause any measurable effects on image survey completeness.

The project is facing delays in detector manufacturability and is carrying a risk regarding the contractor's ability to deliver flight detectors by the need date. According to officials, the detectors can be difficult to develop since each lot produced is slightly different. A project official said that the project is evaluating whether it can relax requirements on detectors and still accept them for flight.

The project is also carrying a risk regarding the uncertainty about its launch vehicle, which could affect the project's design. Since the launch vehicle will likely be unknown until fiscal year 2025, the project is at risk of overdesigning in order to accommodate the two plausible launch vehicles. Overdesigning could lead to cost growth and schedule delays. To help mitigate the risk, the project, with input from NASA, completed a coupled loads analysis to look at the dynamic loads for the launch vehicle and payload coupled together. The project is also completing a Launch Services Requirement Document that captures the launch dynamics, thermal, depressurization, and electromagnetic environments.

Project Office Comments

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



Source: Maxar Technologies. | GAO-23-106021

On-Orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1)

The OSAM-1 project plans to demonstrate a capability to autonomously refuel and extend the life of on-orbit satellites. 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. The satellite's operations can be extended if the refueling is successful. The project also plans to use the SPace Infrastructure DExtrous Robot (SPIDER) payload to demonstrate on-orbit assembly and installation of an antenna and manufacturing of a beam. NASA plans to transfer OSAM-1 technologies to commercial entities.

Timeline

Formulation
- 05/16 Formulation start
- 10/16 System requirements/ mission definition review
- 11/17 Preliminary design review
- 06/20 Key decision point C

Implementation
- 02/22 Critical design review
- 01/23 GAO review
- 09/23 System integration review
- 12/26 Latest launch readiness date

Project Information

NASA Lead Mission Directorate: **Space Technology**

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

International Partners: **None**

Launch Location: **To be determined**

Launch Vehicle: **To be determined**

Mission Duration: **12 months**

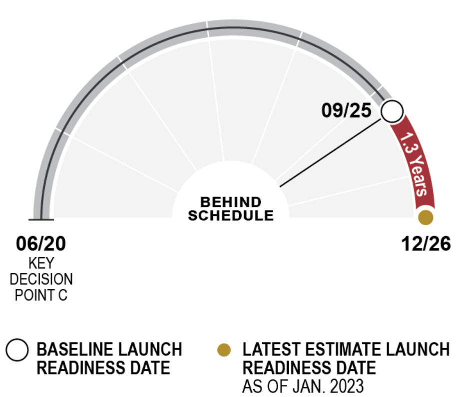
Requirement Derived from: **Consolidated Appropriations Act, 2016**

Project Summary

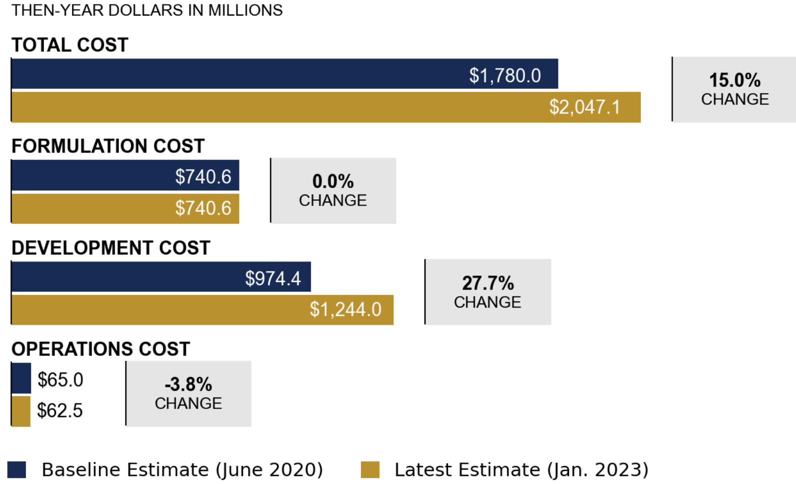
The OSAM-1 project is executing to a new life-cycle cost estimate of about $2.0 billion and launch readiness date of December 2026. In May 2022, the OSAM-1 project rebaselined, adding $267.1 million to its life-cycle costs and delaying the project's launch readiness date by 15 months from September 2025 to December 2026. These changes are due to the effects of the COVID-19 pandemic, several technical and programmatic issues, and scope changes.

The OSAM-1 project is tracking design issues and contractor performance challenges that could result in additional schedule delays. For example, the subcontractor responsible for producing component motors for the servicing payload and SPIDER robot arm systems has had workforce and quality control issues. Additionally, according to project officials, the contractor responsible for developing the spacecraft is behind schedule in building and testing spacecraft flight software. The project is working with the contractors to mitigate these issues.

Schedule Performance



Cost Performance



Cost and Schedule Status

The OSAM-1 project is executing to a new life-cycle cost estimate of about $2.0 billion and launch readiness date of December 2026. The project rebaselined in May 2022, adding $267.1 million in costs and delaying the project's launch readiness date by 15 months. According to the project, over half of the cost growth and most of the schedule delays were due to effects of the COVID-19 pandemic. These effects included on-site work stoppages and restrictions at NASA and contractor sites; supply chain disruptions at five vendors; and increased workmanship errors due to manufacturing backlogs and challenges retaining staff. The most significant delays were to the servicing payload, which will use a robotic arm to attempt to grasp, refuel, and extend the life of Landsat 7. The project could not work on actuators, which help move the robot arm, due to delayed motor parts. The remaining cost growth and schedule delays were due to technical and programmatic issues, and scope changes.

The project evaluated options to descope work or hardware from its baseline if it experiences additional cost growth and schedule delays. Potential descopes include reducing component testing and redundancy, both of which would increase technical risk, and descoping the SPIDER Makersat Payload, which has experienced technical challenges and schedule delays. If NASA descoped the payload, the project would not be able to demonstrate manufacturing of a structurally and thermally stable beam in space, but officials told us this would not affect the project's ability to meet its mission requirement.

Technology and Design

The OSAM-1 project held its critical design review in February 2022, reporting that it released approximately 95 percent of its design drawings at the review. This exceeds our best practice of releasing 90 percent of design drawings by this review to lower the risk of experiencing design changes and subsequent cost growth and schedule delays.

The servicing payload's light detection and ranging (LIDAR) development experienced multiple delays and is a top project issue. The LIDAR uses lasers to determine the range and position between the servicing payload and Landsat 7. The technology required a redesign of its fiber tray, which processes the received laser signals, because the initial tray did not process these signals quickly enough. Post-redesign, the LIDAR team experienced workmanship issues and delays due to work taking longer than expected. The project is identifying more resources to limit future schedule delays.

Contractor Performance

The project continues reporting contractor performance issues with Honeybee Robotics, the subcontractor responsible for developing the motors that are part of the robot arm systems (RAS) for the servicing and SPIDER payloads. These delays have not yet affected the project's overall rebaselined schedule, but are being tracked as schedule risks. Since the rebaseline, Honeybee Robotics delayed delivery of the servicing payload motors several times, using almost 3 months of the project's schedule reserves. Project officials said that all of the motors were damaged during assembly due to a design error, which led to parts rework and delaying the build of the payload robot. As of January 2023, the project reported receiving all but two of the reworked motors. The delivered motors all had issues, but the officials determined they could be used as is because the issues do not affect the technical performance of the RAS.

Motor development delays are also affecting the SPIDER RAS schedule. The system needs motors to move the hand at the end of the SPIDER robot arm, which allows it to grapple antenna elements and torque and de-torque bolts during antenna assembly and disassembly. As of January 2023, the RAS delivery had been delayed by 7 months due to insufficient staffing to support early design and test preparations, supply chain challenges, and other technical issues identified during inspections. To mitigate these issues, the project is providing on-site NASA personnel at Honeybee Robotics for quality assurance and moved integration of the SPIDER RAS to later in the schedule, among other things.

The project has experienced delays to the first servicing payload flight robot system build due to actuator and electronics unit delivery delays. Officials said that the actuator delays are primarily due to Maxar not having enough staff or staff with the right skills to build and test actuators. As a result, the project moved actuator electrical assembly work to Goddard Space Flight Center. Project officials said that in summer 2022, Maxar senior officials agreed to hire four additional staff, but as of January 2023 Maxar filled only one position. Goddard Space Flight Center also identified a failure in its robot electronics engineering test unit that required rework and resulted in schedule delays.

The project assesses that Maxar, which is also responsible for spacecraft development, is behind schedule in building and testing flight software, which could result in delays to spacecraft delivery. The project is tracking a risk that as a result of these delays, the project may identify issues late in testing that could result in rework after the spacecraft is delivered and delay the project's system-level integration and test. Project officials said that OSAM-1 is not Maxar's highest priority program and the contractor has had difficulty hiring and retaining staff. The project is providing flight software and systems engineering support to try to mitigate additional delays.

Project Office Comments

OSAM-1 project officials provided technical comments on a draft of this assessment, which were incorporated as appropriate.

Plankton, Aerosol, Cloud, ocean Ecosystem (PACE)

PACE is a polar-orbiting satellite 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 started under earlier NASA missions, which will enable researchers to study the long-term trends of Earth's oceans and atmosphere, and ocean-atmosphere interactions. PACE will also enable assessments of air and coastal water quality, such as the locations of harmful algae blooms.

Source: NASA. | GAO-23-106021

Timeline

Project Information

NASA Lead Mission Directorate: **Science**

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

International Partners: **Netherlands Space Office**

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

Launch Vehicle: **Falcon 9**

Mission Duration: **3 years**

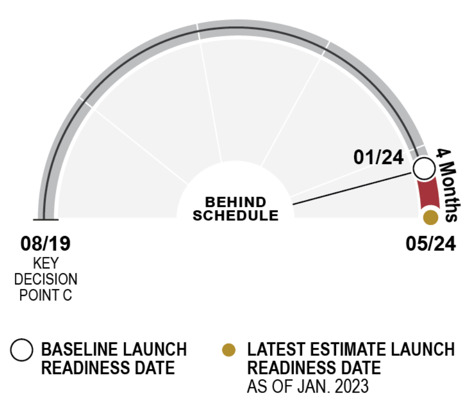
Requirement Derived from: **2007 Earth Science Decadal Survey**

Project Summary

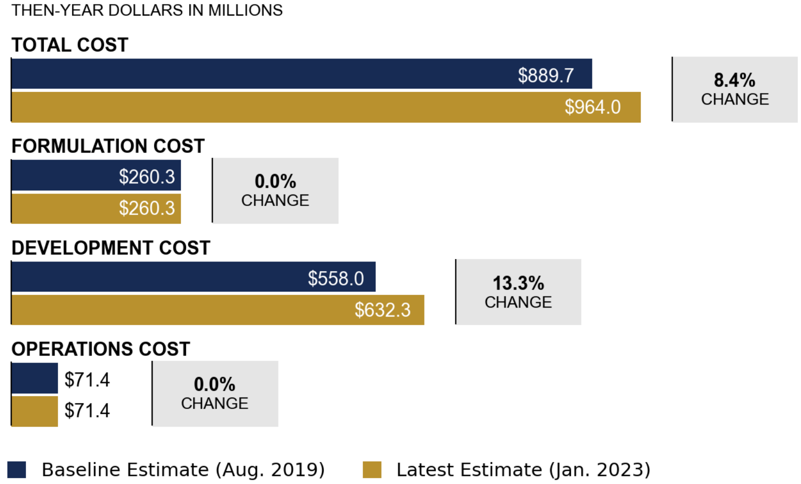
The PACE project is operating within its revised cost and schedule baselines. In November 2022, the project passed its system integration review. The project held the review 3 months later than planned due to the late delivery of the project's primary instrument, the Ocean Color Instrument (OCI). Prior to this review, both of the project's polarimeters were fully integrated into the spacecraft and completed environmental testing.

Since then, the project integrated its instruments with the spacecraft to create the PACE observatory. While the project is progressing through integration and testing, the project has experienced persistent issues with reaction wheel bearings. The bearings are a key part of the reaction wheels, which are used to point the spacecraft in the desired direction. The project procured new bearings after finding some of the bearings were contaminated. As of December 2022, all four reaction wheels were delivered and integrated. The project is evaluating spares that the project could use in case any of the bearings fail during testing.

Schedule Performance



Cost Performance



Cost and Schedule Status

The PACE project continues to operate within its revised cost and schedule baselines, which were updated in February 2022. The revised baselines added $74.3 million in life-cycle costs and 4 months to the launch readiness date. In June 2022 (GAO-22-105212), we found that the project attributed this cost growth to COVID-19 and technical issues. Since the February 2022 revision, the project used its project-held reserves to address minor COVID-19-related cost and schedule effects. In addition, while the project resolved some of the technical issues that led to cost growth, the project is still working to replace flight reaction wheel bearings that were contaminated.

The project is tracking a risk that it may need to increase its estimated operations costs, largely due to changes it identified in federal IT security requirements. Project officials said the increased costs would be used to cover additional staff needed to complete software updates. Project officials said the project worked to identify opportunities to cover the operations cost shortfall. For example, project officials said they may be able to move funding from the project's development phase to operations. However, the project currently expects it will need an additional $2.5 million per year of operations.

The project is on track to meet its launch readiness date of May 2024 despite delays to a couple of milestones. For example, the system integration review was delayed by 3 months, from August 2022 to November 2022. This review evaluates the project's readiness to enter the system assembly, integration and test, and launch phase of development. As a result of this delayed review, the project plans to enter this phase of development in February 2023, 4 months later than planned.

Officials said that the system integration review was delayed because of issues with the OCI, the project's primary science instrument. For example, a key piece of testing equipment malfunctioned, which project officials said resulted in staff having to calculate the necessary measurements manually. According to officials, addressing these issues left insufficient time to integrate the instrument. The OCI has since been integrated with the spacecraft and the project's launch date remains unchanged.

Integration and Test

In November 2022, the project successfully completed its system integration review. Prior to this review, the PACE project fully integrated its spacecraft with the two polarimeters, which are instruments that complement the OCI. Since then, the project integrated instruments with the spacecraft to create the PACE observatory. In addition, the project completed environmental testing for all three instruments and several of the spacecraft's components before creating the PACE observatory.

Persistent issues with the reaction wheel bearings have been a challenge for the project. The reaction wheels are critical to the PACE mission because they are used to point the spacecraft in a desired direction to take measurements. The bearings sit inside an axle that allows the reaction wheels to rotate freely. Previously, the project found that the reaction wheel bearings it planned to use were corroded due to moisture contamination. After identifying the corrosion, the project began inspecting the damaged bearings and procured new ones. As of December 2022, all four reaction wheels were delivered and integrated, and completed environmental testing.

The project continues to track a risk related to one of the reaction wheel bearings. The team plans to evaluate other available bearings for the spare reaction wheel to reduce risk in the case that any of the bearings fail during the rest of the environmental testing campaign.

Project Office Comments

In commenting on a draft of this assessment, PACE project officials stated that the project integrated and tested all reaction wheels and required hardware components by the end of 2022, enabling the project to transition into observatory-level environmental testing in January 2023. The officials noted that, since then, the project successfully completed the first of three major environmental tests and is well positioned to start the other two by April 2023. The officials did not provide any technical corrections or comments.

Psyche

Psyche will be the first mission to visit a metal asteroid and aims to understand iron cores, a previously unexplored component of the early building blocks of planets. The project plans to send a spacecraft to orbit the Psyche asteroid to (1) determine 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. This could enable more data to be communicated in a given amount of time between a probe in deep space and Earth.

Source: NASA/Jet Propulsion Laboratory-California Institute of Technology/Arizona State University/Space Systems Loral/Peter Rubin. | GAO-23-106021

Timeline

Formulation	12/16	Project selection
Formulation	04/18	Project mission system review
Formulation	03/19	Preliminary design review
Formulation	05/19	Key decision point C
Implementation	05/20	Critical design review
Implementation	12/20	System integration review
Implementation	01/23	GAO review
Implementation	10/23	Latest launch readiness date

Project Information

NASA Lead Mission Directorate: **Science**

NASA Lead Center: **Jet Propulsion Laboratory**

International Partners: **None**

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

Launch Vehicle: **Falcon Heavy**

Mission Duration: **38-month science operation**

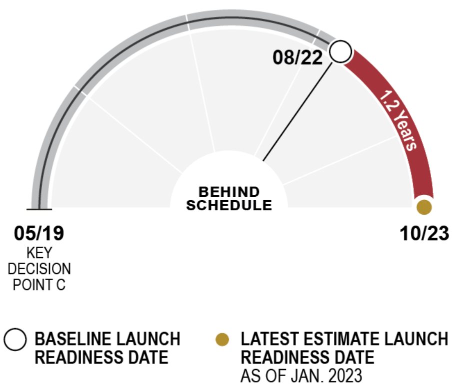
Requirement Derived from: **Discovery Program Announcement of Opportunity 2014**

Project Summary

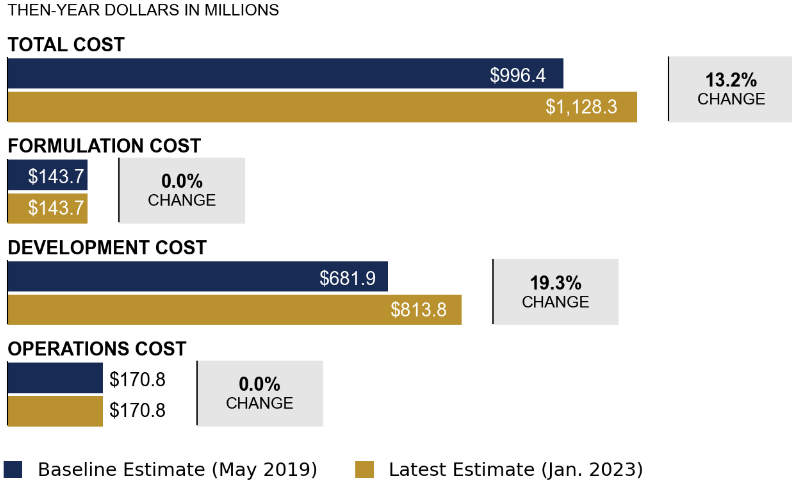
Psyche missed its fall 2022 launch window due to incomplete flight software and insufficient time for testing. Subsequently, in October 2022, NASA decided to increase the project's original development cost baseline by 19.3 percent and delay the launch by 14 months to October 2023. The project's new life-cycle cost is $1,128.3 million, but the estimate is under review because the project anticipates that operations costs could increase to accommodate a longer mission duration.

After missing the launch window, NASA and the Jet Propulsion Laboratory (JPL) convened an independent review board that investigated the causes for the launch delay. The review board found that one of the major factors was an imbalance between the workload and the available workforce at JPL. The Psyche project is working to implement the review board's findings as the project continues. Project officials said the guidance, navigation, and control (GNC) flight software, which was a main driver of the launch delay, has been delivered and testing is progressing.

Schedule Performance



Cost Performance – Under Review



Cost and Schedule Status

Psyche missed its fall 2022 launch window. Subsequently, in October 2022, NASA decided to continue the project and approved a replan for the project that incorporated cost increases and schedule delays. The increased life-cycle cost for Psyche is $1,128.3 million and includes $131.9 million in development cost overruns, which is 19.3 percent higher than the original development cost baseline. The life-cycle cost estimate is still under review, however, as NASA determines the full extent of operations cost increases.

Psyche missed its launch window due to incomplete GNC flight software and immature testbeds, leaving inadequate time for validation and verification testing. The project's new launch readiness date of October 2023 is 14 months later than its original committed launch readiness date. The revised launch date includes a few months of schedule reserves to accommodate issues that may arise during verification and validation.

The project's new October 2023 launch date could result in a longer flight time and longer mission operations that could further increase operations costs. Due to the launch delay and longer flight time, the spacecraft will now arrive at the Psyche asteroid in 2029, more than 3 years later than previously planned. In addition, when the spacecraft arrives at Psyche, the asteroid will be in a different point in its orbit around the sun than it would have been if the project launched in 2022. According to project documentation, this creates different conditions that will require a longer mission at the asteroid to ensure that all the science requirements are met. For example, during one of the spacecraft's orbits of the asteroid, the light will be receding in the northern polar region. This results in the spacecraft being able to see only 60 percent of the surface instead of the planned 80 percent requirement during this period of time. The primary science mission is now anticipated to take 38 months instead of the previous 22-month mission in order to accommodate these conditions and collect necessary observations. As a result of these changes, the current operations cost for the project is under review.

Independent Review Board Findings

NASA and JPL convened an independent review board to determine why Psyche missed its planned launch period. The review board found many factors that contributed to the missed opportunity, some specific to the Psyche project and some relevant to the JPL institution as a whole. The review board made recommendations and NASA agreed that actions are required to reduce the likelihood of future mission delays or failures.

For example, the review board found that a major factor in the project's launch delay was an imbalance between the project's workload and the available workforce at JPL. NASA officials said that they will work closely with JPL management to address the challenges raised in the report. In addition, the review board recommended increasing staffing, establishing open communications, improving the project's reporting system, and strengthening the review system to better highlight issues that might affect mission success. In response to the review board's findings, the Psyche project added staff, including filling previously vacant chief engineer and guidance navigation and control engineer positions. JPL also formed a team to actively manage the staffing shortage across multiple projects including Psyche.

To support JPL's staffing needs, NASA will delay the launch of one of its other planetary missions currently in formulation—Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy (VERITAS)—by at least 3 years, from 2028 to 2031. NASA officials said that this choice will allow experienced staff at JPL to complete development of missions further along in development than VERITAS, and free resources to enable the continuation of the Psyche mission.

Integration and Test

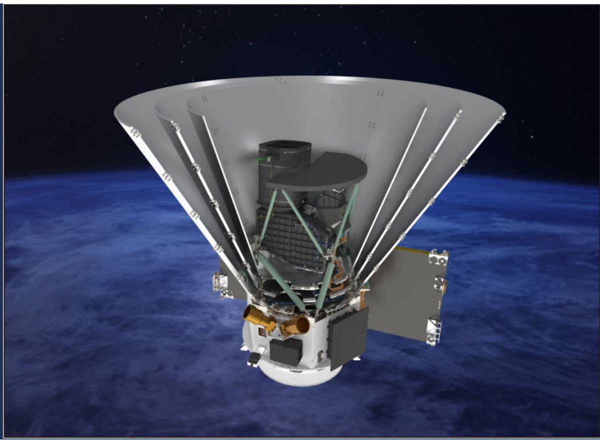
The delayed GNC flight software and testing equipment have been delivered and the project is progressing through its software verification and validation testing. The project reports that the vast majority of hardware-related verification and validation is complete. In addition, to prepare for initial power-on testing activities, the assembly, test, and launch operations team safely moved the spacecraft. The project is also in the process of reassessing whether there are any life-limiting issues or concerns that need to be addressed with the spacecraft in order to meet the new mission requirements.

Other Issues to Be Monitored

The delay of Psyche's launch readiness date also effects two other NASA efforts, the Janus mission and the Deep Space Optical Communications technology demonstration. NASA continues to assess launch options for the Janus mission, a small satellite mission that will study the formation and evolutionary implications for small asteroids. Janus was originally planned to launch as a rideshare with Psyche. NASA's Deep Space Optical Communications technology demonstration that will test high-rate laser communications remains integrated in the Psyche spacecraft and will launch as planned with Psyche.

Project Office Comments

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



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

The SPHEREx mission will use a telescope to probe the origin and destiny of the universe, explore whether planets around the 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-California Institute of Technology. | GAO-23-106021

Timeline

Formulation

02/19 Project selection

10/19 Project mission system review

10/20 Preliminary design review

01/21 Key decision point C

Implementation

01/22 Critical design review

01/23 GAO review

11/23 System integration review

04/25 Latest launch readiness date

Project Information

NASA Lead Mission Directorate: **Science**

NASA Lead Center: **Jet Propulsion Laboratory**

International Partners: **Korea Astronomy and Space Science Institute**

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

Launch Vehicle: **Falcon 9**

Mission Duration: **37 months**

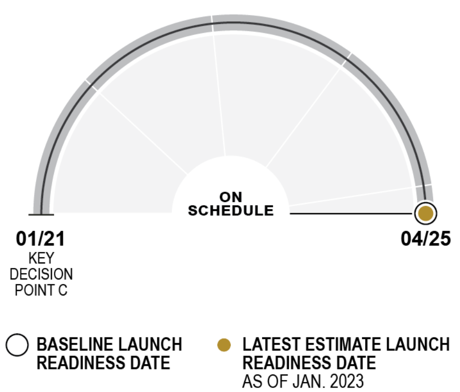
Requirement Derived from: **2010 Astrophysics Decadal Survey**

Project Summary

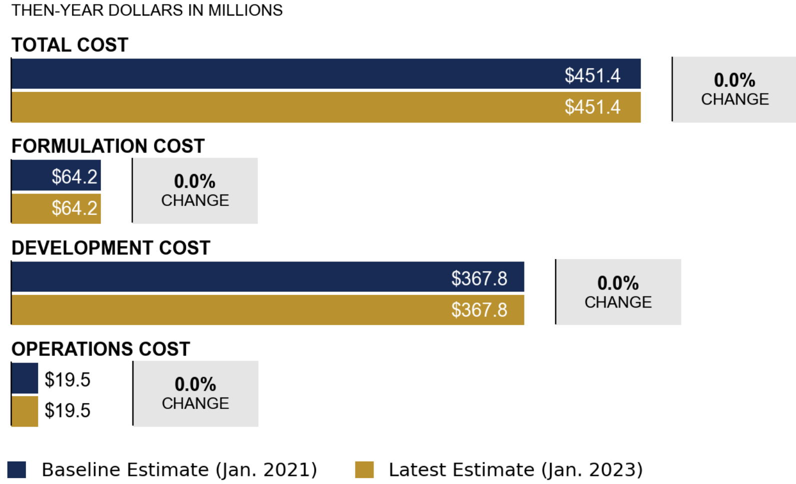
The SPHEREx project continues to operate within its cost and schedule baselines. In the last year, NASA released $38.1 million in headquarters-held reserves to cover cost increases outside of the project's control, primarily related COVID-19. NASA will consider future cost and schedule adjustments after the project's system integration review, which is planned for November 2023.

The project successfully passed its critical design review and worked to resolve issues identified before and during this review. For example, the project's standing review board was concerned about a coating failure on the telescope's beam splitter flight parts. The project replaced and tested a newly coated part to address the concern. It continues to track a risk that the project may lose science data if the coating fails again due to unknown latent defects.

Schedule Performance



Cost Performance



Cost and Schedule Status

The SPHEREx project continues to operate within the cost and schedule baselines set at its key decision point C in January 2021. Since then, NASA released a total of $38.1 million in headquarters-held reserves to the project to cover cost increases outside of the project's control. Of that, the Science Mission Directorate released $23 million following the project's critical design review to cover COVID-19-related costs through March 2022. The directorate released the remaining $15.1 million of headquarters-held reserves in November 2022 to cover cost growth that primarily affected the payload area. This growth resulted from COVID-19-related staffing issues, lack of skilled staffing at vendors, supply chain issues, inflation, and resource shortages resulting from the war in Ukraine.

The project is working toward a February 2025 launch date, which is 2 months earlier than its baseline launch readiness date of April 2025, but 5 months later than its previous targeted launch date. In March 2022, NASA approved the new February 2025 targeted launch date as part of the release of the headquarters-held reserves. According to project officials, this shift resulted in a 6-month delay to the project's system integration review, which is now planned for November 2023. This review evaluates the readiness of the project to begin the system assembly, integration, and test activities.

NASA will consider any future cost and schedule adjustments at the project's key decision point D, which follows the system integration review. Project officials said they looked for opportunities to save on costs and offset the effects of COVID-19. For example, according to officials, the project saved approximately $2.5 million dollars by removing additional testing that was beyond the work needed to be in line with the project's risk classification.

Technology and Design

The project successfully passed its critical design review in January 2022. Following this review, the project worked to resolve issues identified by the project's standing review board. For example, the review board was concerned about the beam splitter's coating failure. According to project officials, the beam splitter is the part of the telescope that splits light into different spectrums. When the coating failed, it resulted in streaks and spots on the surface of the beam splitter. Project officials said the coating failure delayed the planned delivery of the beam splitter to the telescope vendor and they planned to mitigate the delay by rearranging the telescope integration and test schedule. The project mitigated the delay with minimal effect to the project's critical path—the portion of the program with the least amount of schedule reserve available. A different beam splitter part has since been properly coated and completed environmental testing. However the project continues to track a risk that the project may lose science data if the coating fails again due to unknown latent defects.

Previously, the project received no vendor offers to design and manufacture the photon shield. To address this issue, the project moved the photon shield engineering work in-house and identified a vendor for its manufacturing. The photon shield works with the passive cooling system to help keep the telescope cool enough to detect infrared light. According to officials, the project added staff to work on the passive cooling system and photon shield, which contributed to the need for headquarters-held cost reserves.

The project has identified opportunities for cost and schedule savings, such as moving some of the manufacturing work for the photon shield in-house. Officials also said they identified savings from removing testing activities for the passive cooling system. However, the project is tracking a risk that the lack of environmental testing could cause the project to not fully understand the thermal environment. This may affect the quality of the science data because the telescope needs to be cool enough to detect infrared light without interference from the spacecraft.

Operations

The project is tracking a risk that it may need more resources to process science data during the operations phase as a result of underestimating the performance of the observatory. To mitigate this risk, officials expect operations costs to increase. The project plans to watch this risk until its system integration review, and, according to officials, may request an increase in operations costs as part of the key decision point D.

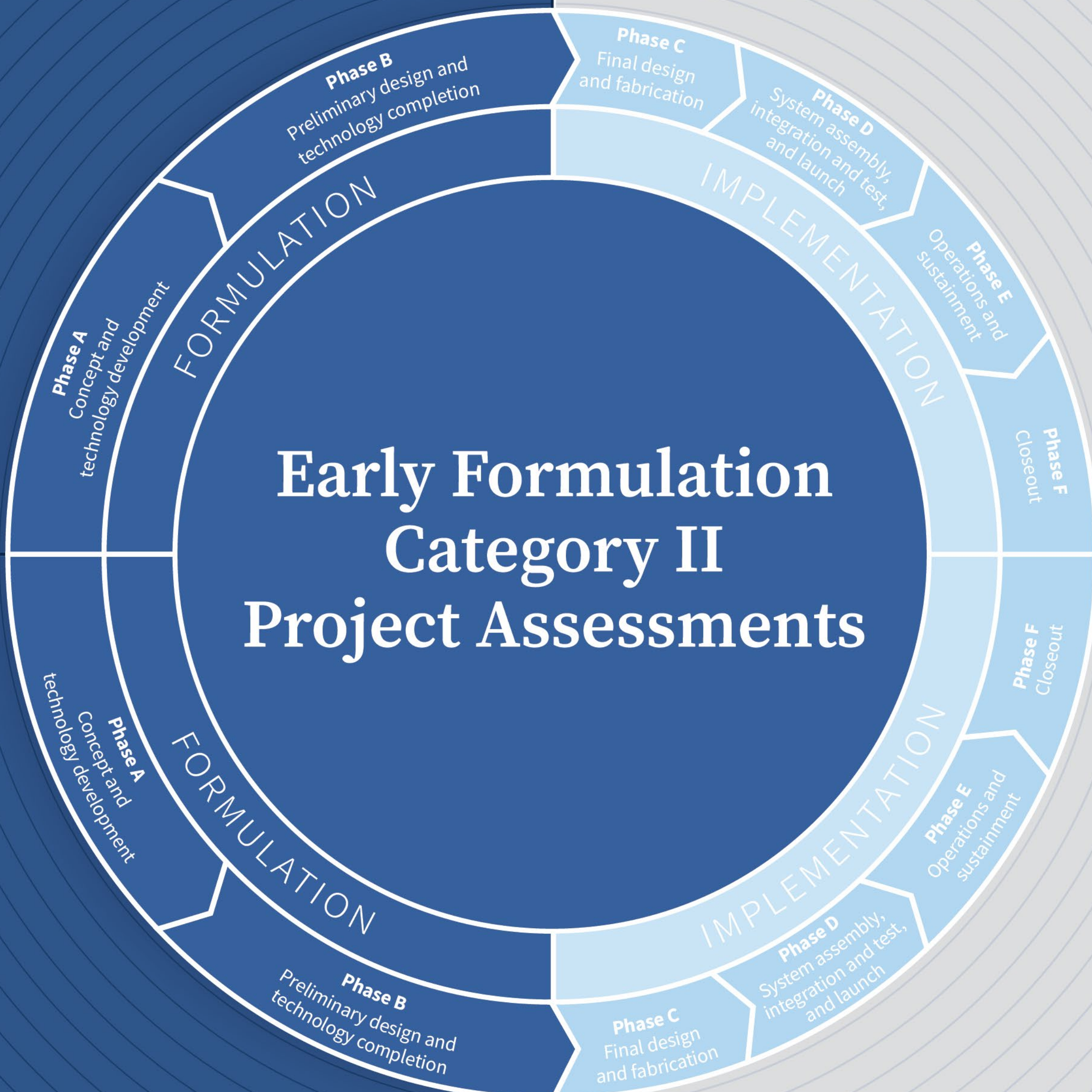
Project Office Comments

In commenting on a draft of this assessment, SPHEREx project officials stated that they agreed with the assessment. The officials also provided technical comments, which were incorporated as appropriate.

Artemis Projects

- Gateway – Deep Space Logistics (**DSL**)

Early Formulation Category II Project Assessments



Non-Artemis Projects

- Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging (**DAVINCI**)
- Geospace Dynamics Constellation (**GDC**)
- HelioSwarm
- Sustainable Flight Demonstrator (**SFD**)
- Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy (**VERITAS**)

Source: GAO analysis of NASA data. | GAO-23-106021

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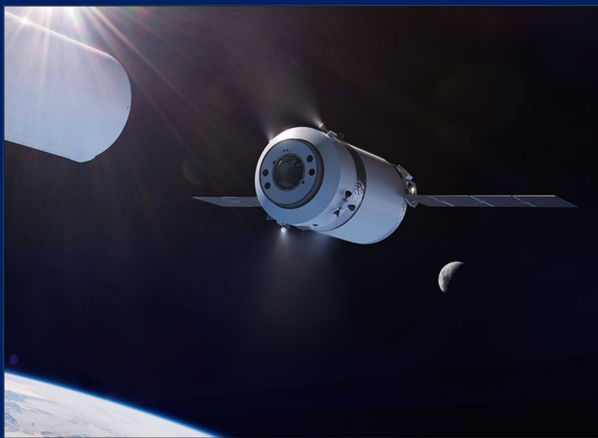


Gateway – Deep Space Logistics (DSL)

Project that will execute commercial end-to-end services supplying the Gateway with cargo deliveries and supplies prior to crew arrival to maximize the length of crew stays on the Gateway. One delivery is expected for each crewed Artemis mission to the Gateway.

Next Milestone

Authority To Proceed with first Gateway Logistics Services mission (to be determined)

Preliminary Estimates as of January 2023

Cost	Launch Date
To be determined	To be determined

Source: SpaceX. | GAO-23-106021

Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging (DAVINCI)

Spacecraft and deep atmosphere probe to measure the composition and environmental properties of Venus's atmosphere and surface to understand how its evolution diverged from Earth's and determine whether it ever had oceans of liquid water.

Next Milestone

Mission Requirements Review (May 2023)

Preliminary Estimates as of January 2023

Cost	Launch Date
To be determined	Fiscal year 2030

Source: NASA/Goddard Space Flight Center. | GAO-23-106021

Geospace Dynamics Constellation (GDC)

Multiple spacecraft planned to study Earth's upper atmosphere to understand its interaction with Earth's magnetosphere and produce insights into space weather processes.

Next Milestone

System Requirements Review (no earlier than January 2024)

Preliminary Estimates as of January 2023

Cost	Launch Date
$851 million to $980.2 million	September 2027 to May 2028

Source: NASA. | GAO-23-106021

HelioSwarm

Constellation of nine spacecraft—one hub spacecraft, and eight co-orbiting small satellites—that will investigate solar wind turbulence and its evolution by measuring solar plasma from different points in space simultaneously.

Next Milestone

System Requirements Review (October 2024)

Preliminary Estimates as of January 2023

Cost	Launch Date
To be determined	Fiscal year 2028 or 2029

Source: NASA. | GAO-23-106021

Sustainable Flight Demonstrator (SFD)

Flight demonstration project that plans to develop and flight test environmentally sustainable airframe technology to inform industry decisions associated with the next generation of single aisle aircraft.

Next Milestone

System Requirements Review (October 2023)

Preliminary Estimates as of January 2023

Cost	First Flight Date
$726 million to $1,190.8 million	September 2028

Source: NASA. | GAO-23-106021

Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy (VERITAS)

Spacecraft that will map Venus's surface and interior to determine the planet's geologic history and understand why it developed differently than Earth by assessing Venus's tectonic and volcanic history.

Next Milestone

Project Mission System Review (to be determined)

Preliminary Estimates as of January 2023

Cost	Launch Date
To be determined	No earlier than 2031

Source: Corby Waste. | GAO-23-106021

Appendix II: Objectives, Scope, and Methodology

This is our 15th annual report assessing selected large-scale NASA programs and 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 the project's end of development. We did not include projects that held key decision point (KDP) A or its equivalent after December 1, 2022.

The objectives of our review were to assess (1) the cost and schedule performance of NASA's portfolio of major projects; (2) the development and maturity of technologies; and (3) the current status of NASA's major projects, as reflected in individual project assessments. Individual assessments for 31 of the 34 major NASA projects are included in appendix I. Six of these are abbreviated assessments because the projects are early in their life cycle and have not been designated as requiring the agency's highest levels of management oversight and approval. We also do not provide assessments for the Exploration Ground Systems (EGS), the Space Launch System (SLS), or the Surface Water and Ocean Topography (SWOT) projects, which launched or completed development in 2022.

To conduct our review, we developed several standard data questionnaires. NASA's Office of the Chief Financial Officer completed the questionnaires on project cost and schedule data. We used another questionnaire that was completed by project offices to gather general data on the projects, such as their category (i.e., category 1, 2, or 3), as well as information on projects' technology and design maturity, key schedule events, and development partners.[1] 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 technology and design. We compared the current questionnaire data to questionnaire data from our prior reviews in order to analyze long-term trends. To determine the categorization (i.e., category 1 or non-category 1) of major NASA projects

[1]According to NASA's key project management policy, NASA designates a project as category 1 if the total life-cycle cost of the project is over $2 billion, the project includes significant radioactive material, or the project has a human spaceflight component. Projects with lower life-cycle cost estimates are category 2 or 3 depending on their cost and priority level. NASA, *NASA Space Flight Program and Project Management Requirements*, Procedural Requirements 7120.5F (Aug. 3, 2021).

included in our reviews from 2014 to 2023, we used data collected from the project-provided questionnaires.

To assess the cumulative cost and schedule performance of major NASA projects, we compared current development cost and schedule data we received from NASA for the 16 projects in the implementation phase during our review to the projects' original baselines established at KDP C.[2] The Commercial Crew Program has a tailored project life cycle and project management requirements, so it was excluded from these analyses. All of the latest estimates for cost and schedule data were provided by NASA in response to our questionnaires and were as-of January 2023. We took additional steps to assess the quality and reliability of data, such as checking to ensure the data summed to the totals provided and reviewing any changes since our last data collection. The team followed up with the agency on any perceived errors or unexplained cost changes.

To examine longer-term trends for NASA's portfolio of major projects in development, we compared the original baseline development costs as well as the total cumulative cost and schedule overruns for the portfolio for each year between 2014 and 2023. We grouped these costs according to the category of each project reported to us in project questionnaires. The cost and schedule performance data for each project in the portfolio are in each of our annual reports since we began reporting in 2009.

To assess annual cost and schedule performance, we compared the cumulative cost and schedule performance data received from NASA during this review to the performance data presented in the prior year's report for projects in the implementation phase during our review. This analysis identifies whether a project's latest development cost or schedule estimate is overrunning the estimates from our prior year report. Prior year report cost and schedule estimates were generally based on

[2]All cost and schedule original baseline data are from estimates documented at each project's KDP C, with the exception of the SLS project. For SLS, we used the 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. At least five other projects—EGS, Orion Multi-Purpose Crew Vehicle (Orion), Solar Electric Propulsion (SEP), On-Orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1), NASA Indian Space Research Organisation – Synthetic Aperture Radar (NISAR)—have rebaselined, but we use the original baseline data when calculating cumulative overruns for the purposes of our analyses.

data collected 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 and schedule performance of projects in formulation because they have not yet established baselines.

To understand what steps NASA is taking to improve project performance for its major projects, we reviewed NASA's corrective action plan report from 2022, NASA's acquisition policy directive, NASA's Science Mission Directorate (SMD) Large Mission Study Report, our June 2022 report on the status of major NASA projects, and GAO's High-Risk Series.[3] We also met with the NASA Chief Program Management Officer and other NASA senior leaders.

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). We took steps to assess the reliability of the project office-supplied data on the number of critical technologies and associated technology readiness levels. For example, we reviewed any changes since our last report. Since TRLs at PDR represent a snapshot in time, previously reported data do not change. For projects that held PDR since our last report, we compared any changes since our last data collection. 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 VI for the definitions of TRLs.

For the 11 projects that identified critical technologies and held their PDRs, we compared the TRLs of those projects' reported critical technologies against our technology maturity best practice to determine the extent to which these projects met the best practice. Our best practices work has shown that reaching a TRL 6 by PDR is the level of maturity needed to minimize risks for space systems entering product

[3]NASA, *Policy for NASA Acquisition*, Policy Directive 1000.5C (revised 2022); NASA, Science Mission Directorate, *Large Mission Study Report*; NASA, *2022 High Risk Corrective Action Plan*, 2022; GAO, *NASA: Assessment of Major Projects,* GAO-22-105212 (Washington, D.C.: June 23, 2022); and *High-Risk Series: Efforts Made to Achieve Progress Need to Be Maintained and Expanded to Fully Address All Areas,* GAO-23-106203 (Washington, D.C.: Apr. 20, 2023).

development.[4] TRL 6 indicates that a representative prototype of the technology has been demonstrated in a relevant environment that simulates the harsh conditions of space. We did not assess technology maturity for those projects that had not yet reached PDR at the time of this assessment or for projects that reported no critical technologies. Due to changes in our methodology in 2020 surrounding how projects report critical technologies, we compared this year's results with data after that change, therefore including data from 2021 and 2022.

Of the projects past PDR that we reviewed for technology maturity, we excluded six projects from our analysis because they did not report any critical technologies. We also excluded the Human Landing System (HLS) – Initial Capability, which held a PDR-equivalent review in December 2020, because the project does not receive information about critical technologies from its contractor. HLS officials told us that they have a variety of ways to gain insight on the contractor's performance, such as through an interim design review that officials said functioned as a checkpoint between PDR and critical design review.

We also excluded four flight and technology demonstration projects from our technology maturity best practice analysis: Electrified Powertrain Flight Demonstrator (EPFD), Low Boom Flight Demonstrator (LBFD), OSAM-1, and SEP.[5] We excluded these in part because NASA does not apply a best practice of TRL 6 by PDR to these projects. Instead, we reviewed how NASA assesses technology maturity for these projects. To identify the agency's practices for assessing and managing technology maturity for these types of projects, we reviewed relevant documentation—including NASA-wide policies, mission directorate plans and guidance, and project-specific plans and status reports. To further understand how the agency assesses technology maturity, we sent written questions to the Office of the Chief Engineer.

In addition, we interviewed officials from the Space Technology Mission Directorate (STMD) and the Aeronautics Research Mission Directorate (ARMD) about how they assess technology maturity for flight or technology demonstration projects, and discussed related policies,

[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).

[5]We excluded one flight demonstration project—the Sustainable Flight Demonstrator—from this analysis as the project is still in the concept and technology development phase and has not yet held KDP B or PDR.

guidance, and documentation. STMD and ARMD are the mission directorates responsible for the demonstration projects included in our review. To understand how other mission directorates within NASA assess technology maturity, we interviewed or sent written questions to officials from the Exploration Systems Development Mission Directorate, SMD, and the Space Operations Mission Directorate. We also analyzed questionnaire data to determine whether the flight or technology demonstration projects in our review had matured their TRLs over the course of the projects' development. We interviewed or sent written questions to project officials for the four projects included in our assessment to understand the current technology maturity status and determine their plans to mature those technologies further.

Project Profile Information on Each Individual Project Assessment

This year, we developed individual project assessments for 25 projects with estimated life-cycle costs greater than $250 million. We did not complete individual assessments for projects that launched or completed development in 2022—EGS, SLS, and SWOT. For each assessment, we included a description of the project's objectives; information concerning the lead NASA mission director, 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. We included abbreviated assessments for an additional six projects that are early in formulation—or have not yet held preliminary design review—and that NASA designated as category 2. The abbreviated assessments include a project description and preliminary cost and schedule estimates, if available. We also developed summaries of NASA's Artemis efforts, including a description of the first five missions, and of the Gateway program and the Extravehicular Activity and Human Surface Mobility Program. These summaries describe how the projects included in our review relate to these programs or missions.

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. For the Commercial Crew Program, 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. We also had NASA confirm that preliminary estimates for the 17 projects in formulation remained accurate as of January 2023. NASA provided preliminary estimates of life-cycle cost ranges and associated schedules—which are generally established at KDP A or B—for 10 projects that had not yet entered implementation. Five other projects have preliminary schedule estimates, but associated preliminary cost estimates are yet to be determined. For one other project in formulation, NASA has not yet established preliminary cost or schedule estimates. For one project, NASA provided a preliminary schedule estimate, but then later reported it as under review. According to NASA's key project management policy, projects establish preliminary cost and schedule range estimates at KDP A.[6] At KDP B, these estimates are updated to be risk-informed range estimates with a joint cost and schedule confidence level. Estimates established at KDP A or B are preliminary and are not considered a formal commitment by the agency on cost and schedule for the mission deliverables.

To assess project time frames, we determined when NASA initiated the project, which is generally referred to as formulation start. Projects can be initiated in two basic ways: a direct assignment of a project or a competitive process, typically through a broad agency announcement such as an announcement of opportunity. NASA refers to a project's start as KDP A or the beginning of the formulation phase. Projects selected as a result of a one-step announcement of opportunity enter formulation at KDP A. Projects selected as a result of a two-step announcement of opportunity 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 or an equivalent milestone such as first flight. The implementation phase includes the operations of the mission and concludes with project disposal.

Project Challenges Discussion on Each Individual Project Assessment

To assess the status, risk, and challenges for each project, we submitted a questionnaire to each project office. In the questionnaire, we requested information on the maturity of critical technologies, the number of releasable design drawings or other design stability data at project milestones, and international partnerships.[7] When applicable, we compared the level of maturity of critical technologies at PDR and the percentage of design drawings released at critical design review against

[6]NASA, *NASA Space Flight Program and Project Management Requirements,* Procedural Requirements 7120.5F (Aug. 3, 2021).

[7]We did not collect this information for the Commercial Crew Program or EGS because they are excluded from the related portfolio analyses.

our best practices.[8] We also interviewed representatives from projects across multiple NASA centers to discuss the information on the questionnaire and the projects' statuses. We did not interview representatives from either the six projects that are early in formulation—or have not yet held preliminary design review—and that NASA designated as category 2, or from the three projects that launched or completed development.

We then reviewed project documentation—including monthly status reports, schedules, risk assessments, and major project review documentation—to corroborate any testimonial evidence we received in the interviews. These reviews allowed us to identify further challenges faced by NASA projects. The second page of each project assessment highlights key challenges that affected that project or could affect that project's performance. For this year's report, we identified challenges across the projects we reviewed in the categories of cost and schedule, design, integration and test, launch vehicle, contractor performance, operations, and technology. These challenges do not represent an exhaustive or exclusive list and are based on our definitions and assessments, not those of NASA.

We conducted this performance audit from May 2022 to May 2023 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.

[8]GAO-20-48G; and GAO, *Best Practices: Capturing Design and Manufacturing Knowledge Early Improves Acquisition Outcomes*, GAO-02-701 (Washington, D.C.: July 15, 2002).

Appendix III: Estimated Costs and Launch Dates for Major NASA Projects Assessed in GAO's 2023 Report

In this report, we reviewed 34 major NASA projects. Nine of these are Artemis-related projects in the formulation phase, which takes the project from concept to preliminary design. Table 7 shows the preliminary key schedule milestone event date, such as a launch readiness, design certification, or completion of construction of the Artemis-related projects. The table also includes associated cost estimates for the nine projects.

Table 7: Preliminary Cost and Schedule Estimates of Artemis-Related Major NASA Projects in Formulation

Project name	Preliminary key schedule milestone date	Preliminary cost estimate (dollars in millions)
EHP – LTV	August 2028	769.8 – 1,058.6
EHP – xEVA (Axiom Space)	July 2025	TBD
EHP – xEVA (Collins Aerospace)	January 2026	
Gateway – DSL	TBD	TBD
Gateway Initial Capability[a]	July 2025 – February 2026	3,006.8 – 3,718.6
Gateway – HALO[b]	July 2025 – February 2026	1,173.0 – 1,530.3
Gateway – PPE[b]	July 2025 – February 2026	623.2 – 750.0
HLS – Initial Capability	December 2025	TBD
HLS – SLD	July 2028 – October 2029	8,021.1 – 12,048.1
ML2	December 2026	1,370.0
SLS Block 1B	Under review	TBD

Legend: EHP – LTV: Extravehicular Activity and Human Surface Mobility Program – Lunar Terrain Vehicle; xEVA: Exploration Extravehicular Activity; DSL: Deep Space Logistics; HALO: Habitation and Logistics Outpost; PPE: Power and Propulsion Element; HLS: Human Landing System; SLD: Sustaining Lunar Development; ML2: Mobile Launcher 2; SLS: Space Launch System.

Source: GAO analysis of NASA data. | GAO-23-106021

Note: Data for our current assessment were collected as of January 2023.

[a]The Gateway Initial Capability program's preliminary cost range includes costs to launch the PPE and HALO elements of the Gateway together. It also includes the launch vehicle, program, mission, and execution costs estimated to range between $1,210.6 million and $1,438.3 million.

[b]The Gateway HALO and PPE preliminary cost ranges represent the management agreement costs.

Table 8 shows the preliminary key schedule milestone event date and associated cost estimates for eight non-Artemis major NASA projects in the formulation phase.

Table 8: Preliminary Cost and Schedule Estimates of Non-Artemis Major NASA Projects in Formulation

Project name	Preliminary key schedule milestone date	Preliminary cost estimate (dollars in millions)
DAVINCI	Fiscal year 2030	TBD
Dragonfly	June 2027	2,100 – 2,500
EPFD[a]	October 2024 – June 2025	311.8 – 469.4
GDC	September 2027 – May 2028	851.0 – 980.2
HelioSwarm	Fiscal year 2028 or 2029	TBD
MSR	June 2028 – July 2028	5,900.0 – 6,150.0
SFD	September 2028	726.0 – 1,190.8
VERITAS	No earlier than 2031	TBD

Legend: DAVINCI: Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging; EPFD: Electrified Powertrain Flight Demonstration; GDC: Geospace Dynamics Constellation; MSR: Mars Sample Return; SFD: Sustainable Flight Demonstrator; VERITAS: Venus Emissivity, Radio science, InSAR, Topography, and Spectrotroscopy.

Source: GAO analysis of NASA data. | GAO-23-106021

Note: Data for our current assessment were collected as of January 2023.

[a]EPFD's preliminary schedule range is currently under review.

Table 9 shows the original cost and key schedule milestone baselines, set at a project's confirmation review, as well as the current key schedule milestone dates and life-cycle cost estimates for five Artemis-related projects in implementation. Implementation includes building, launching, and operating the system, among other activities.

Table 9: Life-Cycle Cost and Schedule Estimates of Artemis-Related Major NASA Projects in Development

Project name	Original baseline key schedule milestone date	Current key schedule milestone date	Original baseline life-cycle cost estimate (dollars in millions)[a]	Current life-cycle cost estimate (dollars in millions)
EGS	November 2018	November 2022	2,812.9	3,705.1
SLS	November 2018	November 2022	9,064.0	11,778.8
Orion[b]	April 2023	November 2024	11,283.5	13,810.8
VIPER	November 2023	November 2024	433.5	497.4
SEP	December 2024	October 2028	335.6	382.4

Legend: EGS: Exploration Ground Systems; SLS: Space Launch System; Orion: Orion Multi-Purpose Crew Vehicle; VIPER: Volatiles Investigating Polar Exploration Rover; SEP: Solar Electric Propulsion.

Source: GAO analysis of NASA data. | GAO-23-106021

Note: Data for our current assessment were collected as of January 2023.

[a]All original baselines in the table are from the project's confirmation review except for SLS, which rebaselined in June 2020 and adjusted its baseline downward after removing cost for scope that was not associated with its key development schedule milestone.

[b]The Orion project expects to experience additional schedule delays and cost growth, but the exact magnitude is unknown. NASA officials said they do not expect Artemis II delays to affect future Artemis missions.

Table 10 shows the original cost and key schedule milestone baselines as well as the current key schedule milestone dates and life-cycle cost estimates for 12 non-Artemis major NASA projects in implementation.

Table 10: Life-Cycle Cost and Schedule Estimates of Non-Artemis Major NASA Projects in Development

Project name	Original baseline key schedule milestone date	Current key schedule milestone date	Original baseline life-cycle cost estimate (dollars in millions)[a]	Current life-cycle cost estimate (dollars in millions)
CCP-SpaceX	April 2017	November 2020	2,598.7	2,735.0
SWOT	April 2022	December 2022	754.9	807.4
LBFD[b]	January 2022	May 2023	582.4	732.7
Psyche[b]	August 2022	October 2023	996.4	1,128.3
PACE	January 2024	May 2024	889.7	964.0
Europa Clipper	September 2025	October 2024	4,250.0	5,000.0
NISAR	September 2022	October 2024	866.9	1,118.0
SPHEREx	April 2025	April 2025	451.4	451.4
IMAP	December 2025	December 2025	781.8	781.8
OSAM-1	September 2025	December 2026	1,780.0	2,047.1
Roman	October 2026	May 2027	3,934.0	4,316.0
NEO Surveyor	June 2028	June 2028	1,595.1	1,595.1
CCP-Boeing	August 2017	Under review	4,299.0	4,528.3

Legend: CCP: Commercial Crew Program; SWOT: Surface Water and Ocean Topography; LBFD: Low Boom Flight Demonstrator; PACE: Plankton, Aerosol, Cloud, ocean Ecosystem; NISAR: NASA Indian Space Research Organisation – Synthetic Aperture Radar; SPHEREx: Spectro-Photometer for the History of the Universe, Epoch of Re-ionization and Ices Explorer; IMAP: Interstellar Mapping and Acceleration Probe; OSAM-1: On-Orbit Servicing, Assembly, and Manufacturing 1; Roman: Nancy Grace Roman Space Telescope; NEO: Near Earth Object.

Source: GAO analysis of NASA data. | GAO-23-106021

Note: Data for our current assessment were collected as of January 2023.

[a]All original baselines in the table are from the project's confirmation review.

[b]The current schedule estimate for LBFD is under review, and the current life-cycle cost estimate for Psyche is under review. Until the reviews are complete, information presented above is based on the latest estimate we received from NASA.

NASA approved rebaselines for six major projects since they set their original cost and key schedule milestone baselines at key decision point

C. Table 11 shows the latest approved rebaselined estimates for cost and key schedule milestone dates (such as launch or launch readiness), as well as the current estimates for cost and key schedule milestone dates for these projects.

Table 11: Approved Rebaseline and Current Life-Cycle Cost and Schedule Estimates for Major NASA Projects

Project name	Date of latest approved rebaseline	Latest approved rebaseline key schedule milestone date	Current key schedule milestone date	Latest approved rebaseline life-cycle cost estimate (dollars in millions)	Current life-cycle cost estimate (dollars in millions)
EGS	June 2020	November 2021	November 2022	3,413.1	3,705.1
NISAR	August 2022	October 2024	October 2024	1,118.0	1,118.0
Orion[a]	August 2021	May 2024	November 2024	13,811.0	13,810.8
OSAM-1	May 2022	December 2026	December 2026	2,047.1	2,047.1
SEP	March 2022	October 2028	October 2028	382.4	382.4
SLS	June 2020	November 2021	November 2022	11,782.3	11,778.8

Legend: EGS: Exploration Ground Systems; NISAR: NASA Indian Space Research Organisation – Synthetic Aperture Radar; Orion: Orion Multi-Purpose Crew Vehicle; OSAM-1: On-Orbit Servicing, Assembly, and Manufacturing 1; SEP: Solar Electric Propulsion; SLS: Space Launch System.

Source: GAO analysis of NASA data. | GAO-23-106021

Note: Data for our current assessment were collected as of January 2023.

[a]The Orion project expects to experience additional schedule delays and cost growth, but the exact magnitude is unknown. The project was reevaluating its cost and schedule at the time of our review. We use the latest cost and schedule estimates provided by NASA for Orion.

Appendix IV: List of Major NASA Projects Included in GAO's Annual Assessments from 2009 to 2022

We reviewed 78 major NASA projects or programs since our initial assessment in 2009. See table 12 for a list of 47 projects that were included in our assessments from 2009 to 2022. These projects were not included in the 2023 individual project assessments because development culminated in an event such as a launch, an achievement of minimum success criteria, or cancellation.

Table 12: Major NASA Projects Reviewed in GAO's Annual Assessments from 2009 to 2022

Major project name	Year first reported	Date of development end	Result of development
Aquarius	2009	2012	Launched
Ares I	2009	2011	Canceled
Asteroid Redirect Robotic Mission	2016	2017	Canceled
Dawn	2009	2009	Launched
Double Asteroid Redirection Test	2018	2021	Launched
ExoMars Trace Gas Orbiter	2012	2013	Canceled
Exploration Ground Systems	2016	2022	Achieved launch readiness
Gamma-ray Large Area Space Telescope	2009	2009	Launched
Glory	2009	2011	Launched but did not reach orbit
Global Precipitation Measurement Mission	2009	2014	Launched
Gravity Recovery and Climate Experiment Follow-On	2014	2018	Launched
Gravity Recovery and Interior Laboratory	2010	2012	Launched
Herschel	2009	2010	Launched
Ice, Cloud, and Land Elevation Satellite-2	2011	2018	Launched
Ionospheric Connection Explorer	2010	2012	Launched
Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport	2014	2018	Launched
James Webb Space Telescope	2009	2021	Launched
Juno	2010	2012	Launched
Kepler	2009	2010	Launched
Landsat Data Continuity Mission	2009	2013	Launched
Landsat 9	2017	2021	Launched
Laser Communications Relay Demonstration	2018	2021	Launched
Lucy	2018	2021	Launched
Lunar Atmosphere and Dust Environment Explorer	2011	2014	Launched
Lunar Reconnaissance Orbiter	2009	2010	Launched
Magnetospheric Multiscale	2010	2015	Launched
Mars 2020	2015	2020	Launched

Major project name	Year first reported	Date of development end	Result of development
Mars Atmosphere and Volatile EvolutioN	2011	2014	Launched
Mars Science Laboratory	2009	2012	Launched
National Polar-orbiting Operational Environmental Satellite System Preparatory Project	2009	2012	Launched
Orbiting Carbon Observatory	2009	2009	Launched but did not reach orbit
Orbiting Carbon Observatory-2	2011	2015	Launched
Orion[a]	2009	2011	Canceled
Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer	2013	2017	Launched
Parker Solar Probe	2011	2018	Launched
Radiation Belt Storm Probes	2010	2013	Launched
Radiation Budget Instrument	2017	2018	Canceled
Solar Dynamics Observatory	2009	2010	Launched
Soil Moisture Active Passive	2011	2015	Launched
Space Launch System	2012	2022	Launched
Space Network Ground Segment Sustainment	2013	2021	Achieved minimum success
Stratospheric Observatory for Infrared Astronomy	2009	2014	Full operational capability
Surface Water and Ocean Topography	2014	2022	Launched
Tracking and Data Relay Satellite Replenishment K	2011	2013	Launched
Tracking and Data Relay Satellite Replenishment L	2011	2014	Launched
Transiting Exoplanet Survey Satellite	2015	2018	Launched
Wide-field Infrared Survey Explorer	2009	2010	Launched

Source: GAO analysis of NASA data. | GAO-23-106021

[a]The original Orion project 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. In 2014, NASA adopted Orion as the common name for Orion Multi-Purpose Crew Vehicle, which stems from the canceled project.

Appendix V: Cumulative Development Cost and Schedule Overruns for NASA's Current Portfolio of Major Projects

Table 13 shows the cumulative cost and schedule changes for major NASA projects as measured from their original development cost baseline approved at key decision point C.

Table 13: Cumulative Development Cost and Schedule Overruns for NASA's Current Portfolio of Major Projects

			Changes from original baseline to current assessment		
Current performance status	**Project**	**Original baseline development cost estimate (then-year dollars in millions)**	**Development schedule delay (years)**	**Development cost overrun (then-year dollars in millions)**	**Development cost growth percentage**
No variance expected from cost or schedule baselines	IMAP	589.5	0	0.0	0.0
	NEO Surveyor	1,228.6	0	0.0	0.0
	SPHEREx	367.8	0	0.0	0.0
Mixed cost or schedule performance	Europa Clipper	2,412.8	(0.9)	96.2	4.0
Overrunning original estimate	SWOT	571.5	0.7	38.3	6.7
	Roman	2,898.1	0.6	371.9	12.8
	PACE	558.0	0.3	74.3	13.3
	VIPER	336.2	1.0	63.9	19.0
	Psyche	681.9	1.2	131.9	19.3
	OSAM-1	974.4	1.3	269.6	27.7
	LBFD[a]	467.7	1.3	139.7	29.9
	SEP	155.9	3.8	47.3	30.3
	Orion[a]	6,768.4	1.6	2,532.8	37.4
	NISAR	661.0	2.1	260.1	39.3
	SLS	6,390.0	4.0	2,714.8	42.5
	EGS	1,843.5	4.0	886.9	48.1
Totals		**26,905.3**	**20.9**	**7,627.7**	

Legend: IMAP: Interstellar Mapping and Acceleration Probe; NEO: Near Earth Object; SPHEREx: Spectro-Photometer for the History of the Universe, Epoch of Re-ionization and Ices Explorer; SWOT: Surface Water and Ocean Topography; Roman: Nancy Grace Roman Space Telescope; PACE: Plankton, Aerosol, Cloud, ocean Ecosystem; VIPER: Volatiles Investigating Polar Exploration Rover; OSAM-1: On-Orbit Servicing, Assembly, and Manufacturing 1; LBFD: Low Boom Flight Demonstrator; SEP: Solar Electric Propulsion; Orion: Orion Multi-Purpose Crew Vehicle; NISAR: NASA Indian Space Research Organisation – Synthetic Aperture Radar; SLS: Space Launch System; EGS: Exploration Ground Systems.

Source: GAO analysis of NASA data. | GAO-23-106021

Note: Positive values indicate cost growth or launch delays. Values in parentheses indicate cost decreases or earlier than planned launch dates. Data were collected as of January 2023.

[a]The cost or schedule for the LBFD and Orion projects are under review. Until those reviews are complete, information presented above is based on the latest estimates GAO received from NASA.

Appendix VI: Technology Readiness Levels

Table 14: 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 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 or characteristics.	Research and development are initiated, including analytical and laboratory studies to validate predictions regarding the technology.
4	Component 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 or brassboard validated in a relevant environment.	A medium-fidelity component 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/subsystem 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 is 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 NASA TRLs from NASA Procedural Requirements 7123.1C, Appendix E. | GAO-23-106021

Table 15: 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 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 are defined. Basic principles are coded and experiments are performed with synthetic data.
3	Analytical and experimental proof-of-concept of critical function or characteristics.	Development of limited functionality to validate critical properties and predictions using non-integrated software components occurs.
4	Component or breadboard validation in a laboratory environment.	Critical software components are integrated and functionally validated to establish interoperability and begin architecture development. Relevant environments are defined and performance in the environment is predicted.
5	Component or brassboard validated in a relevant environment.	End-to-end software elements are implemented and interfaced with existing systems/simulations conforming to the target environment. End-to-end software systems are tested in a relevant environment, meeting predicted performance. Operational environment performance is predicted.

TRL	Definition	Software description
6	System/subsystem model or prototype demonstration in a relevant environment.	Prototype implementations of the software are demonstrated on a full-scale with realistic problems and are partially integrated with existing hardware/software systems. Limited documentation is available. Engineering feasibility is fully demonstrated.
7	System prototype demonstration in an operational environment.	Prototype software exists and has all key functionality available for demonstration and test. Prototype software is well integrated with operational hardware/software systems, demonstrating operational feasibility. Most software bugs are removed. Limited documentation is available.
8	Actual system completed and flight qualified through test and demonstration.	All software is thoroughly debugged and fully integrated with all operational hardware and software systems. All user documentation, training documentation, and maintenance documentation are completed. All functionality is successfully demonstrated in simulated operational scenarios. Verification and validation are completed.
9	Actual system flight proven through successful mission operations.	All software is thoroughly debugged and fully integrated with all operational hardware and software systems. All documentation is completed. Sustaining software support is in place. The system has been successfully operated in the operational environment.

Source: GAO analysis and representation of NASA TRLs from NASA Procedural Requirements 7123.1C, Appendix E. | GAO-23-106021

Appendix VII: Comments from NASA

National Aeronautics and Space Administration

Office of the Administrator
Mary W. Jackson NASA Headquarters
Washington, DC 20546-0001

May 11, 2023

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-23-106021).

NASA continues to embrace the challenge of furthering global scientific and technological achievement and expanding the realm of what is possible in aeronautics and space. GAO's congressionally mandated annual assessment is an opportunity for NASA to receive an independent perspective on its acquisition of major programs and projects. I appreciate the open and constructive dialogue with the GAO engagement team and look forward to continued collaboration on potential cost and schedule improvements for current and future projects.

This year's report represents the 15^{th} annual assessment of NASA's major acquisitions. Since the inaugural report's issuance in 2009, GAO has provided NASA with several insights into various aspects of our acquisition approaches, many of which have resulted in programmatic developments and enhancements. The 2022-2023 engagement cycle included 34 major projects, 21 in formulation and 13 in development, and we expect the number of projects to increase next year as the NASA portfolio grows to reflect expanded national objectives.

In this year's report, the GAO states that NASA's cumulative cost performance across the portfolio of major projects has improved over the last year, mainly due to the James Webb Space Telescope leaving the audit. The remaining cumulative cost and schedule growth is driven by a subset of Artemis related projects – Space Launch System, Exploration Ground Systems, and Orion. The GAO sums the cumulative cost and schedule growth against original baselines for the projects currently in the portfolio. Use of cumulative data against original baselines means the trends associated with projects cannot effectively improve until they exit the Quick Look scope along with their associated cumulative data. When measured against current baselines, NASA has made significant progress in controlling cost and schedule for other portions of the portfolio, particularly for small- and mid-sized major projects. NASA looks forward to continuing to work with the GAO on identifying ways to reflect, fairly and accurately, NASA's overall cost and schedule performance.

NASA recognizes the inherent challenges of acquiring large, complex, and often first-of-their-kind space flight and aeronautics programs. Therefore, NASA has worked over many years to improve policies and processes that control cost and schedule while ensuring mission success. In December 2021, NASA established a Chief Program Management Officer (CPMO) to improve program and project management practices throughout the Agency, including executive leadership for the NASA High Risk Corrective Action Plan (CAP). NASA has made substantial progress in the implementation of its CAP, including the most recent update approved by NASA leadership in summer 2022. NASA further appreciates GAO's recognition of these initiatives in the Quick Look assessment and will continue to provide GAO with updates on our progress.

In 2022, NASA elevated the role of the Chief Acquisition Officer to the Deputy Administrator, Pamela Melroy, ensuring high-level strategic coordination across the Agency's acquisition and procurement activities. Among other initiatives, Deputy Administrator Melroy released a memorandum of intent to NASA Officials-in-Charge outlining acquisition and procurement priorities to ensure resource and workforce alignment with two principles: Acquisition Innovation and Rigor, and Workforce and Culture.

NASA appreciates that GAO acknowledges the Artemis Campaign's programs and major projects separate from our other work. As the Agency prepares to set cost and schedule baseline commitments for many of these projects in the coming months, having GAO's review and perspective on the progress to date will be helpful. The Exploration Systems Development Mission Directorate is also transitioning to the legislatively stipulated Moon to Mars Program Office, with the goal of increased integration between elements and focused accountability to ensure a sustainable presence on the lunar surface.

In addition to cost and schedule performance, this cycle of Quick Look focused on technology maturation and readiness. NASA recognizes the importance of ensuring that critical technologies have been adequately tested to the greatest extent possible prior to spacecraft integration and launch. We appreciate GAO's acknowledgement that technology readiness and best practices look different across our different mission directorates, and this is reflected throughout the report.

NASA thanks the GAO for continuing to work with project subject matter experts to review and incorporate technical edits as part of this audit. The consideration of these comments ensures an accurate and balanced presentation of each project's technical status. We look forward to working with GAO to ensure the technical review process continues to add value in the future.

NASA is at a historic inflection point, poised to advance the most significant series of science and human exploration missions in over a generation. While the Agency strives to keep ingenuity and innovation in space science, human exploration, and aerospace technology development moving forward, we are acutely aware of the fiscal environment and continually work to optimize the use of all our resources with rigorous acquisition management.

3

NASA remains committed to working jointly with the GAO to address any questions or concerns. If you have any questions or require additional information regarding this response, please contact Jenny Russell at (202) 358-7839.

Sincerely,

Bill Nelson

Appendix VIII: GAO Contact and Staff Acknowledgments

GAO Contact

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

Staff Acknowledgments

In addition to the contact named above, Kristin Van Wychen (Assistant Director); Juli Steinhouse (Analyst-in-Charge); Ryan Braun; Tina Cota-Robles; Cassidy Cramton; Lorraine Ettaro; Kurt Gurka; Matthew Holly; Erin Kennedy; Joy Kim; Meredith Allen Kimmett; Natalie Logan; Douglas Luo; John Ortiz; Jose A. Ramos; Carrie Rogers; Erin E. Roosa; Edward J. SanFilippo; Daniel Singleton; Ryan Stott; Hai Tran; John Warren; Alyssa Weir; and Adam Wolfe made significant contributions to this report.

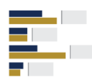
Appendix IX: Additional Source Information for Images and Figures

This appendix contains credit, copyright, and other source information for images, tables, or figures in this product when that information was not listed adjacent to the image, table, or figure.

Front cover banner graphic: NASA (Gateway), Johns Hopkins University Applied Physics Laboratory (Dragonfly), NASA (Low Boom Flight Demonstrator).

Front cover: NASA/Bill Ingalls (Artemis I Launch).

Appendix I:


GAO analysis of NASA data (all preliminary cost and cost performance figures),


GAO analysis of NASA data (all preliminary schedule and schedule performance figures), and


GAO analysis of NASA documentation (all timeline figures).

Related GAO Products

NASA Lunar Programs: Improved Mission Guidance Needed as Artemis Complexity Grows. GAO-22-105323. Washington, D.C.: September 8, 2022.

NASA Lunar Programs: Moon Landing Plans Are Advancing but Challenges Remain. GAO-22-105533. Washington, D.C.: March 1, 2022.

NASA: Lessons from Ongoing Major Projects Could Improve Future Outcomes. GAO-22-105709. Washington, D.C.: February 9, 2022.

NASA: Lessons from Ongoing Major Projects Can Inform Management of Future Space Telescopes. GAO-22-105555. Washington, D.C.: December 1, 2021.

NASA Lunar Programs: Significant Work Remains, Underscoring Challenges to Achieving Moon Landing in 2024. GAO-21-330. Washington, D.C.: May 26, 2021.

James Webb Space Telescope: Project Nearing Completion, but Work to Resolve Challenges Continues. GAO-21-406. Washington, D.C.: May 13, 2021.

NASA Human Space Exploration: Significant Investments in Future Capabilities Require Strengthened Management Oversight. GAO-21-105. Washington, D.C.: December 15, 2020.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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