United States Government Accountability Office

Report to Congressional Committees

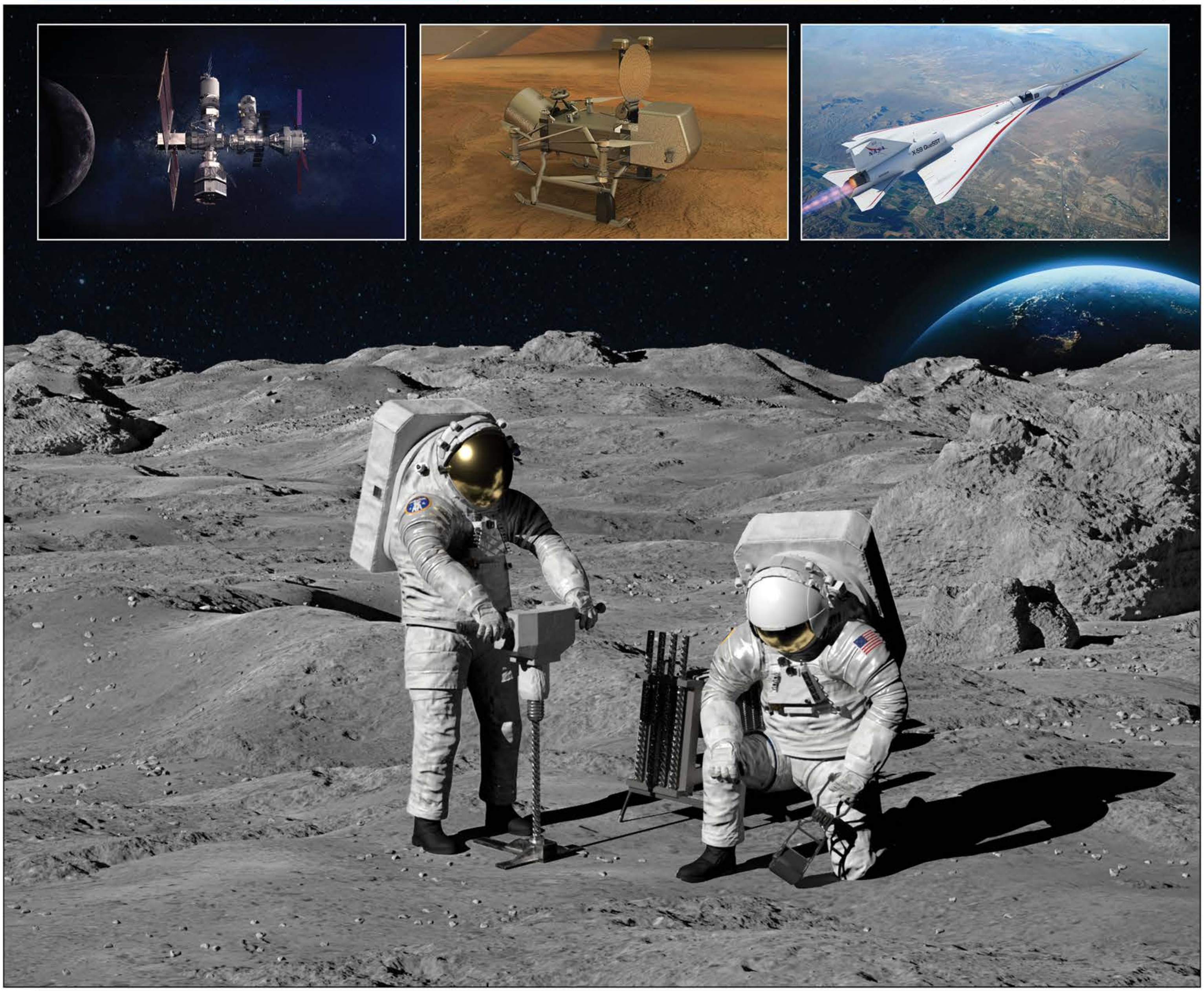
June 2022

NASA

Assessments of Major Projects

Accessible Version

LUNAR EXPLORATION | ASTROPHYSICS | PLANETARY SCIENCE | AERONAUTICS



GAO-22-105212

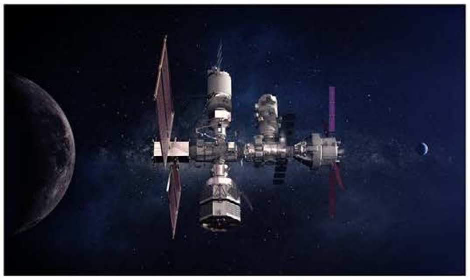
GAO Highlights

Highlights of GAO-22-105212, a report to congressional committees

June 2022

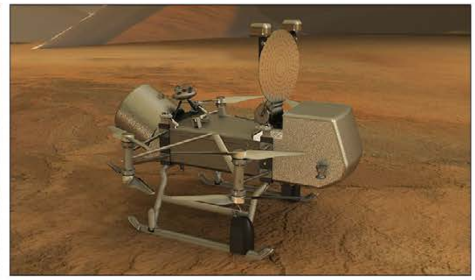
NASA

Assessments of Major Projects



Gateway – Lunar outpost

Low Boom Flight Demonstrator



Dragonfly – Planetary explorer

Source: NASA, Lockheed Martin Aeronautics, Johns Hopkins University Applied Physics Laboratory. | GAO-22-105212

Why GAO Did This Study

NASA plans to invest at least $80 billion in its major projects to continue exploring Earth, the moon, and the solar system. Major projects are those with costs of over $250 million. An explanatory statement included a provision for GAO to prepare status reports on NASA's major projects. This is GAO's 14th annual assessment.

This report describes the cost and schedule performance of NASA's major projects and GAO's assessment of these projects' technology development and design stability. The report 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.

What GAO Recommends

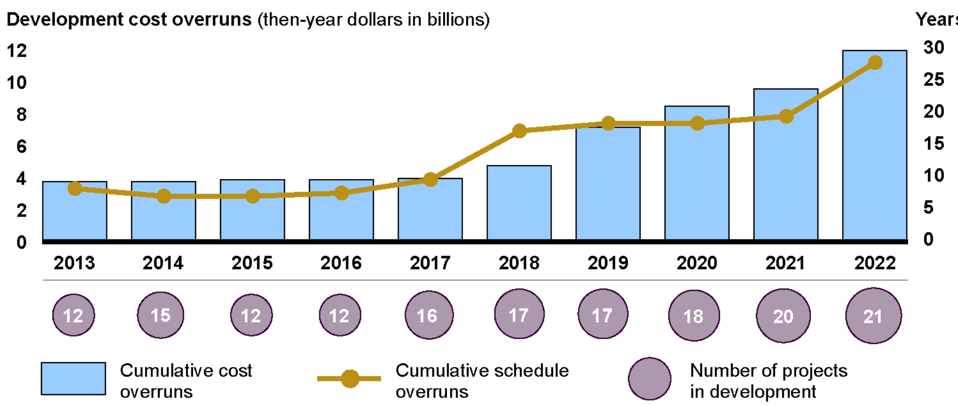
In prior work, GAO made multiple recommendations to improve NASA's management of its major projects. NASA agreed with most of those recommendations and implemented many changes. However, as of March 2022, NASA had not fully addressed 23 recommendations—six of which have been awaiting actions for over 5 years.

View GAO-22-105212. For more information, contact W. William Russell at (202) 512-4841 or russellw@gao.gov.

What GAO Found

Continuing a recent trend, NASA's portfolio of major projects experienced significant cost and schedule overruns and more projects were added (see figure). Of the 21 major projects in the development phase of NASA's acquisition process (which includes building and launching the system), 15 were responsible for cumulative cost overruns of about $12 billion and cumulative schedule delays of 28 years. But just three projects—the James Webb Space Telescope, Space Launch System, and Orion—are responsible for more than three-quarters of the cost growth and almost half of the delays.

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



Source: GAO analysis of NASA data. | GAO-22-105212

In the past year, the majority of NASA's projects in development increased their cost estimates, schedule estimates, or both. Technical issues and new scope were the primary causes of overruns. However, COVID-19 exacerbated these challenges with government and contractor facility shutdowns and remote work.

Current overruns and the risk of future COVID-19 issues could have a cascading effect on NASA's ability to manage its portfolio. NASA designates cost reserves to help projects address risks. However, when projects exhaust these reserves and need additional funding, it can limit the agency's ability to fund existing missions or start new ones. For example, NASA officials said some new projects are preparing for later launch dates due in part to funding limitations caused by other projects' cost overruns. NASA is taking steps to improve its portfolio management, but it is too soon to determine the results of these efforts.

Contents

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Figures

Abbreviations

AEPS	Advanced Electric Propulsion System
ATLO	assembly, test, and launch operations
CCP	Commercial Crew Program
CDR	critical design review
CGI	Coronagraph Instrument
CLA	Coupled Loads Analysis
CLPS	Commercial Lunar Payload Services
CNES	Centre National d'Etudes Spatiales
CoDICE	Compact Dual Ion Composition Experiment
CSP	Communications Services Project
DART	Double Asteroid Redirection Test
DAVINCI	Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging
DraGNS	Dragonfly Gamma-ray Neutron Spectrometer

DraMS	Dragonfly Mass Spectrometer
DSL	Deep Space Logistics
EAP	Electrified Aircraft Propulsion
EGS	Exploration Ground Systems
EIS	Europa Imaging System
EMI	electromagnetic interference
EPFD	Electrified Powertrain Flight Demonstration
ESA	European Space Agency
ESM	European Service Module
ESPRIT-RM	European System Providing Refueling, Infrastructure, and Telecommunications Refueler Module
EUS	Exploration Upper Stage
EVA	extravehicular activity
GDC	Geospace Dynamics Constellation
GERS	Gateway External Robotic System
HALO	Habitation and Logistics Outpost
HLS	Human Landing System
I-HAB	International Habitat
ICPS	Interim Cryogenic Propulsion Stage
IMAP	Interstellar Mapping and Acceleration Probe
ISRO	Indian Space Research Organisation
ISS	International Space Station
I-T	ionosphere-thermosphere
JPL	Jet Propulsion Laboratory
JWST	James Webb Space Telescope
KDP	key decision point
LBFD	Low Boom Flight Demonstrator
LCRD	Laser Communications Relay Demonstration
MASPEX	MAss Spectrometer for Planetary EXploration
MAV	Mars Ascent Vehicle
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
NPR	NASA Procedural Requirement
OCI	Ocean Color Instrument
OMB	Office of Management and Budget
Orion	Orion Multi-Purpose Crew Vehicle
ORR	operational readiness review

OSAM-1	On-Orbit Servicing, Assembly and Manufacturing 1
OTA	Optical Telescope Assembly
PACE	Plankton, Aerosol, Cloud, ocean Ecosystem
PDP	Plasma Diagnostics Package
PDR	preliminary design review
PPBE	Planning, Programming, Budgeting, and Execution
PPE	Power and Propulsion Element
PUNCH	Polarimeter to Unify the Corona and Heliosphere
Roman	Nancy Grace Roman Space Telescope
RPOD	Rendezvous Proximity Operations and Docking
SATCOM	Satellite Communications
SCA	Sensor Chip Assemblies
SCE	Sensor Control Electronics
SDR	system definition review
SEP	Solar Electric Propulsion
SGSS	Space Network Ground Segment Sustainment
SIR	system integration review
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
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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June 23, 2022

Congressional Committees

NASA is planning to invest at least $80 billion over the life cycle of its current portfolio of 37 major projects, which we define as those projects or programs with a life-cycle cost of over $250 million. These projects aim to continue exploring Earth and the solar system, extend human presence beyond low Earth orbit to the lunar surface, and understand climate change, among other things. This report provides an overview of NASA's planning and execution of these major acquisitions—an area that has been on GAO's high-risk list since 1990.[1] It includes assessments of NASA's key projects across mission areas, such as the Space Launch System (SLS) for human exploration; 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 included a provision for us to prepare project status reports on selected large-scale NASA programs, projects, and activities, and the explanatory statement of the House Committee on Appropriations accompanying the Consolidated Appropriations Act, 2021, again includes a similar provision.[2] This is our 14th annual report responding to that mandate. This report includes our analysis of (1) the cost and schedule performance of NASA's portfolio of major projects and (2) the development and maturity of technologies and progress in achieving design stability. Individual assessments of 33 of the 37 major NASA projects are included in appendix I. Six projects launched or completed development in 2021. Accordingly, we include the six in our various

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

[2]See Explanatory Statement, 155 Cong. Rec. H1653, 1824-25 (daily ed., Feb. 23, 2009), on H.R. 1105, the Omnibus Appropriations Act, 2009, which became Pub. L. No. 111-8. Also see Explanatory Statement, 166 Cong. Rec. H7879, 7944 (daily ed, Dec. 21, 2021), on H.R. 133, Consolidated Appropriations Act, 2021, which became Pub. L. No. 116-260. In this report, we refer to these projects as major projects rather than large-scale projects since this is the term used by NASA.

analyses described above, but we do not include individual assessments for four of these projects. To follow up on significant events that occurred after launch, we are including a final assessment for two projects that launched last year—the James Webb Space Telescope (JWST) and Lucy, a spacecraft investigating a population of asteroids orbiting the sun in tandem with Jupiter.

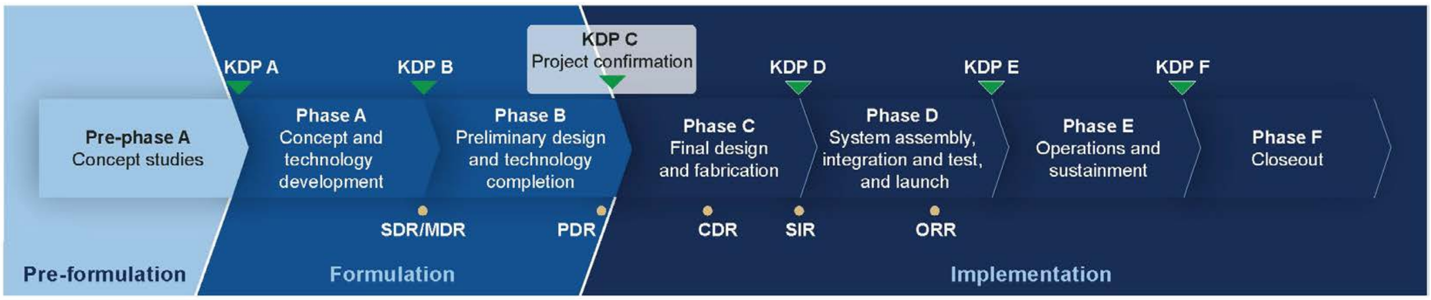
To respond to the objectives of this review, we collected information on cost and schedule performance, technology maturity, and design stability using NASA headquarters and project office questionnaires. We also analyzed projects' monthly status reports, reviewed NASA guidance and policies, and interviewed NASA project, directorate, and headquarters officials. In addition, we reviewed project documentation and met with project officials to identify COVID-19 effects on cost and schedule performance. We reviewed data on the technology readiness levels (TRL) of each project's critical technologies and compared technology maturity levels against GAO best practice and NASA policy. To complete our 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 2021 to June 2022 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

The life cycle for NASA space flight projects consists of two phases—formulation, which takes a project from concept development to preliminary design, and 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 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



Management decision reviews

- KDP = key decision point

Technical reviews

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

Source: GAO analysis of NASA data. | GAO-22-105212

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. In phase A, a project team develops a range of cost and schedule estimates, which are used to inform its budget planning. During phase B, the project team also develops programmatic measures and technical leading indicators, which track various project metrics such as requirement changes, staffing demands, and mass and power utilization. Near the end of formulation, leading up to the preliminary design review (PDR), the project team completes technology development and its preliminary design. Formulation culminates in a confirmation review at key decision point (KDP) C, where cost and schedule baselines are established, documented, and confirmed. Due to changes that may occur prior to KDP C, such as to a project's scope or technologies, the estimates of a project's cost and schedule can be adjusted prior to establishing the baselines at KDP C.

After a project holds its confirmation review, it begins implementation, consisting of phases C, D, E, and F. In this report, we refer to projects in phases C and D as being in development. A critical design review (CDR) is held 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. An operational readiness review is held during the latter half of Phase D 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 can be viewed as a contract between the agency and the project manager. The project manager has the authority to manage the project within the parameters outlined in the agreement. The management agreement includes cost and schedule reserves held at the project level and within the project manager's control.[3] Cost reserves are for costs that are expected to be incurred—for instance, to address project risks—but are not yet allocated to a specific part of the project. Schedule reserves are extra time in project schedules that can be allocated to specific activities, elements, and major subsystems to mitigate delays or address unforeseen risks. 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 consisting of formulation, development, and operations costs and a 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 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,

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

schedule, risk, and uncertainty, the result of which indicates a project's likelihood of meeting a given set of cost and schedule targets.[4]

The total amount of cost and schedule reserves held at the project level varies based on where the project is in its life cycle. NASA's policy on whether projects are required or recommended to hold certain levels of cost and schedule reserves at key project milestones varies by NASA 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 confirmation review and 10 percent at the time of delivery to the launch site.[5] Projects track their reserves between phases to help ensure they hold reserves consistent with these requirements.

When certain conditions in the agency baseline commitment are no longer met—for example, if a project will exhaust its headquarters-held reserves and require a certain amount of additional cost or schedule beyond the agency baseline commitment to complete development—NASA replans or rebaselines the project and in certain cases is required to notify Congress. See table 1 for an overview of NASA replans and rebaselines.

Table 1: Characteristics of NASA Program Replans and Rebaselines

Category	Description	Potential congressional reporting
Replan	A replan is a process by which a program updates or modifies its plans. It generally is driven by changes in program or project cost parameters, such as if development cost growth is 15 percent or more of the estimate in the baseline report or a major milestone is delayed by 6 months or more from the baseline's date. A replan does not require a new project baseline to be established.	When the NASA Administrator determines that development cost growth is likely to exceed the development cost estimate by 15 percent or more, or a program milestone is likely to be delayed from the baseline's date by 6 months or more, NASA must submit a report to the Committee on Science, Space, and Technology of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate.[a]
Rebaseline	Rebaselining is the process that results in a change to the project's agency baseline commitment. A rebaseline is initiated if the estimated development cost exceeds the baseline development cost estimate by 30 percent or more, or if the NASA Associate Administrator determines other events make a rebaseline appropriate.	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 for the contractor to continue work beyond a specified time frame.[b]

Source: GAO analysis of NASA policy and 51 U.S.C. § 30104. | GAO-22-105212

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

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

[a]51 U.S.C. § 30104(e)(1).

[b]51 U.S.C. § 30104(f).

NASA Organization and Portfolio Management

NASA uses agency-level management councils to conduct high-level oversight, to set requirements and strategic priorities, and to guide key assessments of the agency. For example, the agency uses its Acquisition Strategy Council to make strategic decisions to ensure that the projects the agency is pursuing are, in the long-term, the right mix to meet the agency's goals. Chaired by the Associate Administrator, the Acquisition Strategy Council's role is to formulate and recommend integrated acquisition strategy options in order to inform budget development. Other councils focus on areas such as infrastructure and human resources, major agency-wide decisions, or managing program performance. The council members evaluate issues and support decision authorities when issues involve or require high levels of difficulty, integration, visibility, and approval.

To manage its individual programs and projects, NASA has five mission directorates (see table 2).

Table 2: NASA Mission Directorates with Associated Mission

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 frontiers of Earth science, heliophysics, planetary science, astrophysics, and biological and physical sciences
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[a]	Defines and manages systems development for programs critical to Artemis and plans the moon-to-Mars exploration approach
Space Operations Mission Directorate[a]	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-22-105212

[a]The NASA Administrator announced in September 2021 that the agency's former Human Exploration and Operations Mission Directorate was separated into two new mission directorates, the Exploration Systems Development Mission Directorate and the Space Operations Mission Directorate.

Mission directorates are responsible for managing their portfolios of programs and projects. Mission directorates manage their portfolios through their authority to

- initiate new programs and projects,
- select projects resulting from a competitive process when appropriate,
- approve formulation agreements and project plans,
- oversee project performance,
- manage the development of the mission directorate budget to support requirements and objectives, and
- allocate resources in support of their individual programs and projects.

They also report to various agency forums on program and project progress, including any variations in cost, schedule, technical, and risk performance that could affect agency commitments and performance goals.

Mission directorates make portfolio management decisions largely through the Planning, Programming, Budgeting, and Execution (PPBE) process. During the planning phase, NASA's Office of the Chief Financial Officer provides budget guidance for mission directorates and NASA centers.[6] The programming phase is an annual process to analyze and align missions, constraints, and resources. In the budgeting phase, NASA finalizes and presents its initial budget estimates to the Office of Management and Budget (OMB), and OMB works with NASA to finalize its budget for inclusion in the President's budget request. The execution phase is when the fiscal year's budget is executed. The evaluation and reporting that takes place during the execution phase for the fiscal year are used as inputs to the planning, programming, and budgeting phases for future year budgets.

Mission directorates consult and collaborate with a range of stakeholders during the PPBE process on how to form budget estimates and distribute those funds to existing projects and new projects. These stakeholders include Congress, the presidential administration, industry, academia, and the science community, among others. Mission directorates consult academia and the science community and they play a large role in helping mission directorates shape their priorities and goals, and decide on upcoming projects to pursue. For example, decadal surveys provide NASA with the science communities' opinion on mission goals, and are one of the inputs NASA uses to determine when to add new missions. The Science Mission Directorate asks the National Research Council

[6]The 10 NASA Centers provide mission support to projects and programs assigned to them.

once every decade to look 10 or more years into the future and produce separate reports prioritizing research areas, observations, and notional missions for key science areas of astrophysics, planetary science, heliophysics, and Earth science. These decadal surveys result in a number of recommendations for the agency to pursue in the following years.[7]

NASA has numerous directives and policies to guide project management, but the primary one for major projects is NASA Procedural Requirements 7120.5F—which we refer to throughout this report as NASA's key project management policy.[8] This policy establishes the requirements by which NASA formulates and implements space flight programs and projects. As part of an August 2021 update, NASA increased the life-cycle cost associated with its category thresholds that determine the level of internal oversight and approval a project receives (see table 3).

Table 3: August 2021 Project Category Guideline Updates to NASA's Key Project Management Policy

Category	Previous project life-cycle cost threshold	Latest project life-cycle cost threshold
Category 1 Projects Decision authority is the NASA Associate Administrator	Over $1 billion	Over $2 billion
Category 2 Projects Decision authority is the Mission Directorate Associate Administrator	$250 million to $1 billion	$365 million to $2 billion
Category 3 Projects Decision authority is the Mission Directorate Associate Administrator	Less than $250 million	Less than $365 million

Source: GAO analysis of NASA Procedural Requirements 7120.5E and 7120.5F. | GAO-22-105212

Note: In addition to its life-cycle cost estimate, a project can also be categorized based on its level of radioactive material or distinction as a human space flight project. Further, a project can be categorized based on its priority level 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]In December 2021, we reported on how NASA could incorporate lessons learned from its portfolio of major projects when considering decadal survey recommendations. GAO, *NASA: Lessons from Ongoing Major Projects Can Inform Management of Future Space Telescopes*, GAO-22-105555 (Washington, D.C.: Dec. 1, 2021).

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

According to agency documentation, NASA increased these thresholds to respond to inflation and historical data. These new category thresholds do not affect NASA's policy to require any project with a life-cycle cost of $250 million or more to conduct a joint cost and schedule confidence level at KDP C and any subsequent rebaselines. In addition, it does not affect NASA's statutory external reporting requirements to report to congressional committees its progress against cost and schedule baselines for projects with a life-cycle cost over $250 million, although officials say they are pursuing a potential update of the threshold.[9]

NASA Projects Reviewed in GAO's Annual Assessment

Of the 37 projects we reviewed this year, 12 are related to NASA's efforts to return to the moon and beyond, known as Artemis (see table 4).

Table 4: Artemis-Related Major NASA Projects Reviewed in GAO's 2022 Assessment

Life-cycle phase	Project name	Project description
Projects in formulation	Exploration Extravehicular Activity (xEVA)	Development of three kinds of hardware to support NASA's return to the lunar surface: tools for lunar science and maintenance, interfaces to connect to other systems, and space suits
Projects in formulation	Gateway - Deep Space Logistics (DSL)	Project will execute commercial end-to-end services to provide Gateway, an outpost in lunar orbit, with cargo and supplies prior to crew arrival
Projects in formulation	Gateway - Habitation and Logistics Outpost (HALO)	The initial crew module for Gateway that will provide living quarters and communication functions to the lunar surface and for visiting vehicles
Projects in formulation	Gateway - Power and Propulsion Element (PPE)	Solar electric propulsion spacecraft that will provide Gateway with power, communications, and the ability to change orbits
Projects in formulation	Human Landing System (HLS)	Commercial human lander that will provide crew access to the lunar surface and demonstrate capabilities required for deep space missions
Projects in formulation	Mobile Launcher 2 (ML2)	Newly designed launch platform and tower for the SLS Block IB vehicle with the upgraded Exploration Upper Stage
Projects in formulation	Space Launch System Block IB (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
Projects in implementation	Exploration Ground Systems (EGS)	Modernized and upgraded infrastructure at Kennedy Space Center to support SLS and its planned first launch, Artemis I
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

[9]51 U.S.C. § 30104.

Life-cycle phase	Project name	Project description
Projects in implementation	Solar Electric Propulsion (SEP)	High power solar electric propulsion technologies that consist of both the Advanced Electric Propulsion System and Plasma Diagnostics Package efforts. SEP's advanced electric propulsion thruster is a critical technology for the Gateway Power and Propulsion Element[a]
Projects in implementation	Space Launch System (SLS)	NASA's first human rated heavy-lift vehicle designed for deep space operations
Projects in implementation	Volatiles Investigating Polar Exploration Rover (VIPER)	Rover that aims to understand how much water is on the moon and where it is located

Source: GAO analysis of NASA data. | GAO-22-105212

[a]While our report was out for comment, the agency provided technical comments that the Plasma Diagnostics Package was removed from the SEP project's requirements as of April 2022.

The Artemis I and II missions are the first planned uncrewed and then crewed demonstration missions of the SLS, Orion Multi-Purpose Crew Vehicle (Orion), and Exploration Ground Systems (EGS) programs. The Artemis I and II missions are currently planned for spring 2022 and May 2024, respectively.[10] The Artemis III mission, expected to take place no earlier than 2025, will be a crewed lunar landing using a Human Landing System (HLS) that docks in lunar orbit with Orion. NASA is also developing the Gateway, which will be an outpost orbiting the moon to support later Artemis missions and NASA's longer-term lunar exploration goals to create a sustained presence on and around the moon. NASA is designing components of the Gateway to act as a habitat and safe work environment for astronauts and as a communications relay between the lunar surface and the Earth. See the individual assessments in appendix I for additional details on Artemis and Gateway.

The 25 remaining other major projects are primarily science or aeronautics projects and include six that have launched or completed development since our review began and that are currently conducting operations (see table 5).

Table 5: Non-Artemis Major NASA Projects Reviewed in GAO's 2022 Assessment

Life-cycle phase	Project name	Project description
Projects in formulation	Communications Services Project (CSP)	Project plans to demonstrate the feasibility of acquiring satellite communications services for NASA missions from commercial providers
Projects in formulation	Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging (DAVINCI)	Spacecraft and probe that plans to measure composition of Venus' atmosphere to understand how it developed and formed and determine whether the planet ever had an ocean

[10]While our report was out for comment, the agency provided an update that the Artemis I mission launch date was delayed to no earlier than summer 2022, pending completion of further testing.

Life-cycle phase	Project name	Project description
Projects in formulation	Dragonfly	Robotic rotorcraft that will explore the diverse environments of Titan—Saturn's largest moon—and study chemical components and prebiotic processes needed for the development of life
Projects in formulation	Electrified Powertrain Flight Demonstration (EPFD)	Technology demonstration aircraft to demonstrate high-power hybrid electric propulsion system technologies for commercial aircraft
Projects in formulation	Geospace Dynamics Constellation (GDC)	Multiple spacecraft planned to study the Earth's upper atmosphere to understand its interaction with Earth's magnetosphere and produce insights into space weather processes
Projects in formulation	Mars Sample Return (MSR)	Robotic systems and a Mars ascent rocket to collect and send samples of Martian rocks, soils, and atmosphere to return back to Earth for study
Projects in formulation	Near Earth Object Surveyor (NEO Surveyor)	Space-based telescope to search for near-Earth objects as small as 140 meters across that could potentially impact the Earth
Projects in formulation	Venus Emissivity, Radio science, InSAR, Topography, And Spectroscopy (VERITAS)	Spacecraft that will map Venus' surface to determine the planet's geologic history and understand why it developed differently than Earth
Projects in implementation	Commercial Crew Program (CCP)	Program that facilitates and oversees the development of crew transportation systems by commercial companies to carry NASA astronauts to and from the International Space Station
Projects in implementation	Europa Clipper	Spacecraft in orbit around Jupiter that will conduct flybys of Europa to investigate whether the Jupiter moon could harbor conditions suitable for life
Projects in implementation	Interstellar Mapping and Acceleration Probe (IMAP)	Spinning 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
Projects in implementation	Low Boom Flight Demonstrator (LBFD)	Demonstration aircraft that plans to show that noise from supersonic flight—sonic boom—can be reduced to levels acceptable to the public for commercial use in overland supersonic flight paths
Projects in implementation	Nancy Grace Roman Space Telescope (Roman)	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
Projects in implementation	NASA Indian Space Research Organisation - Synthetic Aperture Radar (NISAR)	Joint satellite mission with the Indian Space Research Organisation to collect radar data to study the solid Earth, ice masses, and ecosystems to address questions related to global environmental change, Earth's carbon cycle, and natural hazards
Projects in implementation	On-Orbit Servicing, Assembly and Manufacturing 1 (OSAM-1)	Robotic spacecraft to demonstrate a capability to autonomously refuel and extend the life of on-orbit satellites as well as perform on-orbit assembly and installation of an antenna and manufacturing of a beam
Projects in implementation	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
Projects in implementation	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

Life-cycle phase	Project name	Project description
Projects in implementation	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
Projects in implementation	Surface Water and Ocean Topography (SWOT)	Satellite that will take repeated high-resolution measurements of the world's oceans and freshwater bodies to develop a global survey
Projects in implementation that recently launched or completed development	Double Asteroid Redirection Test (DART)	Spacecraft that plans to travel to the near-Earth asteroid Didymos and impact the smaller of the two bodies so NASA can assess the result of the impact. Launched November 2021
Projects in implementation that recently launched or completed development	James Webb Space Telescope (JWST)	Large, infrared-optimized space telescope designed to help understand the origin and destiny of the universe and further the search for Earth-like planets. Launched December 2021
Projects in implementation that recently launched or completed development	Landsat-9	Earth observation satellite that will help provide a continuous space-based record of land surface observations. Launched September 2021
Projects in implementation that recently launched or completed development	Laser Communications Relay Demonstration (LCRD)	Technology demonstration of bidirectional laser communications between a satellite and ground stations for future use on commercial and government satellites. Launched December 2021
Projects in implementation that recently launched or completed development	Lucy	Spacecraft to investigate the Trojans—a population of asteroids orbiting the sun in tandem with Jupiter—to understand the formation and evolution of planetary systems. Launched October 2021
Projects in implementation that recently launched or completed development	Space Network Ground Segment Sustainment (SGSS)	A new ground system of updated software and equipment to provide communications services through the Space Network's tracking and data relay satellites. Achieved minimum success in June 2021

Source: GAO analysis of NASA data. | GAO-22-105212

Appendix III includes a list of all the projects that we reviewed from 2009 to 2021.

Recent GAO Work on Selected NASA Projects

Over the past 10 years, we issued several in-depth reports assessing NASA's progress in acquiring its largest projects and programs.[11] For example, in May 2021, we reported that NASA made progress completing some early lunar program development activities but faces an ambitious schedule to achieve its goal of returning humans to the moon.[12] We also released a series of reports documenting the progress and challenges of projects that aim to continue human space exploration beyond low-Earth orbit, including Orion, SLS, and EGS. In December 2020, we reported on the completion of some key test events in advance of the Artemis I uncrewed test flight as well as some launch delays and issues with NASA's program management.[13] We also reported for several years on the JWST project, one of the agency's most complex science missions that launched successfully in December 2021 after a series of significant cost increases and schedule delays. In our May 2021 report, we noted that the project successfully worked to reduce the number of known mission risks prior to launch, but it will continue managing risk to complete mission objectives, even after its recent launch.[14]

Since we initially designated NASA's acquisition management as high-risk, we have made numerous recommendations to reduce acquisition risk. NASA has generally agreed with our recommendations and implemented changes in response to many of them, but additional action is needed to fully address the recommendations. As of March 2022, a total of 23 recommendations—including eight priority recommendations—related to this high-risk area remain open. Through these recommendations, we identified multiple areas where NASA should take action to improve the management of its portfolio of major projects. For example, NASA needs to develop a life-cycle cost estimate for the Artemis III mission and define and determine a schedule to ensure requirements are aligned across programs.

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

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

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

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

COVID-19

In March 2020, the President declared a national emergency as a result of the spread of COVID-19. States and many employers—including locations where work on major NASA project activities was ongoing—implemented changes to curb the spread of the virus. In some instances these changes included closing facilities, affecting major NASA project work for varying lengths of time. We reported in May 2021 that nearly all of the projects in NASA's portfolio of major projects reported experiencing some challenges related to COVID-19 in 2020, including reduced efficiency due to social distancing protocols, travel restrictions that limited progress and delayed or changed oversight, and supply chain inefficiencies.[15]

Portfolio Facing Unprecedented Cost Overruns and Schedule Delays Exacerbated by COVID-19

NASA's projects are experiencing the largest collective cost overruns and schedule delays from their original baselines since we began reporting in 2009. The performance of major NASA projects against their baselines has continued to deteriorate for the past 6 years, although just six projects account for the majority of these overruns. In the past year alone, major NASA projects collectively increased estimated development costs by over $2.8 billion and delayed their schedules by over 9.8 years. While COVID-19 effects are not the primary driver of cost increases and delays across the portfolio, these effects exacerbated cost and schedule growth and the majority of projects in the portfolio are working to mitigate them. Cost overruns and COVID-19 effects also added challenges to NASA's management of its portfolio by limiting budget availability for new projects and projects already in formulation.

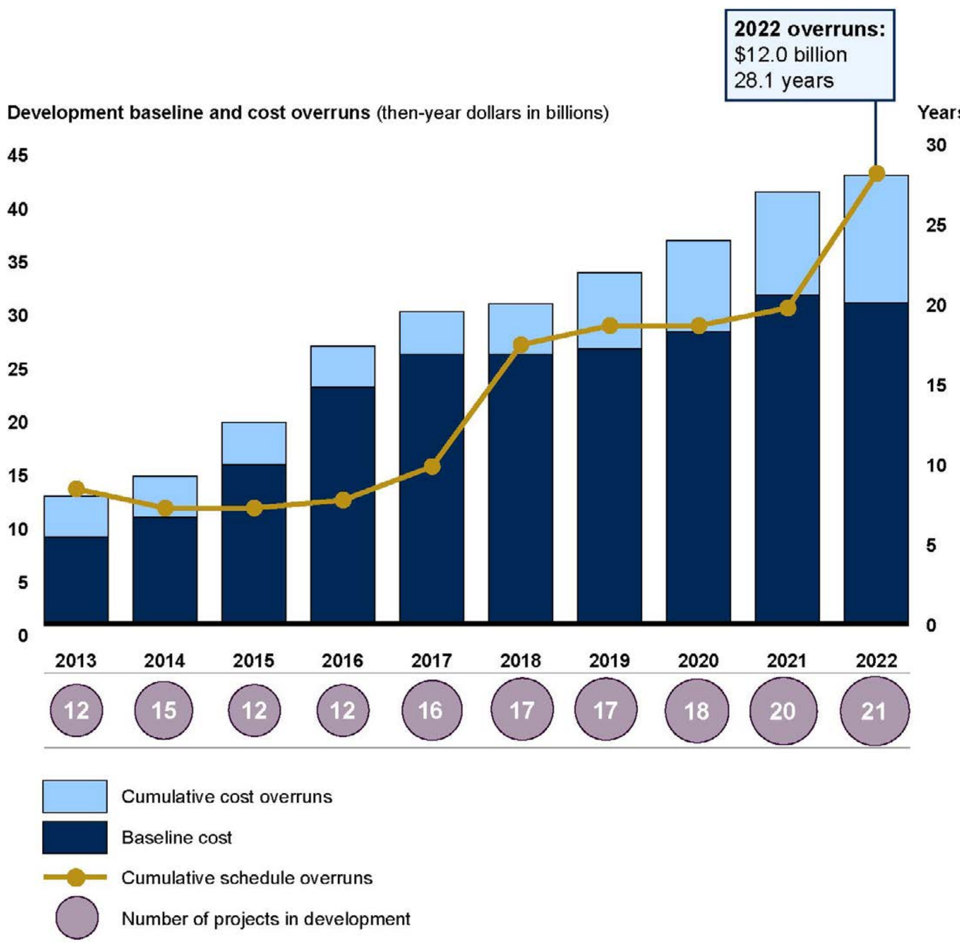
Largest Ever Portfolio of Major Projects in Development Faces Largest Ever Overruns and Delays

NASA is managing the largest number of major projects in development since 2009 while cumulative cost and schedule overruns—overruns

[15]GAO, *NASA: Assessment of Major Projects*, GAO-21-306 (Washington, D.C.: May 20, 2021).

against the original baselines—continue to increase (see fig. 2). This is the sixth year in a row that cost and schedule performance deteriorated. Specifically, the portfolio's development cost cumulative overruns increased from $9.6 billion last year to approximately $12.0 billion, and its cumulative schedule delays collectively increased from 19.7 years to 28.1 years. The number of projects in development increased by one in the last year.

Figure 2: Cumulative Development Cost and Schedule Overruns for NASA's Portfolio of Major Projects Since 2013



Source: GAO analysis of NASA data. | GAO-22-105212

Note: The years in the figure are the year we issued our annual assessment of major NASA projects. Data are primarily as-of January 2022 with a few exceptions noted in appendix II. NASA currently has 22 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.

Cumulative cost and schedule overruns associated with six projects—JWST, SLS, Orion, EGS, Space Network Ground Segment Sustainment (SGSS), and Solar Electric Propulsion (SEP) —account for over 93 percent of the portfolio's total cumulative cost overruns and 83 percent of its total cumulative schedule delays. All six of these projects have previously rebaselined. Five of these projects triggered a congressional notification and met the threshold for rebaseline by exceeding their development cost baselines by over 30 percent. One project—Orion—was rebaselined as the result of NASA's decision to increase the project's scope—including adding a Rendezvous Proximity Operations Docking capability—as well as to account for delays driven by Artemis I and an externally-provided service module. We previously reported on key cost drivers for five of these projects: Orion, SGSS, JWST, EGS, and SLS.[16] For example, we reported on contractor performance issues and schedule delays for Orion and how management oversight issues and technical challenges increased costs for JWST.[17] The SEP project experienced cost and schedule growth in the past year as part of a rebaseline to rescope the project, adjust the order of its deliverables, and complete negotiations with its contractor.

Two projects—Landsat 9 and Lucy—completed development under cost and ahead of schedule, which improved the cumulative performance of the portfolio.

- Landsat 9 launched 2 months early in September 2021 with development costs $138.5 million below its baseline, which NASA attributed in part to its early launch and mature flight hardware. We previously found that the project's firm-fixed-price contract allowed Landsat 9 to avoid cost increases associated with contractor schedule delays.[18]
- Lucy launched 1 month early in October 2021 with development costs $57.2 million below its baseline. NASA attributes the lower costs to launch vehicle cost savings, unused reserves, and favorable project

[16]GAO, *James Webb Space Telescope: Actions Needed to Improve Cost Estimate and Oversight of Test and Integration*, GAO-13-4 (Washington, D.C.: Dec. 3, 2012); GAO-21-105; *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-21-306.

[17]GAO-13-4; GAO-21-105; GAO-19-262SP; GAO-20-405; and GAO-21-306.

[18]GAO-21-306.

management. The project is using the development cost savings to fund recently increased operations costs.

Table 6 shows the cumulative cost and schedule changes for major NASA projects as measured from their original development cost baseline approved at their project confirmation review. For a list of all the projects and their current cost and schedule estimates, see appendix IV.

Table 6: 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 millions of dollars)	Development schedule delay (months)	Development cost overrun (then-year millions of dollars)	Development cost growth percentage
No variance expected from cost or schedule baselines	IMAP	589.5	0	0.0	0.0
No variance expected from cost or schedule baselines	SPHEREx	367.8	0	0.0	0.0
No variance expected from cost or schedule baselines	VIPER	336.2	0	0.0	0.0
Underrunning original estimate	Landsat 9	634.2	(2)	(138.5)	-21.8
Underrunning original estimate	Psyche	681.9	0	(30.8)	-4.5
Underrunning original estimate	Lucy	622.2	(1)	(57.2)	-9.2
Mixed cost or schedule performance	DART	258.3	(3)	11.8	4.6
Mixed cost or schedule performance	Europa Clipper	2,412.8	(11)	96.2	4.0
Overrunning original estimate	SWOT	571.5	14	67.5	11.8
Overrunning original estimate	Roman	2,898.1	7	371.9	12.8
Overrunning original estimate	PACE	558.0	4	74.3	13.3
Overrunning original estimate	OSAM-1[a]	974.4	0	146.1	15.0

			Changes from original baseline to current assessment		
Current performance status	**Project**	**Original baseline development cost estimate (then-year millions of dollars)**	**Development schedule delay (months)**	**Development cost overrun (then-year millions of dollars)**	**Development cost growth percentage**
Overrunning original estimate	NISAR[a]	661.0	12	113.3	17.1
Overrunning original estimate	LBFD	467.7	11	104.5	22.3
Overrunning original estimate	SEP	155.9	46	47.3	30.3
Overrunning original estimate	Orion	6,768.4	13	2,532.8	37.4
Overrunning original estimate	EGS[a]	1,843.5	42	749.0	40.6
Overrunning original estimate	SLS[a]	6,390.0	42	2,718.3	42.5
Overrunning original estimate	LCRD	91.8	25	53.3	58.1
Overrunning original estimate	SGSS	368.1	48	589.2	160.1
Overrunning original estimate	JWST	2,581.1	90	4,536.0	175.7
Totals		**30,232.4**	**337**	**11,985.0**	

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

Source: GAO analysis of NASA data. | GAO-22-105212

Note: Positive values indicate cost growth or launch delays. Values in parentheses indicate cost decreases or earlier than planned launch dates. Data are primarily as-of January 2022 with a few exceptions noted in appendix II.

[a]The EGS, NISAR, OSAM-1, and SLS projects expect to experience additional cost growth or schedule delays, but the exact magnitude is unknown. The projects were reevaluating their cost or schedules at the time of our review. We use the latest cost and schedule estimates provided by NASA for EGS, NISAR, and SLS. For OSAM-1, we calculated a 15 percent cost growth to capture some of the cost growth expected from a pending replan.

Looking forward, the portfolio of major NASA projects in development will continue to evolve. For example, six projects completed development in 2021—therefore, the cost and schedule performance results of these projects will not be included in our future reviews. This is the largest number of projects to complete development that we have ever reported during a single audit cycle, and the agency accomplished this while facing additional challenges of operating during the COVID-19 pandemic. Three of those projects had cost or schedule savings. The remaining three projects—JWST, SGSS, and Laser Communications Relay Demonstration (LCRD)—collectively account for at least 43 percent of the portfolio's total development cost overruns and 48 percent of its collective schedule delays.

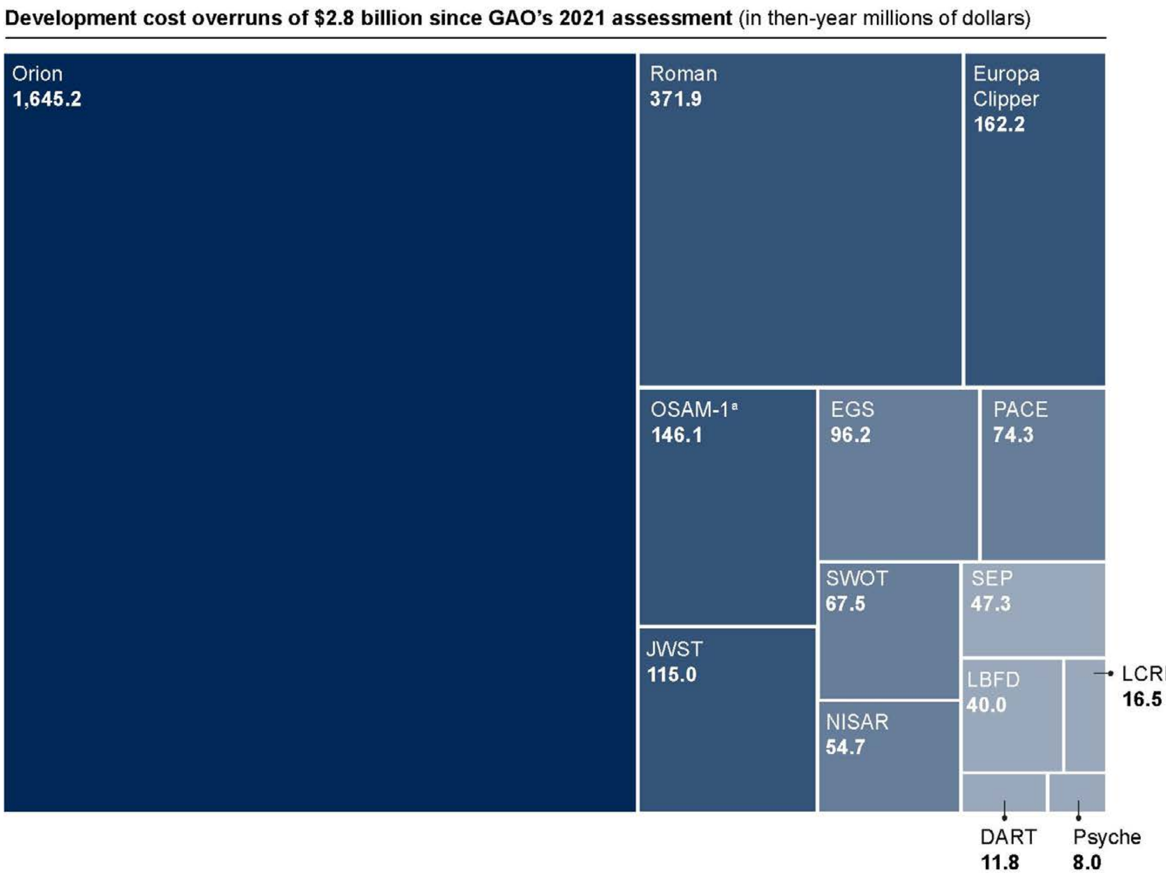
In addition, NASA currently plans for at least five more projects to start the implementation phase in 2022, which will result in them entering our analysis next year. The initial effect will likely be lower cumulative development cost and schedule growth for the portfolio because new projects are less likely to have experienced any growth. Four of those new projects will support Artemis and, as a result, are inherently more complex and risky because they support human spaceflight. Lastly, as of March 2022, four projects have pending cost and schedule revisions ongoing, which will also affect the portfolio's future performance.

Annual Cost Overruns and Schedule Delays Were Exacerbated by COVID-19

Since our last report, major NASA projects in development collectively increased estimated development costs by over $2.8 billion and delayed the collective schedule by over 9.8 years.[19] Orion was the main contributor of annual cost overruns and SEP was the main contributor of schedule overruns, mainly due to technical issues and changes in scope. Fifteen of the 21 projects in development in the portfolio experienced increases to their cost estimates, schedule estimates, or both in the past year. COVID-19 effects are also contributing to cost and schedule increases for a majority of projects. Figure 3 and figure 4 show the projects' annual cost overruns and schedule delays. For a comprehensive list of annual cost and schedule performance by project, see appendix V.

[19]GAO-21-306. This annual total does not include cost and schedule underruns from four projects with a combined cost underrun of $141.2 million and collective schedule underruns of 17 months. Including these underruns, the portfolio of major projects in development increased its estimated costs by about $2.7 billion and delayed its collective schedule by 8.4 years.

Figure 3: Annual Development Cost Overruns for Major NASA Projects since GAO's 2021 Assessment



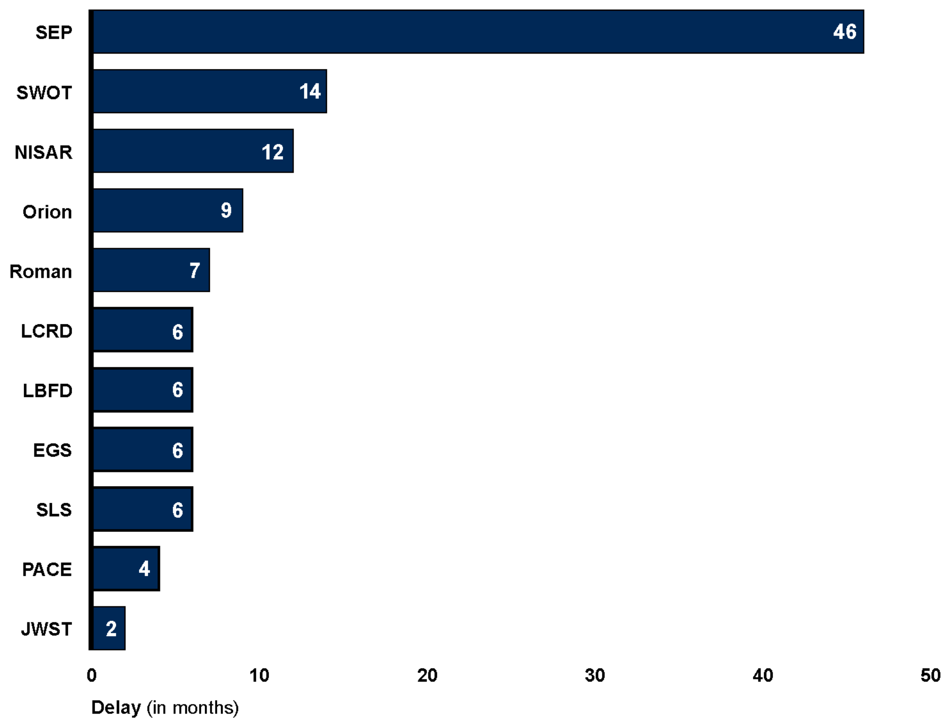
Source: GAO analysis of NASA data. | GAO-22-105212

Legend: Orion: Orion Multi-Purpose Crew Vehicle; Roman: Nancy Grace Roman Space Telescope; OSAM-1: On-orbit Servicing, Assembly, and Manufacturing 1; EGS: Exploration Ground Systems; PACE: Plankton, Aerosol, Cloud, ocean Ecosystem; JWST: James Webb Space Telescope; SWOT: Surface Water and Ocean Topography; NISAR: NASA Indian Space Research Organisation – Synthetic Aperture Radar; SEP: Solar Electric Propulsion; LBFD: Low Boom Flight Demonstrator; LCRD: Laser Communications Relay Demonstration; DART: Double Asteroid Redirection Test.

Note: Data are primarily as-of January 2022 with a few exceptions noted in appendix II. This figure reflects cost increases against what was reported in our May 2021 annual assessment of major NASA projects. This figure does not include projects that reported cost underruns since our last report.

[a]For OSAM-1's latest estimate, we calculated a 15 percent cost growth from its original baseline to capture some of the cost growth expected from a pending replan.

Figure 4: Annual Development Schedule Delays for Major NASA Projects in Development since GAO's 2021 Assessment



Source: GAO analysis of NASA data. | GAO-22-105212

Legend: SEP: Solar Electric Propulsion; SWOT: Surface Water and Ocean Topography; NISAR: NASA Indian Space Research Organisation – Synthetic Aperture Radar; Orion: Orion Multi-Purpose Crew Vehicle; Roman: Nancy Grace Roman Space Telescope; LCRD: Laser Communications Relay Demonstration; LBFD: Low Boom Flight Demonstrator; EGS: Exploration Ground Systems; SLS: Space Launch System; PACE: Plankton, Aerosol, Cloud, ocean Ecosystem; JWST: James Webb Space Telescope.

Note: Data are primarily as-of January 2022 with a few exceptions noted in appendix II. This figure reflects schedule delays against what was reported in our May 2021 annual assessment of major NASA projects. This figure does not include projects that reported schedule underruns since our last report.

Two projects—Orion and Roman—account for more than $2 billion in cost overruns in the last year, which is more than 70 percent of the portfolio's annual cost overruns. These two projects also contributed 1.3 years of schedule delays in the past year. COVID-19 affected cost and schedule performance to varying degrees for these projects.

- NASA rebaselined the Orion project in August 2021, which increased costs by $1.6 billion and added 9 months of delays since our last report. Of the $1.6 billion, the revised baseline includes over $600 million dollars for the Rendezvous Proximity Operations and Docking capability that will allow Orion to dock with other systems, such as the

HLS. It also includes nearly a half-billion dollars for uncertainty going forward—which officials said includes uncertainty around contractor performance, the Artemis I launch date, and COVID-19. The project estimates that $145 million of the $1.6 billion in the new baseline is directly attributable to COVID-19 effects.

- Roman replanned its cost and schedule in June 2021 and added $371.9 million and 7 months to its baseline since our last report. Less than 1 percent of the costs are attributed to a minor accounting error; Roman officials attributed the rest of the cost and schedule increases to COVID-19 related effects such as inefficiencies from remote work, supply chain effects, and vendor delays. Roman established its original baselines in February 2020, before the President declared a national emergency as a result of COVID-19.

Three projects—SEP, Surface Water and Ocean Topography (SWOT), and NASA Indian Space Research Organisation (ISRO) – Synthetic Aperture Radar (NISAR)—accounted for the majority of the portfolio's annual schedule delays. These projects collectively added 6 years of delays in the past year and account for $169.5 million of the portfolio's collective annual cost overruns. The majority of the annual cost and schedule growth for these projects was caused by scope changes or technical issues, which were exacerbated by COVID-19 effects, according to NASA.

- SEP rebaselined its cost and schedule in March 2022. The rebaseline adds at least 46 months in schedule delays and $47.3 million in development cost growth since our last report. Officials said the project needed the additional time and funds to address requirements changes and continued poor contractor performance. The project attributes the 46-month delay in part to a change in scope that required additional contractor negotiations, time needed to adjust the order of deliverables, and a previously omitted test that takes approximately 3 years. The project estimated COVID-19 contributed about $4.1 million in cost growth because of effects such as reduced efficiency and on-site shutdowns at government facilities.
- SWOT replanned its cost and schedule in June 2021, adding $67.5 million in costs and 14 months of schedule delays since our last report. The project attributed about $52.7 million and between 7 and 9 months of those cost and schedule increases to pandemic effects such as shutdown periods, inefficiencies under pandemic operations, the cost of additional staffing to reduce schedule effects, and additional cost reserves for future uncertainties due to COVID-19. The remainder of the cost and schedule overruns are due to technical and

testing issues including issues with the protective blanket for the spacecraft and longer than expected testing set-up among other things.

- NISAR replanned its cost and schedule in April 2021, adding $54.7 million in costs and 12 months to its schedule since our last report. According to project documentation, the overruns stem from technical issues including delays associated with the NASA and ISRO-provided radars. In addition, the project attributed over half of the annual cost and schedule overruns—$37 million and 7 months—to COVID-19-related work stoppages that halted radar work in March 2021 and inefficiencies that exacerbated the delays. However, since the replan occurred, the project continued to experience hardware issues and delays that were further exacerbated by COVID-19. Officials said they have made some progress in addressing the technical issues, but will not retire the associated risks until testing is complete in spring 2022. Project officials said they are waiting to finalize their cost and schedule estimates until they finalize plans to deliver the integrated radar payload to ISRO for integration onto the spacecraft.

Of the remaining 10 projects that collectively account for 2.5 years in schedule delays in the past year and $670.1 million of the portfolio's collective annual cost overruns, COVID-19 affected cost and schedule performance to varying degrees.[20]

- Seven projects attributed cost and schedule increases to a mix of COVID-19 and technical issues. PACE; Low Boom Flight Demonstrator (LBFD); Double Asteroid Redirection Test (DART); Europa Clipper; EGS; On-Orbit Servicing, Assembly and Manufacturing 1 (OSAM-1); and SLS experienced cost increases or schedule delays since our last report due to a mix of technical issues, scope changes, and COVID-19 effects. For example, PACE attributed the majority of its cost increases and schedule delays to COVID-19 effects, such as a facility closure that stopped work for about 4 months. The pandemic further amplified the cost and schedule effects of some significant technical issues PACE experienced in the past year. LBFD replanned its cost and schedule baselines in December 2021 and attributed about two-thirds of its overruns to contractor performance and related quality issues stemming from insufficient and inexperienced staff. The project estimated that COVID-19 effects such

[20]The 2.5 years in annual schedule overruns do not include DART's 3-month or Europa Clipper's 11-month schedule underruns. Including these, the collective schedule overrun for these 10 projects would be 1.3 years.

as reduced efficiency under pandemic protocols accounted for the remainder of its cost and schedule overruns.

- Two projects attributed cost or schedule increases to issues other than COVID-19. JWST and LCRD experienced delays unrelated to COVID-19. Both projects launched in December 2021 after delays and cost increases associated with launch vehicle anomalies.
- One project attributed its cost increases solely to COVID-19 effects. Psyche’s $8 million in cost increases was solely driven by COVID-19 effects such as work stoppages and late hardware deliveries. According to project officials, the later deliveries had downstream effects on costs for staffing since the project had to retain staff for particular hardware longer than previously anticipated.

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

Cost Overruns and COVID-19 Effects Added Challenges to NASA’s Portfolio Management

The unprecedented overruns this year and the risk of future COVID-19 effects are adding challenges to NASA’s portfolio management efforts. For the second year in a row, nearly all of the major projects in development experienced some challenges related to COVID-19, regardless of whether those challenges translated into cost or schedule increases. These challenges ranged from reduced efficiency to supply chain disruptions. In light of the annual overruns coupled with COVID-19 effects, the agency faced additional decisions to prioritize planned funding among projects within its portfolio.

NASA mission directorates have a designated amount of reserves included as part of individual project baselines to address known and unknown risks. However, when a project exhausts its reserves and needs additional mission directorate funding in response to issues such as pervasive technical challenges, additional requirements, or COVID-19 related effects, the directorates must balance planned funding across their portfolios. The overall effect is a limited ability for the mission directorate to continue budgeting for or to start new missions. For example, Science Mission Directorate (SMD) officials said that because additional mission directorate funding was needed to cover cost overruns in implementation projects, including Mars 2020, there was limited ability to budget for new Discovery projects.[21] As a result, mission directorates have to adjust their priorities while still trying to meet the needs of various stakeholders internal and external to the agency including Congress, the presidential administration, and the science community.

We have previously found that leading commercial best practices for portfolio management include focusing on products collectively at an enterprise level in addition to evaluating, selecting, prioritizing, and allocating limited resources to projects that best accomplish strategic or organizational goals.[22] For example, companies weigh the relative costs, benefits, and risks of each proposed product using established criteria and methods to select the best mix of products to develop.

NASA's mission directorates are making some trades to manage their projects within limited funding availability in their portfolio's budget. For example:

- In 2021, in response to the 2011 Planetary Science Decadal Survey recommendations, SMD planned to solicit new proposals for medium-sized projects for the New Frontiers mission.[23] However, due to limited budget availability exacerbated by COVID-19 uncertainties, SMD deferred solicitation and selection of any new projects for New Frontiers in order to preserve funding for another medium-sized New Frontiers program already in formulation, Dragonfly. SMD plans to provide another opportunity for New Frontiers proposals before fall 2024.
- In response to separate decadal survey recommendations, SMD selected two Discovery projects—Venus Emissivity, Radio science, InSAR, Topography, And Spectroscopy (VERITAS) and Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging (DAVINCI)—and started a medium-sized Living With a Star

[21]Discovery consists of small missions intending to use fewer resources and shorter development times with a goal to deepen human understanding of the solar system by exploring the planets, their moons, and small bodies such as comets and asteroids.

[22]GAO, *Best Practices: An Integrated Portfolio Management Approach to Weapon System Investments Could Improve DOD's Acquisition Outcomes*, GAO-07-388 (Washington, D.C.: Mar. 30, 2007).

[23]New Frontiers are medium-class spacecraft missions that conduct valuable scientific investigations to aid understanding of the solar system.

project, the Geospace Dynamics Constellation (GDC).[24] However, shortly after standing up these projects, SMD directed them to stretch out their life cycles with later launch dates due to minimal available funding in the near-term. Officials said that they selected two Discovery projects because they were a high priority in the decadal survey. Officials said they made the selections to avoid wasting the substantial resources already invested by the agency, vendors, and science and engineering communities. Officials stretched out the GDC project to make near-term funding available for other smaller but higher-priority missions approaching confirmation reviews. While officials said this strategy helps preserve funding in the near term, the longer project life cycles also increase total overall costs. However, officials said they can use the additional time to mitigate risks and mature technologies which may reduce risk later on.

- The Exploration Systems Development Mission Directorate decided to grant authority to proceed for the first Gateway Logistics Services mission in 2023 instead of 2020 as originally planned because of limited funding availability and to prioritize funding for other efforts. While waiting for authority to proceed, Gateway officials said that the Deep Space Logistics (DSL) project, which is responsible for overseeing the mission, will work on other tasks to define capabilities and produce specifications for its airlock as well as work on risk reduction task orders to mitigate future risk.

The agency has institutionalized some strategic, senior-level reviews to understand and address the ongoing risks that its portfolio may face. For example, the agency holds monthly Baseline Performance Reviews chaired by the NASA Associate Administrator to discuss issues requiring leadership awareness and identify solutions to challenges as they arise. NASA officials told us that periodically during these meetings, senior management will focus on Category 1 and other highly visible programs and projects as well as perform mission directorate portfolio assessments.[25]

Despite its continued inclusion on our high-risk list, NASA took steps to address issues with acquisition management in the past few years that may benefit its efforts to improve portfolio management. For example, it

[24]The Living With A Star missions were formulated to answer specific science questions about the links between the various solar, Earth, and space systems that affect space weather.

[25]Projects designated as Category 1 are NASA's highest priority projects and generally have life-cycle costs over $2 billion.

established requirements to ensure that its most expensive projects update their cost and schedule estimates at additional reviews throughout their life cycles. It also updated its semiannual High-Risk Metrics Report with revised metrics for reporting project cost and schedule performance, as well as reporting progress made against corrective action plan initiatives and other metrics for program technical performance. In addition, in 2019, the agency's newly established Program Management Improvement Officer began briefing the results of annual portfolio reviews to the OMB. These briefings contain lessons learned from current project management practices across a number of projects. For example, its May 2020 briefing noted that one of the projects highlighted that co-locating NASA personnel with contractors led to positive performance outcomes and even helped resolve performance challenges.

Although the agency put some oversight mechanisms in place and has made some progress in that area, the current poor portfolio performance—unprecedented cost and schedule overruns—indicates there is more work to be done. NASA senior officials recognize this, and stated that there are additional plans in place to address the continuing decline of portfolio performance. These include:

- In December 2020, a senior official briefed key findings from a 2020 Science Mission Directorate Large Mission Study to all of NASA's mission directorates. The study collected lessons learned following cost and schedule overruns in some of NASA's flagship missions, such as JWST. It included findings and recommendations aimed at the creation, execution, and oversight of large strategic missions. For example, the study recommended these large missions conduct requirements analysis and architecture trades prior to phase A to quantify science and cost trade-offs and that they mature critical technologies even earlier than PDR. This would be earlier than GAO's best practice, which is to mature technologies to TRL 6 by PDR. Officials said they began implementing these recommendations in their latest flagship mission, the Mars Sample Return.
- In January 2022, NASA hired a Chief Program Management Officer, a new role. This position will cover the Program Management Improvement Officer functions as well as additional functions to strengthen NASA's enterprise-wide oversight, management, and implementation of program management policies and best practices across the agency. According to NASA officials, the new Chief Program Management Officer will also be responsible for enhancing project management training and reviewing project manager certifications.

- In March 2022, the agency updated its acquisition policy with additional details on the responsibilities for its Chief Acquisition Officer. Senior officials stated that NASA's current Deputy Administrator is slated to fill this role in addition to her other duties.

While these actions are positive steps forward to help improve oversight and insight, is too soon to tell the effect they may have on improving the cost and schedule performance of major projects in NASA's portfolio. We will continue to monitor implementation of these efforts and any effect on portfolio management.

Most Projects Meet Technology Maturity Best Practice but Encounter Difficulties Maturing Design

The majority of major NASA projects matured their technologies to the level recommended by GAO's best practice by their preliminary design review (PDR). However, one of the projects added to the analysis this year—Gateway's Power and Propulsion Element—did not meet our technology maturity best practice for one of its key technologies, which threatens the agency's ability to meet the Gateway program's mission requirements. Furthermore, the number of projects meeting our design stability best practice of releasing 90 percent of design drawings at the critical design review (CDR) remains low. In addition, most projects experienced growth in the number of design drawings after CDR, which can be costly if the project needs to reengineer or rework hardware as a result.

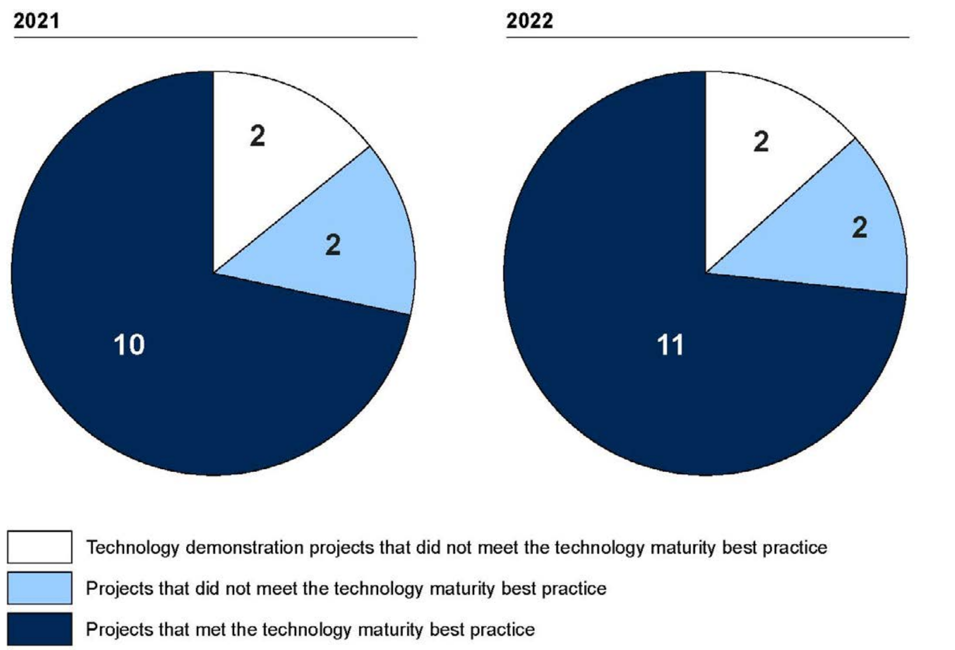
Most Projects Meet Technology Maturity Best Practice, but Gateway Initial Capability Is at Risk

We found that of the 15 major NASA projects that held PDR and identified critical technologies, 11 met GAO's best practice of maturing all critical technologies to a technology readiness level (TRL) 6 by PDR.[26] Achieving

[26]Of the 26 projects past PDR that we reviewed for technology maturity, we excluded 11 projects from this analysis. We excluded eight because they did not report any critical technologies and two because they are technology demonstration projects that did not intend to mature their technologies before PDR. We excluded one other project (Human Landing System) because it was unable to provide information on its critical technologies and associated technology readiness levels until late in our audit cycle. As a result, we could not verify some of the information in time to include its data in our analysis this year.

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 2022 were generally consistent with last year (see fig. 5).

Figure 5: Number of Major NASA Projects Meeting GAO's Best Practice of Achieving a Technology Readiness Level 6 by Preliminary Design Review



Source: GAO analysis of NASA data. | GAO-22-105212

Note: The 2021 data are from GAO's last annual assessment of major NASA projects. The 2022 data are current as of January or February 2022. The data include projects that completed preliminary design review and identified critical technologies. We included two technology demonstration missions in our analysis—the Laser Communication Relay Demonstration (LCRD) and On-Orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1) projects—because while these technology demonstration missions are not required to mature technologies before launch, both of these projects intended to do so by launch. Additionally, both projects have since matured these technologies and LCRD successfully launched in December 2021. We did not include OSAM-1's technologies related to the SPace Infrastructure DExtrous Robot because they were added after the project's preliminary design review.

According to GAO's Technology Assessment Guide, a program identifying and maturing its critical technologies by PDR to a TRL 6 can minimize risks for the systems entering product development.[27] 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 to remain stable.[28] NASA's Systems Engineering policies align with GAO's technology maturity best practice for achieving TRL 6 by PDR. [29] Appendix VI provides a description of technology readiness levels found in this policy.

Four projects included in our analysis held PDR in 2021: Habitation and Logistics Outpost (HALO), Interstellar Mapping and Acceleration Probe (IMAP), Mobile Launcher 2 (ML2), and the Gateway Power and Propulsion Element (PPE).

- HALO met the technology maturity best practice by maturing all six of its critical technologies by PDR.
- IMAP and ML2 did not report any critical technologies at the time of their PDRs and therefore are not included in our analysis.
- PPE did not meet GAO's technology maturity best practice, which threatens the agency's ability to meet requirements for the Gateway Initial Capability that will consist of PPE and HALO. The PPE project did not mature any of its nine critical technologies by PDR. The TRL levels for these technologies ranged from TRL 4 to TRL 5. Having immature technologies past PDR increases the risk of approving a design less likely to remain stable through production. Additionally, late design changes could increase project cost and schedule and affect the PPE project's ability to meet requirements for the Gateway Initial Capability. Among the immature technologies is a thruster required for the high-powered solar electric propulsion system that is currently at a TRL 5 and is being developed by the SEP project. Officials said the SEP thruster technology maturity is progressing and it recently completed its March 2022 critical design review. Due to NASA's decision to launch PPE and HALO together for the Gateway Initial Capability, PPE is required to use this high-power solar electric

[27]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).

[28]GAO-20-48G.

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

propulsion system because it is the only option that can support the co-manifested vehicle's larger mass. In May 2021, we recommended that the Gateway program assess the technical risks of the SEP thruster PPE plans to use and determine whether off-ramps such as reducing requirements or reassessing the schedule are necessary.[30] NASA concurred with this recommendation and provided information on some actions taken. However, we are in the process of evaluating those actions and the extent to which they fully address the recommendation.

As previously reported, three other projects did not meet GAO's technology maturity best practice at the time of their PDR reviews: Roman, LCRD, and OSAM-1.[31] The LCRD and OSAM-1 projects are technology demonstration projects. At the time of their PDRs, LCRD had not matured either of its two critical technologies, and the OSAM-1 project had matured seven of its critical technologies.[32] Since that time, LCRD and OSAM-1 have matured those remaining critical technologies, but Roman still has one critical technology—an optical prism—that has not yet reached maturity.

NASA did not require the LCRD and OSAM-1 technology demonstration projects to mature all of their technologies to TRL 6 by PDR because the purpose of these projects is to develop less mature or higher-risk technologies to TRL 6 or higher by the end of demonstration. As a result, NASA's view is that these projects should not be included in the analysis.[33] However, the LCRD and OSAM-1 projects both intended to mature their technologies to a TRL 6 prior to launch, making them susceptible to the same risks that projects might experience if they fall short of the best practice. As a result, in 2018, when the projects entered our assessment following their PDRs, we included them in our analysis.[34] Since then, NASA and GAO have both published Technology Readiness

[30]GAO-21-330.

[31]GAO, *NASA: Assessments of Major Projects,* GAO-18-280SP (Washington, D.C.: May 1, 2018); and GAO-20-405.

[32]We updated our definition of critical technologies in 2021 to align with GAO's January 2020 Technology Readiness Assessment Guide. OSAM-1 identifies a different number of critical technologies at PDR using our new definition than it did at the time of its PDR in 2017.

[33]GAO-18-280SP and GAO-21-306.

[34]GAO-18-280SP.

Guides that provide further insight into the process of defining and evaluating critical technologies.[35] In light of these publications and as NASA continues to add more technology demonstration projects to its portfolio, we will review our methodology for how we evaluate technology demonstration projects in future assessments.

Our Technology Assessment Guide states that a project correctly identifying critical technologies can prevent waste of valuable resources like funds and schedule later in an acquisition, and not identifying all critical technologies can lead to underrepresentation of technical risk.[36] The 20 projects in the current portfolio that were in development as of January 2022—meaning the project held both PDR and confirmation review—reported an average of 3.5 critical technologies, a slight decrease from the average of 3.9 reported last year.[37] Changes over the last year largely stem from projects moving into and out of the analysis. Five projects in development did not report any critical technologies this year, but many previously reported that they rely on heritage technologies (technologies flown in prior missions). This is notable because critical technologies might include a technology previously classified as heritage. For example, the IMAP project continues not to report any critical technologies, but officials told us that most of the instruments will need to be updated in some fashion and one of the top challenges facing the project is to develop, test, and integrate its 10 instruments. We will continue to monitor technology-related risks for all projects in development.

In June 2020, NASA published a Technology Readiness Best Practices Guide to better disseminate institutional knowledge on best practices for conducting technology readiness assessments for flight projects and

[35]GAO-20-48G. NASA, Office of the Chief Technologist, *Technology Readiness Assessment Best Practices Guide*, SP-20205003605 (June 30, 2020).

[36]GAO-20-48G.

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

NASA's research and technology missions.[38] To accomplish that goal, NASA included a reference to the guide in the August 2021 update of its key program and project management policy. In addition, officials said the guide was informally distributed throughout the agency using various means including presentations and training. NASA also briefed its agency technologists and mission directorate engineers for further circulation of the guide to NASA programs. NASA published the guide as part of the agency's 2018 Corrective Action Plan to address NASA's inclusion in our biennial High-Risk Report after several of its highest-profile mission's experienced cost and schedule growth.[39]

Most Projects Continue to Face Challenges Meeting Design Maturity Best Practice

The majority of projects did not demonstrate a stable design at their CDR. CDR is the time in a project's life cycle when the integrity of the project design and its ability to meet mission requirements are assessed. Our work in the area of product development has shown that releasing at least 90 percent of engineering drawings by CDR lowers the risk of projects experiencing design changes and manufacturing problems that can lead to cost and schedule growth.[40] According to GAO's best practices, engineering design drawings are considered to be a good measure of the demonstrated stability of a product's design because the drawings represent the language used by engineers to communicate to manufacturers the details of a new product design—what it looks like, how its components interface, how it functions, how to build it, and what critical materials and processes are required for fabrication and testing.[41] Once the design of a product is finalized, the drawing is releasable to manufacturers.

Of the 14 projects we reviewed that held CDR as of January 2022, three met the best practice of releasing 90 percent of design drawings by

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

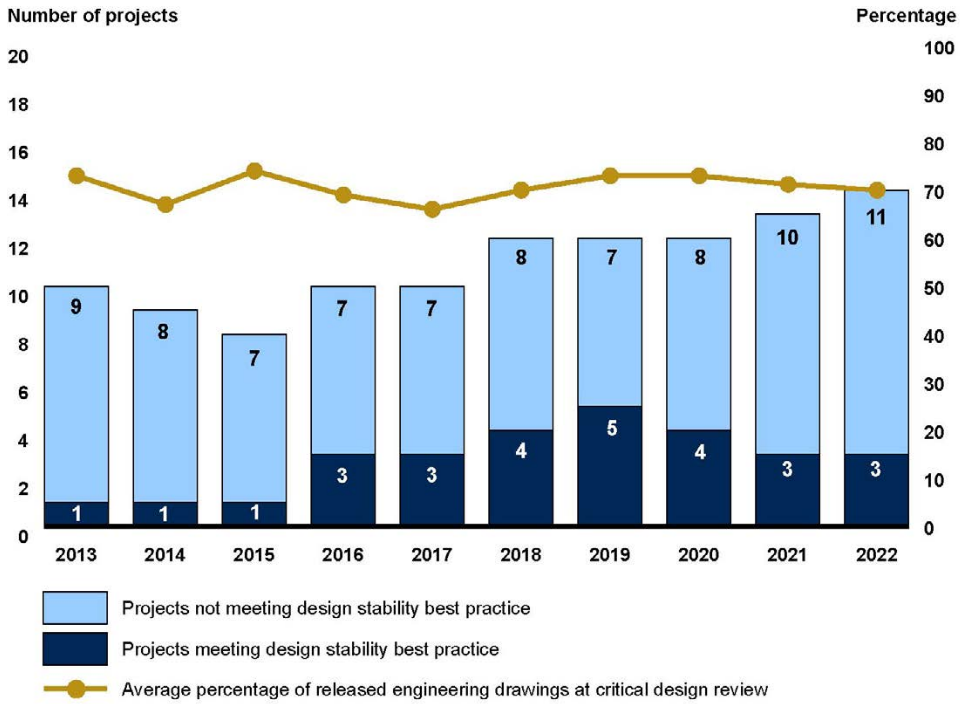
[39]GAO-21-119SP.

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

[41]GAO, *Best Practices: Using a Knowledge-Based Approach to Improve Weapon Acquisition*, GAO-04-386SP (Washington, D.C.: Jan. 1, 2004).

CDR.[42] These three projects—SLS, SWOT, and NISAR—had also met the best practice as of our last review.[43] The average percentage of drawings releasable at CDR across the 14 projects was about 70 percent, a 1 percent decrease from last year (see fig. 6).

Figure 6: Performance of Major NASA Projects against Best Practice for Design Stability



Source: GAO analysis of NASA data. | GAO-22-105212

Note: The years in the figure are the years we issued our annual assessment of major NASA projects. Data are current as of January 2022. GAO's best practice for design stability calls for releasing at least 90 percent of engineering drawings by critical design review.

As shown in figure 6, we have seen little change in our design stability analysis from last year. One project, Mars 2020, launched in 2020 and exited the portfolio this year. Additionally, only three projects—Spectro-Photometer for the History of the Universe, Epoch of Re-ionization and Ices Explorer (SPHEREx); Roman; and Volatiles Investigating Polar

[42]Of the 18 projects past CDR that we reviewed for design stability, we excluded four projects from this analysis because they do not use design drawings as a measure of design stability or track a percentage of total drawings released at CDR.

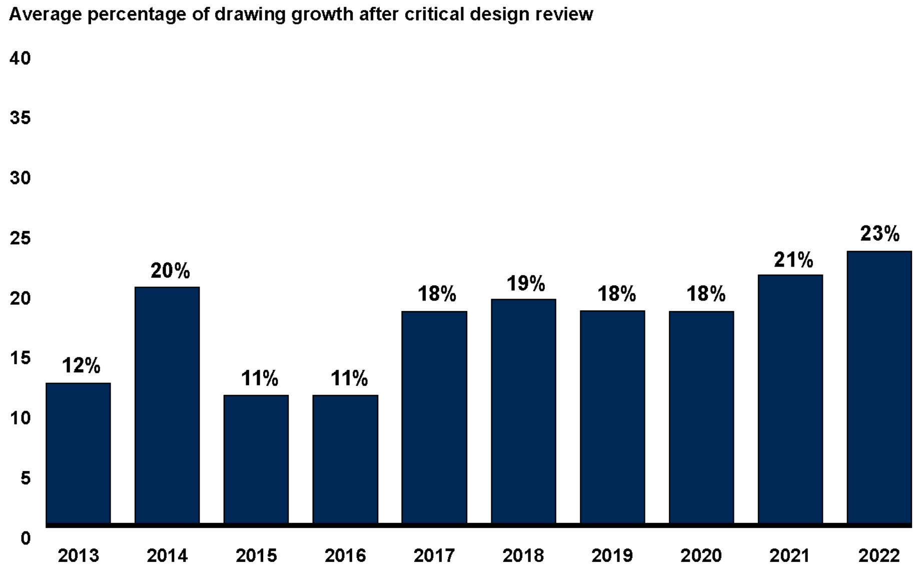
[43]GAO-21-306.

Exploration Rover (VIPER)—held CDR during this reporting period, and SPHEREx did not use drawings.

- SPHEREx did not use design drawings as a metric of design stability and was excluded from this analysis. SPHEREx officials said that they track to the maturity of their models instead, as the models are built to requirements and the project tracks progress against those requirements. SPHEREx officials added that they collect some data on engineering drawings, but do not track a percentage of total drawing released at CDR.
- Roman held its CDR in September 2021 and did not meet the best practice, having released 71.5 percent of design drawings at that time. The spacecraft was the main subsystem responsible for fewer drawings released. Project officials explained that they were still in the process of releasing their final flight design drawings at the time of CDR but expect the numbers of released drawings to increase quickly as the test unit hardware is completed.
- VIPER held its CDR in October 2021 and did not meet the best practice, having released 75 percent of design drawings at that time. Officials attributed this shortfall to the complexity of integrating the rover harnessing design into the overall vehicle and a delay in getting drawings into a releasable state due to the nuances of a new drawing release process.

The average design drawing growth after CDR has gradually increased since 2020 from 18 percent up to 23 percent (see fig. 7). Experiencing a large amount of design drawing growth after CDR that was previously not expected may be an indicator of instability in a project's design late in the development cycle. Design changes at this point can be costly to the project in terms of time and funding because hardware may need to be reengineered or reworked as a result. This year, 11 of the 14 projects that track design drawings and held CDR experienced growth in their number of expected drawings since CDR. For example, PACE saw an increase of 24 percent as compared with last year. PACE project officials previously attributed much of their percent drawing growth after CDR to early work during the COVID-19 remote work environment, as the project held CDR just before the start of the pandemic and was unable to work on hardware in person for an extended period.

Figure 7: Average Percentage of Engineering Drawing Growth after Critical Design Review among Major NASA Projects from 2013 to 2022



Source: GAO analysis of NASA data. | GAO-22-105212

Note: The years in the figure are the years we issued our annual assessment of major NASA projects. Data for 2022 were collected as of January 2022.

NASA released its Common Leading Indicators Detailed Reference Guide in January 2021 to centralize and institutionalize NASA's knowledge about which metrics could be useful for assessing project design stability, including information on how to understand those metrics. The guide provides a more detailed catalog of the required and recommended indicators, as well as a list of other potential metrics that a project could use when analyzing trends to help predict future issues, not only during the design phase but also throughout the project's life cycle.[44] For example, the guide provides details on indicators such as tracking trends on requirement growth and stability, manufacturing nonconformance, and discrepancies from expected or required performance. It also includes a list of other potential metrics for analyzing trends in areas such as staffing or system design. For example, for tracking system design trends, it lists

[44]NPR 7123.1, *NASA Systems Engineering Processes and Requirements* identifies three critical parameters that programs and projects are generally required to report periodically and at life-cycle reviews: mass margin, power margin, and Requests for Action (or other means used by the program/project to track review comments). NPR 7120.5F, *NASA Space Flight Program and Project Management Requirements* identifies a common set of programmatic and technical indicators that are recommended to support trending analysis throughout the life cycle.

metrics such as change requests, the maturity of the system model, and the maturity of the engineering drawings. NASA included a reference to the guide in the August 2021 update of its key project management policy. NASA's 2018 Corrective Action Plan included an initiative to review the set of indicators recommended and required in NASA policy.[45] NASA conducted a study in 2019 to review those indicators and make further recommendations. One of the recommendations from that study was to develop the Common Leading Indicators Detailed Reference Guide.

NASA project managers have a variety of metrics available to measure design stability; however, design drawings remain an important metric used by the majority of major NASA projects past CDR. There are currently only four major projects that have held CDR that do not use design drawings to measure design maturity: Psyche, SPHEREx, EGS, and SGSS. We excluded these four projects from our best practice analysis. However, these projects use metrics that are either recommended or listed as other potential metrics for consideration in NASA's Common Leading Indicators Guide. For instance, Psyche officials said that they assess the project's design by reviewing engineering change requests as well as contractor changes to the contract and scope of work, among other metrics. As noted earlier, SPHEREx officials stated they look at model maturity tracked against requirements. SGSS tracks a variety of metrics such as software size estimates against actual results for any developed software, while EGS tracks metrics like requirements stability and change requests processed. The 14 projects we reviewed track design drawings as one measure of design maturity. Some of these projects use other metrics as well. For example, Roman officials said that they also track that all project requirements are defined by CDR and VIPER officials said that they also track mass margin.

As we previously reported, NASA officials raised concerns about our use of the design drawing best practice to assess design stability because they believe the standard was developed prior to the use of computerized drawings.[46] We recently started work to update our best practices for product development and anticipate that an important component of this

[45]NASA published its 2018 Corrective Action Plan to address the agency's inclusion in our biennial High-Risk Report after several of its highest-profile missions experienced cost and schedule growth.

[46]GAO-21-306.

work will involve identifying current leading practices that facilitate design stability.[47] We will continue to collaborate with NASA as we conduct this work, including leveraging information in the leading indicators guide, as appropriate. In the meantime, design drawings released by CDR remains a useful metric that is tracked by most projects and can be commonly applied across most of NASA's portfolio of major projects.

Agency Comments

We provided a draft of this report to NASA for its review and comment. In its written response, reprinted in appendix VII, NASA generally agreed with our findings, including the outsized effect a subset of projects had on the portfolio's cost and schedule growth. As more projects enter the portfolio, NASA has an opportunity to continue to improve its acquisition management. We look forward to continuing to work with NASA on its efforts to improve cost and schedule performance.

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.

[47]In March 2022, GAO released the first in a series of reports updating our acquisition best practices: GAO, *Leading Practices: Agency Acquisition Policies Could Better Implement Key Product Development Principles,* GAO-22-104513 (Washington, D.C.: Mar. 10, 2022). Subsequent reports will look at topics that include metrics, indicators, and design tools, as well as how those are applied for successful iterative design.

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

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

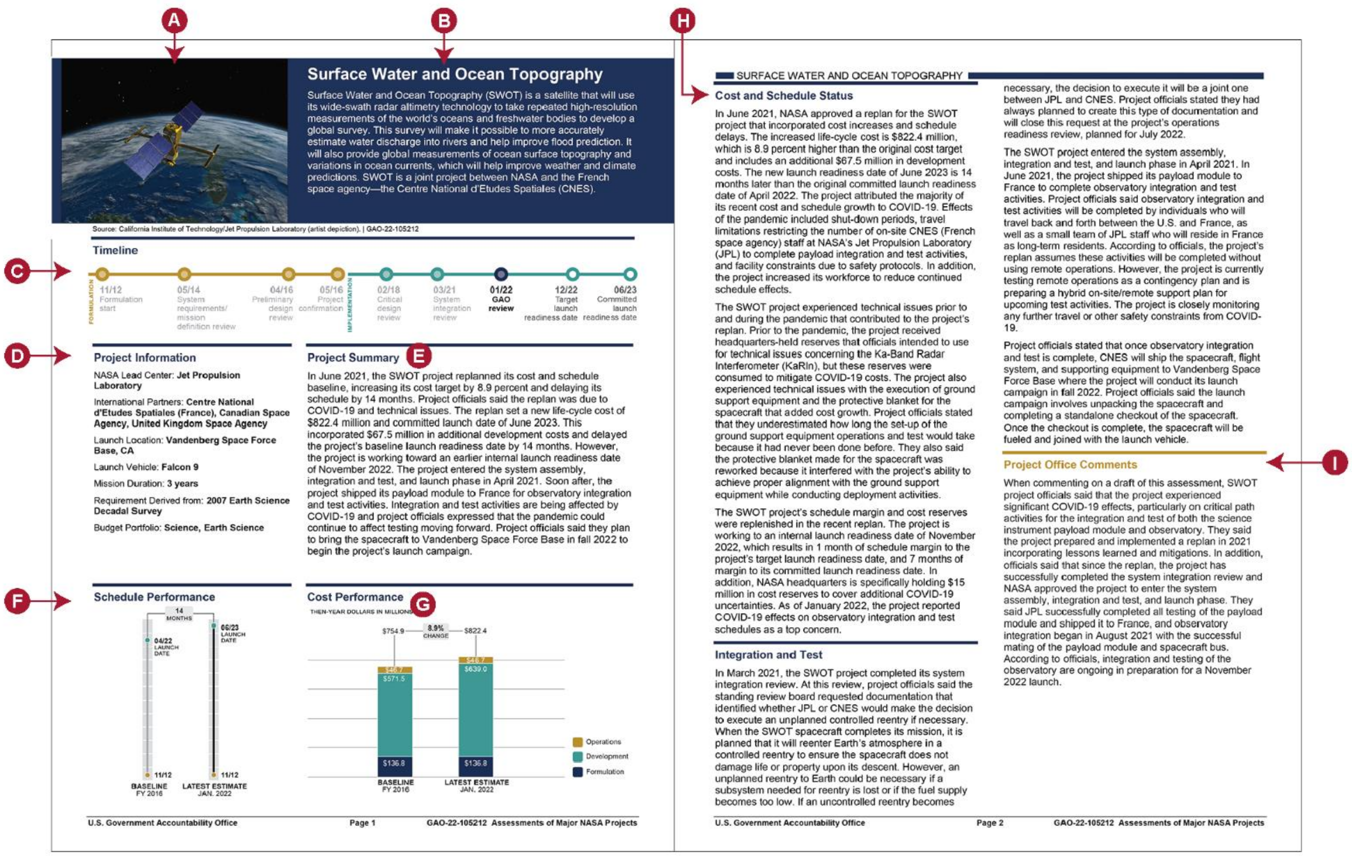
The Honorable Don Beyer
Chairman
The Honorable Brian Babin
Ranking Member
Subcommittee on Space and Aeronautics
Committee on Science, Space, and Technology
House of Representatives

Appendix I: Individual Project Assessments

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

See figure 8 for an illustration of a sample assessment layout.

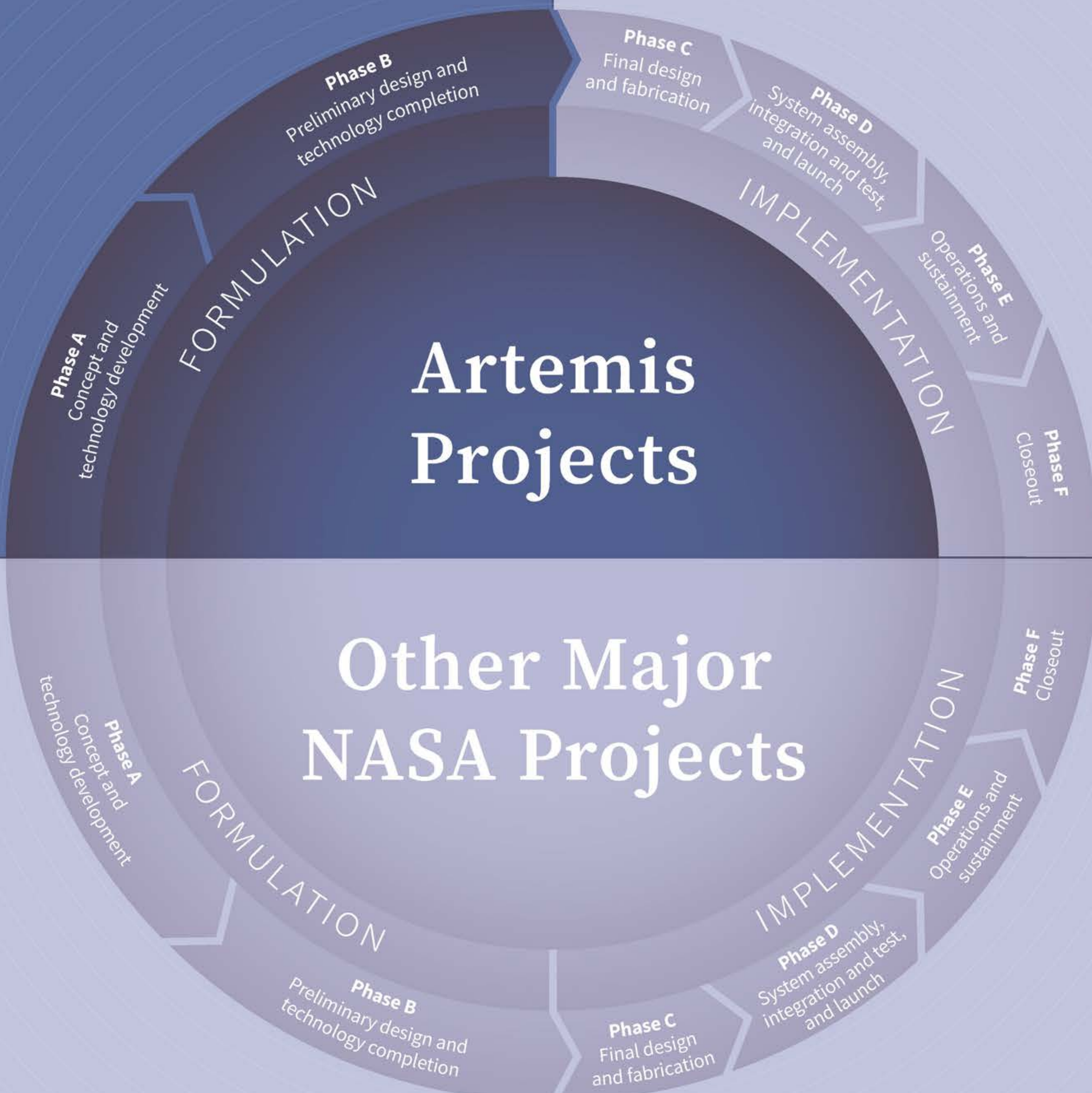
Figure 8: Illustration of a Sample Project Assessment



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

Source: GAO analysis. | GAO-22-105212

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



Source: U.S. Government Accountability Office analysis of NASA data. | GAO-22-105212

Artemis

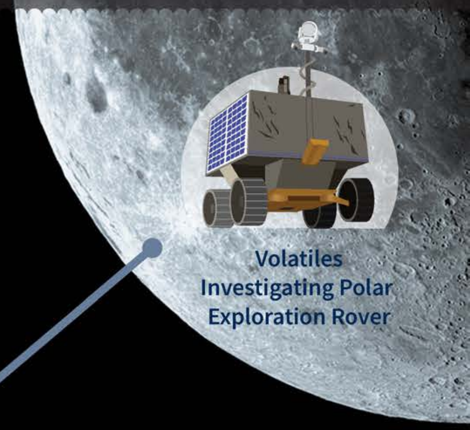
MAJOR NASA PROJECTS AND PROGRAMS SUPPORTING ARTEMIS MISSIONS

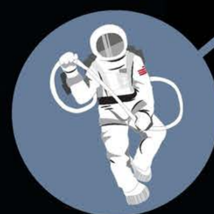
ARTEMIS I & II

Planned for Spring 2022 and May 2024, respectively; these will be uncrewed and then crewed test flights demonstrating the Space Launch System, Exploration Ground Systems, and Orion Multi-Purpose Crew Vehicle.

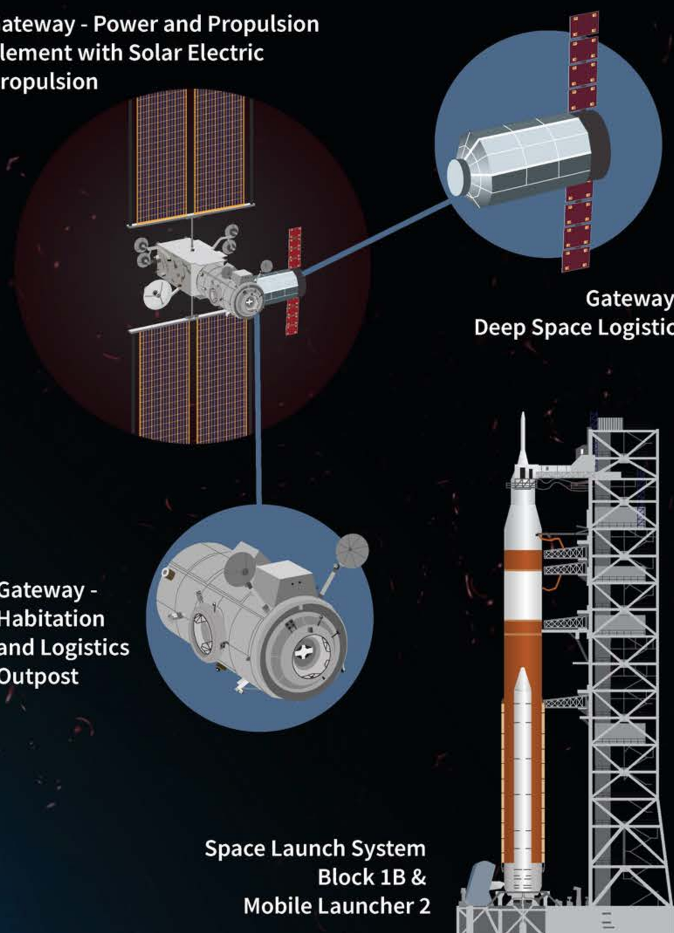
ARTEMIS III

Planned for no earlier than 2025, this mission will be a crewed lunar landing using a Human Landing System that docks in lunar orbit with the Orion crew capsule.





ARTEMIS IV and beyond



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

Source: U.S. Government Accountability Office analysis of NASA documentation (data and images); elen31/stock.adobe.com (moon image); dimazel/stock.adobe.com (earth background). | GAO-22-105212

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Source: NASA. | GAO-22-105212

Exploration Extravehicular Activity

The Exploration Extravehicular Activity (xEVA) project is responsible for providing space suits and other hardware that support astronaut activities on the International Space Station and the lunar surface for the Artemis III and later missions. The project office will oversee a contractor 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; and (3) space suits, including the portable life-support backpack and the pressurized garment that wraps around the astronauts. The Gateway program oversaw the project until December 2021, when NASA approved the creation of a new program within which xEVA is a project.

Project Information

NASA Lead Center: **Johnson Space Center**

Service Life: **5 Years**

Requirement Derived from: **NASA Strategic Plan**

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

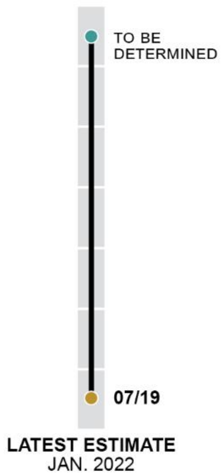
Next Major Project Event: **Contract Award (spring 2022)**

Current Status

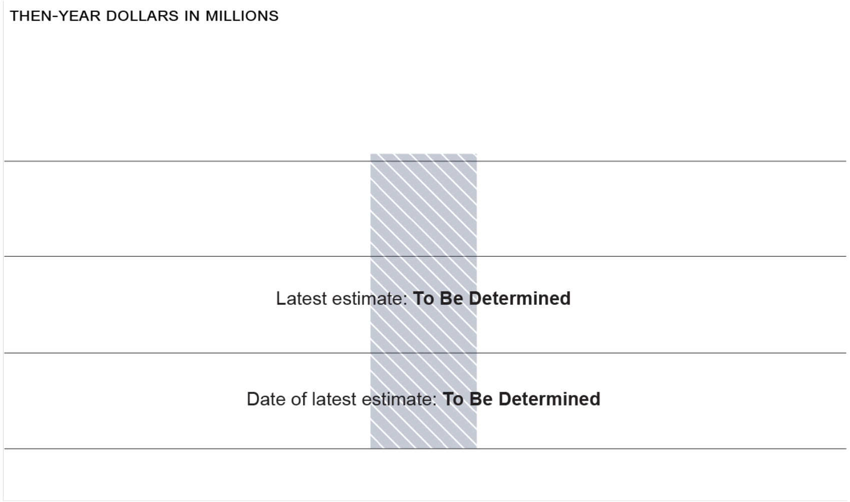
In July 2021, NASA approved a change in acquisition strategy for the space suits and associated hardware from an in-house development to using a contractor. NASA expects to award a contract in spring 2022. The new strategy includes competition among commercial vendors to, among other things, demonstrate and produce the space suits and associated systems. NASA officials stated that a commercial approach will enable innovative solutions among would-be competitors, drive down cost through competition, and enable a commercial market for extravehicular activity (EVA) space suits.

However, NASA noted this new approach presents risks, including having an aggressive schedule to transition the work to a contractor. While the program's goal is to demonstrate the suits capability as early as 2024, NASA will not have the contract awardee's proposed schedule until after contract award. To help mitigate the schedule risk, officials said they provided data on the government's space suit design and technology development efforts to prospective contract awardees. The officials said that, if the contractor chooses to use these data, it could speed up development time frames to support the Artemis III mission. Additionally, officials are creating plans to maintain critical technical skills for its EVA workforce as they transition work to a contractor.

Preliminary Schedule



Preliminary Cost



Project Office Comments

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

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Source: NASA. | GAO-22-105212

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)
- Airlock*

*Not yet a confirmed contribution

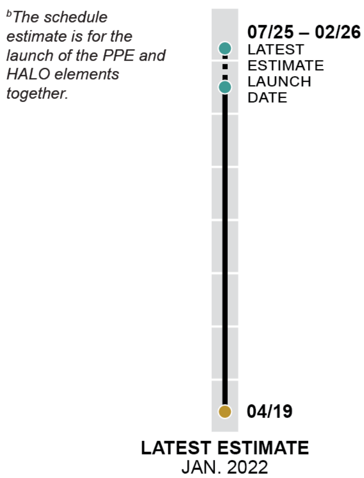
Current Status

In May 2021, the Gateway program established a preliminary cost estimate of $3.0 to $3.7 billion and a preliminary launch schedule from July 2025 to February 2026 for its PPE and HALO elements, which will launch together. The PPE will provide power and propulsion and the HALO will provide living space for crew. The cost estimate also includes the costs of the launch vehicle and program support for integration and launch. The program plans to establish a cost and schedule baseline for the development and launch of these elements in July 2022.

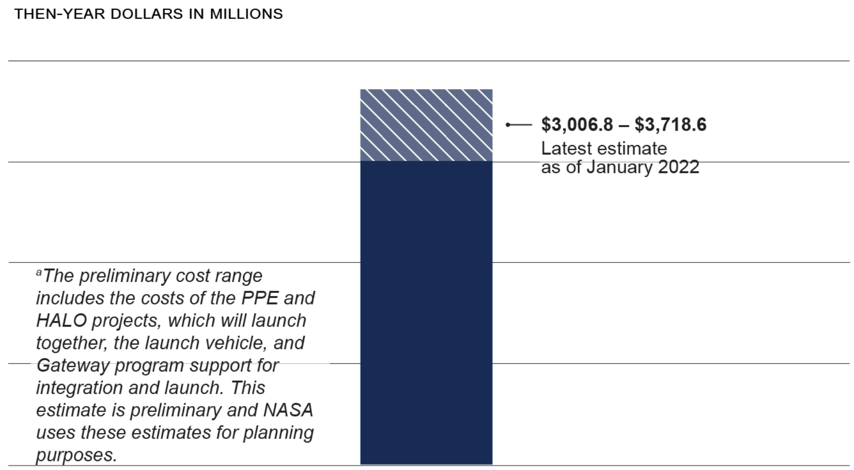
This preliminary cost and schedule estimate does not include the Deep Space Logistics (DSL), which the Gateway program also manages. The program plans to establish separate cost and schedule baselines for the project. The DSL project is responsible for the execution of commercial services and a vehicle that will provide Gateway with cargo and supplies prior to crew arrival. The preliminary cost and schedule estimate also does not include the costs of the Exploration Extravehicular Activity project, which NASA removed from the Gateway program in December 2021 and placed under a new program. The DSL project is responsible for acquiring space suits and tools for extravehicular exploration on the moon.

NASA plans to launch the PPE and HALO in time to support the Artemis IV mission. During this mission, astronauts, who arrive to the Gateway on the Orion crew capsule, will help integrate the International Habitat (I-HAB) with HALO. The I-HAB will provide additional living space to crew on Gateway. Later missions will support lunar landing missions using Gateway.

Preliminary Schedule



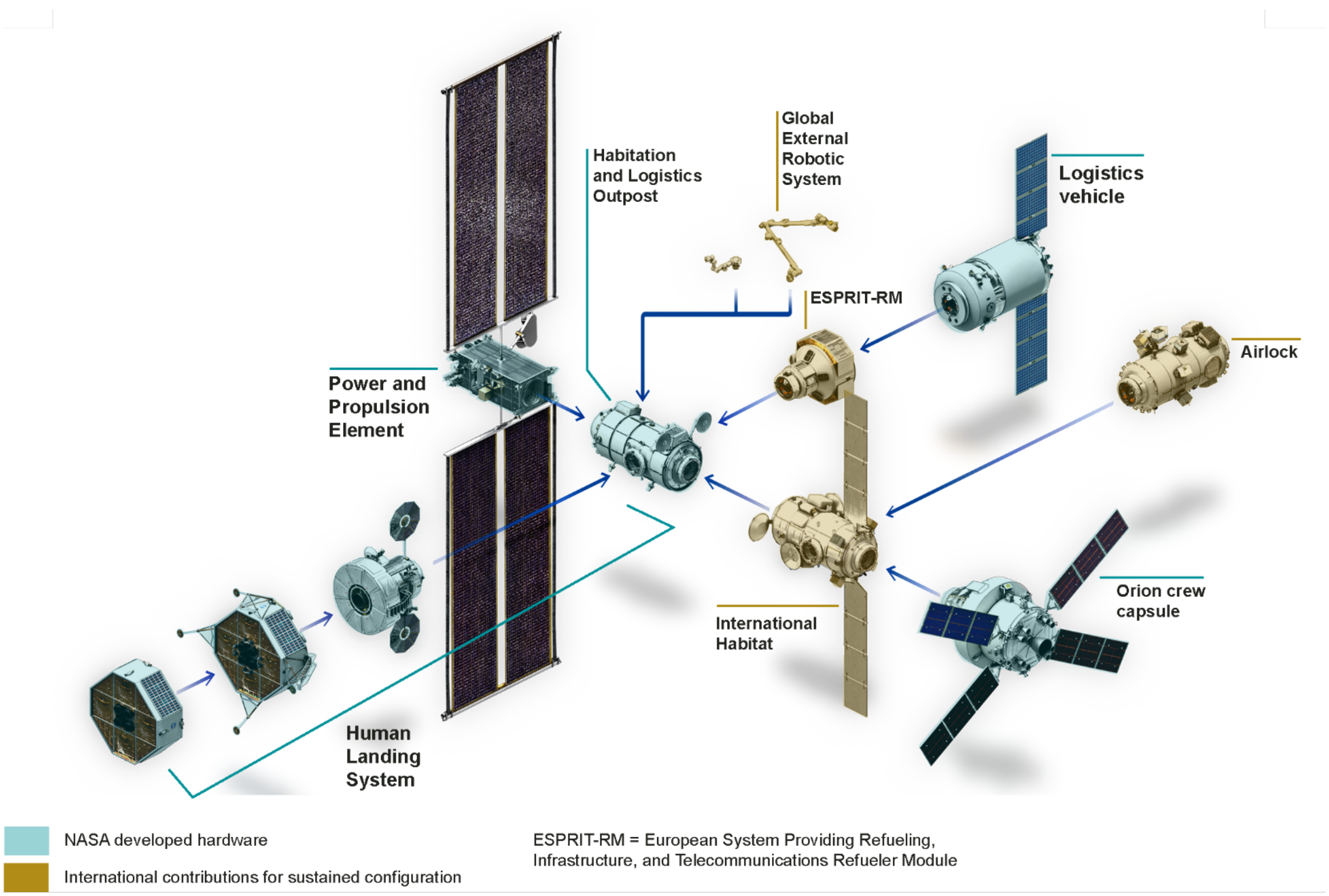
Preliminary Cost



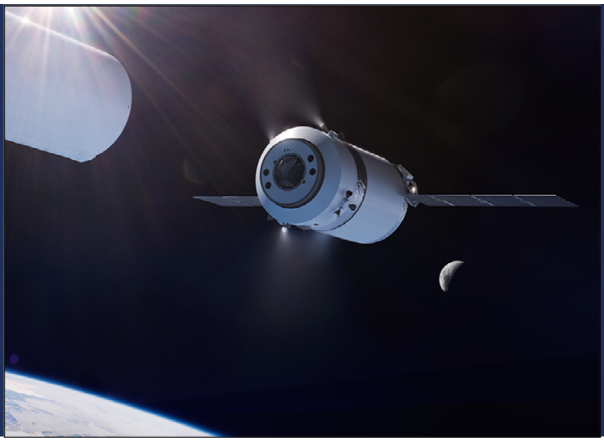
Gateway sustained configuration

The Gateway sustained configuration includes three U.S.-developed elements and four elements contributed by international partners. The illustration 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 transports crew from Earth to Gateway, where they transfer into a Human Landing System for transport to the lunar surface and back. After returning to Gateway, the crew returns 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



Source: GAO analysis of Gateway Program documentation (data); National Aeronautics and Space Administration (NASA) (image). | GAO-22-105212



Source: SpaceX. | GAO-22-105212

Gateway – Deep Space Logistics

The Deep Space Logistics (DSL) project is responsible for the execution of commercial services that will provide Gateway—a sustainable outpost in lunar orbit—with cargo and supplies prior to crew arrival. NASA plans for multiple logistics resupply missions to the Gateway to deliver supplies and provide storage and trash disposal. NASA may also use the Gateway Logistics Services contract to deliver other elements of the Artemis lunar exploration architecture. In March 2020, NASA awarded a firm-fixed-price, indefinite delivery/indefinite quantity contract to SpaceX to provide logistics services.

Project Office Comments

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

Project Information

NASA Lead Center: **Kennedy Space Center**

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

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

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

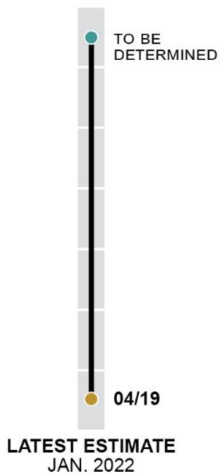
Next Major Project Event: **Authority to proceed with first mission**

Current Status

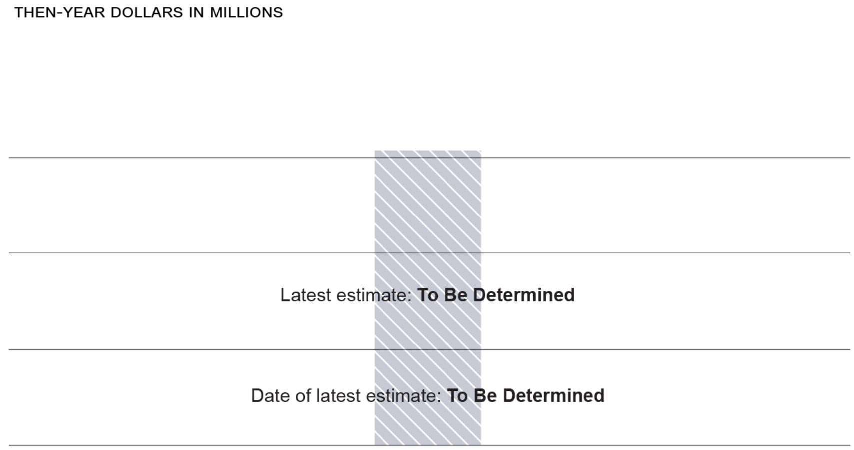
As of July 2021, the DSL project delayed plans to grant SpaceX with authority to proceed for the first Gateway Logistics Services mission from October 2020 to late 2023. NASA officials attribute the delay to funding constraints from operating under a continuing resolution and other NASA funding priorities. NASA plans for the first mission of SpaceX's logistics vehicle, Dragon XL, to deliver another element—Gateway External Robotic System (GERS)—to the Gateway in 2027. Project officials stated they plan to establish cost and schedule baselines for this first mission at a key decision point review but do not yet have an estimate for when they will hold that review. At the same time, officials are also evaluating whether the project needs an additional mission prior to the GERS mission to support the Gateway.

In the meantime, project officials stated they provided SpaceX with about $14 million, as of November 2021, to conduct several special studies for the project. These studies aim, for example, to identify risk areas across flight software, data handling, and communication systems, as well as test selected components of the SpaceX Dragon XL capsule's response to simulated deep space radiation exposure. SpaceX studied the updated project requirements and the potential effects on cost and schedule in case of further delays to receiving the authority to proceed.

Preliminary Schedule



Preliminary Cost



Project Office Comments

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

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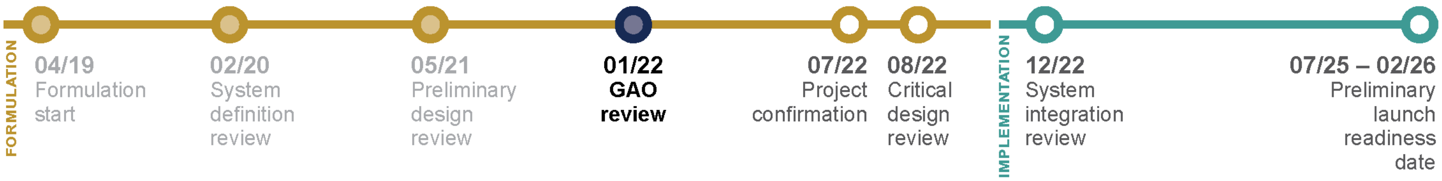
Source: NASA. | GAO-22-105212

Gateway – Habitation and Logistics Outpost

The Gateway's Habitation and Logistics Outpost (HALO) will be the initial crew module for the Gateway. The HALO will provide living quarters and 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 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 co-manifesting. The HALO project is responsible for managing the integration, test, and launch of the co-manifested PPE and HALO.

Timeline



Project Information

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**

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

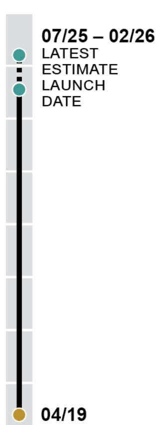
Project Summary

In May 2021, the Gateway program established preliminary cost and schedule estimates for its initial capability, which include both the HALO and PPE projects. The program's preliminary cost estimate included $1.2 to $1.5 billion for its HALO project and a preliminary launch schedule from July 2025 to February 2026 for both the HALO and PPE projects, which will launch together. The program plans to set its cost and schedule baselines for the initial capability in July 2022.

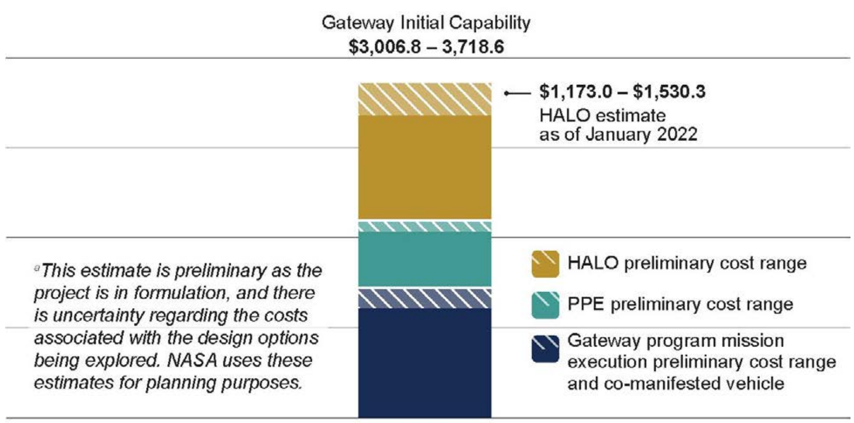
The HALO project held its preliminary design review in May 2021 with all critical technologies meeting GAO's best practice of achieving a technology readiness level 6 by this review, which can minimize risk. The project plans to hold its critical design review in August 2022.

As of February 2022, the co-manifested vehicle is above the Falcon Heavy launch vehicle's mass limit. If the mass is too high, it could affect the vehicle's ability to reach the correct lunar orbit. The project is taking steps to reduce mass, including evaluating whether it needs to potentially off-load some components for initial launch.

Preliminary Schedule



Preliminary Cost



[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

In May 2021, the Gateway program established preliminary cost and schedule estimates for its initial capability—which include both the HALO and PPE projects—to support the Artemis IV mission, a crewed mission to the Gateway. The Gateway program included $1.2 to $1.5 billion for the HALO project within its preliminary cost estimate. The program set a preliminary launch schedule from July 2025 to February 2026 for both the HALO and the PPE, which will launch together on a Falcon Heavy launch vehicle. The Gateway program plans to hold a key decision point review in July 2022 to establish its cost and schedule baselines for the initial capability, which will set the commitments against which the program's performance will be measured. HALO project officials said they anticipate the HALO costs for the Gateway initial capability baseline will fall within the preliminary estimated range.

Previously, in June 2020, NASA definitized a firm-fixed-price and cost-plus-incentive-fee contract valued at $187 million to develop the HALO's preliminary design. In July 2021, NASA reported definitizing a firm-fixed-price modification valued at over $930 million to the project's contract. The modification added work for the HALO's production and integration with the PPE, among other things. This increased the contract's value to a total of approximately $1.27 billion.

Although the HALO's preliminary launch date is between July 2025 and February 2026, the project is working to an earlier launch date of November 2024. HALO project officials explained that they are intentionally working toward an earlier launch date to maintain schedule margin with the contractor and to potentially reduce project costs. Gateway program officials added that the date the HALO project works toward could change when the program holds its July 2022 key decision point review.

Technology and Design

The project held its preliminary design review in May 2021, with all six critical technologies meeting GAO's technology maturity best practice of achieving technology readiness level 6 by preliminary design review. GAO's best practices work has shown that maturing technologies by this review can minimize risks for systems entering product development. The project office plans to hold its critical design review in August 2022.

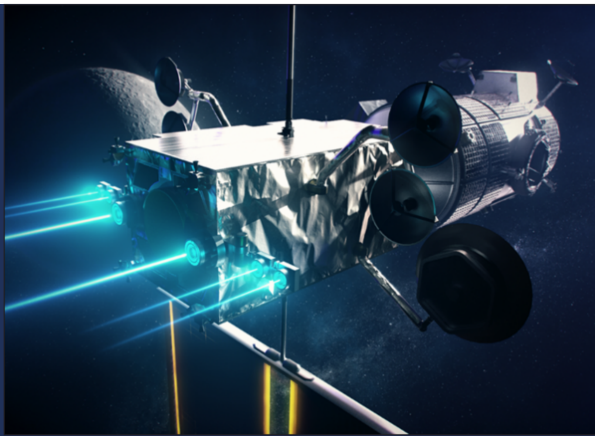
In February 2020, NASA decided to integrate the HALO with the PPE on the ground and launch them together. After NASA integrates the HALO and the PPE together, it creates one vehicle for launch, known as the co-manifested vehicle. This decision resulted in design changes to the HALO and increased technical risk for the overall co-manifested vehicle, such as an increase in mass. The HALO project, Gateway program, and Advanced Exploration Systems division—which oversees the Gateway program—are tracking the co-manifested vehicle mass as a top risk. According to officials, the project office finalized the updated mass allocations for the HALO and the PPE in February 2022, though as of that date, the co-manifested vehicle mass was above the established mission design limits. If the combined mass of the co-manifested vehicle is too high, it could affect its ability to reach the correct lunar orbit. Further, project officials explained that mass affects the overall mission design because the Falcon Heavy has a mass limit.

The project office is taking steps to try to reduce mass. For example, the project also created a mass recovery plan and is assessing mass reduction opportunities. The HALO and PPE projects are working with their respective contractors to manage mass. The project is evaluating whether it will need to off-load some components for initial launch, which would then need to be delivered to Gateway on a future logistics vehicle and installed on-orbit.

The HALO and PPE projects held a co-manifested vehicle synchronization review in February 2021. HALO project officials said the review helped the projects to define interfaces between the HALO and the PPE, and helped the projects work through integration issues together. The officials said that they also coordinated with the PPE project on integration activities, such as how the two projects plan to integrate a propulsion refueling system. Officials said the projects are planning to hold the next co-manifested vehicle synchronization review after completion of the project-specific critical design reviews.

Project Office Comments

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



Gateway – Power and Propulsion Element

The Power and Propulsion Element (PPE) will 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 co-manifesting. After NASA integrates the HALO and PPE together, it creates one vehicle for launch.

Source: NASA. | GAO-22-105212

Timeline

FORMULATION
- 09/17 Formulation start
- 09/19 System requirements review
- 11/21 Preliminary design review
- **01/22 GAO review**
- 05/22 Critical design review
- 07/22 Project confirmation

IMPLEMENTATION
- 05/23 System integration review
- 07/25 – 02/26 Preliminary launch readiness date

Project Information

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**

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

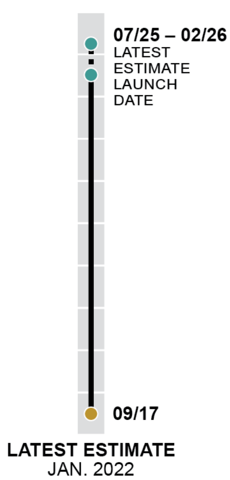
Project Summary

The Gateway program established preliminary cost and schedule estimates for its initial capability in May 2021. This included from $623 to $750 million for the PPE project and a preliminary launch schedule from July 2025 to February 2026 for both the HALO and PPE projects, which will launch together. The Gateway program is planning to set its cost and schedule baselines for the initial capability in July 2022.

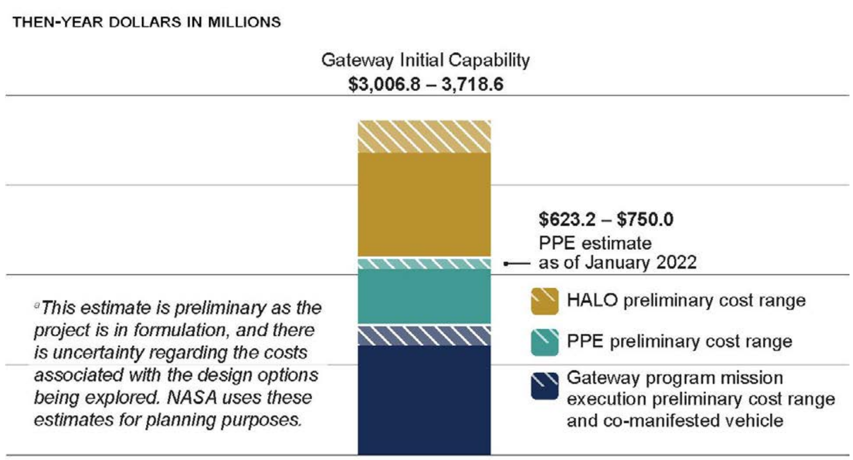
As of December 2021, the PPE project reported almost $142 million in cost growth on its firm-fixed-price contract to design and develop the PPE and 25 months of schedule delays due to requirements changes. Project officials said they expect additional contract modifications and contract cost growth for a range of requirements changes.

The PPE project held its preliminary design review in November 2021 with none of its nine critical technologies mature, which increases project technical and schedule risk. For example, one of the project's top risks relates to efforts to develop its propulsion thruster technology, which is significantly behind schedule. If the thrusters are not ready on time, it will affect the PPE's ability to meet Gateway requirements.

Preliminary Schedule



Preliminary Cost



Cost and Schedule Status

In May 2021, the Gateway program established preliminary cost and schedule estimates for its initial capability—which include both the PPE and HALO projects—to support the Artemis IV mission, a crewed mission to the Gateway. The Gateway program included from $623 to $750 million for the PPE project within its preliminary cost estimate. The program set a preliminary launch schedule from July 2025 to February 2026 for both the PPE and the HALO, which will launch together on a Falcon Heavy launch vehicle. After NASA integrates the HALO and the PPE, it creates one vehicle for launch, known as a co-manifested vehicle. The Gateway program plans to hold a key decision point review in July 2022 to establish its baseline cost and schedule for the initial capability, which will set the commitments against which the program's performance will be measured.

Changes to multiple requirements led to cost growth and schedule delays on the PPE's firm-fixed-price contract to develop and demonstrate power, propulsion, and communications capabilities. When NASA awarded the contract in May 2019, the total value of the contract was $375 million. As of December 2021, the project reported almost $142 million in cost growth and 25 months of schedule delays as a result of NASA's requirements changes. For example, the change to launching as a co-manifested vehicle required the PPE project to increase the power in its SEP system and redesign its propellant tank since the PPE will now be launched in a different configuration when compared to its original design. The project also updated the PPE's design after identifying requirements gaps with Gateway program requirements.

Project officials expect additional contract modifications for a range of requirements changes related to the co-manifest and to align project requirements with Gateway program requirements, among other things. The project office estimates that these changes could result in the contract value growing by roughly 80 percent or $300 million over its value at the time of award.

The PPE project is currently working to deliver PPE to the HALO project in fall 2024 for integration with the HALO. However, the project is tracking the risk of late delivery of its high-powered SEP thrusters, which could affect this schedule or result in cost growth. The effort to develop and produce these thrusters, which NASA's SEP project manages, is significantly behind schedule. As of February 2022, the PPE project office estimated about 6 months difference in the PPE project's need date and the contractor-estimated delivery date for the thrusters. Project officials said they are working with the PPE and SEP projects' contractors to identify options to minimize the negative effect on the overall launch schedule for the co-manifested vehicle.

Technology and Design

The PPE held its preliminary design review in November 2021, with none of its nine critical technologies mature. This does not align with GAO's best practice for technology maturity, which states that critical technologies should achieve technology readiness level (TRL) 6 by preliminary design review to minimize risks for further product development. These technologies include the high-powered SEP thrusters and the solar arrays. Project officials explained that some critical technologies related to its spacecraft bus—a commercial spacecraft platform adaptable for a variety of missions—are at a lower TRL because NASA made changes to heritage subsystems to accommodate the PPE project's requirements. The project is currently planning to hold its critical design review in May 2022.

In our May 2021 report, we found that if the SEP thrusters are not mature when needed for integration with the PPE, the project will not be able to fulfill the current requirements for the Gateway.[1] There is no back up propulsion system to the SEP thrusters. If the SEP thrusters are not available, the PPE project would need to request relief from its technical requirements or reassess the schedule. As a result, we recommended that NASA assess the thruster's technical risks and determine if off-ramps are needed or if the project's schedule should be reassessed. NASA concurred with this recommendation and the project plans to take action on it in 2022. Based on the current schedule, NASA expects to launch the flight thrusters on the PPE in 2024 before life testing is completed in 2028. However, project officials said that they consider this a low-risk decision based on the agency's decades of knowledge on the topic.

The project is also tracking risks related to the PPE's mass that could result in late design changes. As of February 2022, the PPE's expected mass exceeded its mass allocation for the co-manifested vehicle. If the PPE project has to make late design changes to reduce mass, it could result in cost growth and schedule delays. The project office has mass reduction efforts underway, including assessing the removal of certain capabilities from the PPE to reduce mass. Reducing the PPE capabilities could affect other Gateway elements and the overall mission.

Project Office Comments

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

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

Source: NASA. | GAO-22-105212

Human Landing System

The Human Landing System (HLS) will provide crew access to the lunar surface and demonstrate capabilities required for deep space missions. NASA plans to use the HLS for the Artemis III mission to the moon—planned for no earlier than 2025—and for later missions focused on developing a sustainable lunar presence. It will deliver a crew from lunar orbit to the lunar surface, provide capabilities for lunar surface extra-vehicular 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 for Artemis III and with Gateway for later missions. The design, development, testing, and evaluation of the HLS will be contractor-led. NASA will certify the design and flight readiness.

Project Information

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

Crewed Mission Duration: **~24-35 days (values under development and analysis)**

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

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

Next Major Project Event**: Project confirmation (August 2022)**

[2]GAO, *Blue Origin Federation, LLC; Dynetics, Inc.-A Leidos Company,* B-419783; B-419783.2; B-419783.3; B-419783.4, July 30, 2021, 2021 ¶ CPD 265 (Washington, D.C.: July 30, 2021).

[3]Blue Origin Fed. LLC v. United States, Fed. Cl., No. 21-1695C (Nov. 4, 2021).

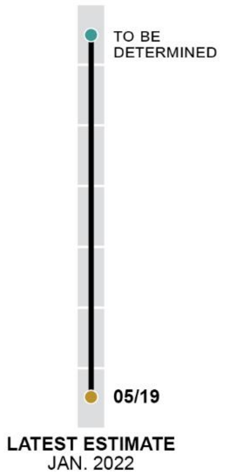
[4]GAO, *NASA Lunar Programs: Significant Work Remains, Underscoring Challenges to Achieving Moon Landing in 2024*, GAO-21-330 (Washington, D.C.: May 26, 2021).

Current Status

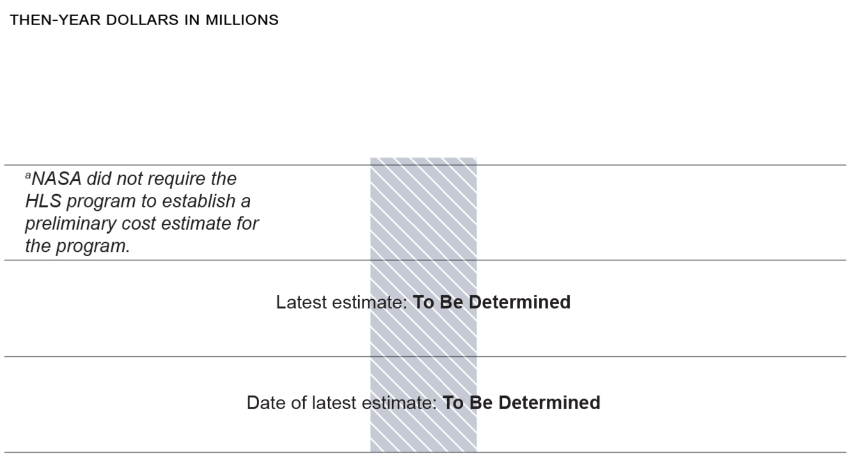
In April 2021, NASA announced the selection of SpaceX to develop the Artemis III lunar lander. The firm-fixed-price contract award value is $2.89 billion. After the award, Blue Origin and Dynetics filed bid protests with GAO, which GAO denied in July 2021.[2] Subsequently, in August 2021, Blue Origin filed a complaint with the U.S. Court of Federal Claims, which the court dismissed in November 2021.[3] NASA officials reported that a 7-month delay for the HLS contributed to delaying the Artemis III lunar-landing mission from 2024 to no earlier than 2025. The program is reviewing initial schedules from SpaceX, and expects to establish cost and schedule baselines in August 2022.

Moving the Artemis III mission to no earlier than 2025 provides the program with additional time to work on the lunar lander, but the time frame is still aggressive. We previously found that NASA's planned pace to develop the HLS was months faster than the average for other spaceflight programs, and a lander is inherently complex because it supports human spaceflight.[4] According to NASA, SpaceX's approach is technically challenging, in part, due to the number of events necessary to execute the mission, but there are mitigating factors. For example, these events will occur in Earth's orbit, as opposed to lunar orbit where an unexpected event could create a higher risk to loss of mission.

Preliminary Schedule



Preliminary Cost[a]



Project Office Comments

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

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Source: NASA. | GAO-22-105212

Mobile Launcher 2

Mobile Launcher 2 (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

Project Information

NASA Lead Center: **Kennedy Space Center**

International Partners: **None**

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

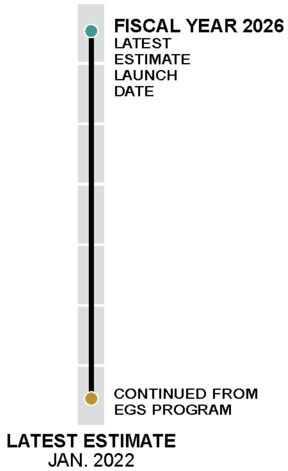
Budget Portfolio: **Deep Space Exploration Systems, Exploration Systems Development**

Project Summary

The ML2 project is in the process of setting its cost and schedule baselines while facing schedule delays, design changes, and likely cost growth. According to project officials, the prime contractor underestimated the time, effort, materials, and complexity involved in developing and constructing the ML2, and this has led to ongoing delays and redesign efforts. According to NASA officials, the contractor's structural design exceeded contract weight requirements, resulting in significant unplanned redesign efforts to reduce weight. The contractor provided a recovery plan that focused first on reducing the weight in the ML2's design. Recently, NASA officials stated that the contractor will provide an updated corrective action plan by May 2022, detailing cost and schedule implications of the redesign work.

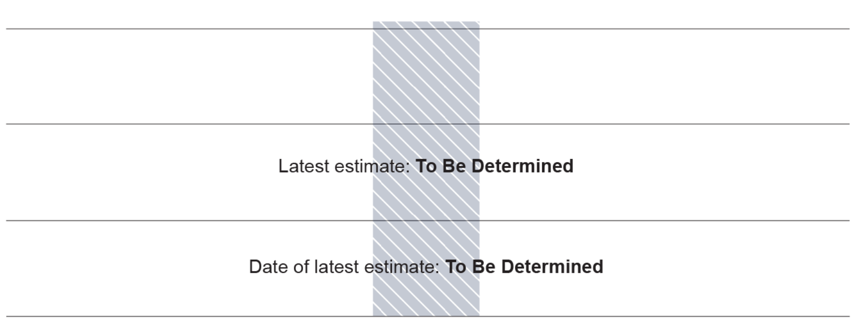
Additionally, while NASA officials said COVID-19 delayed material deliveries and volatile market conditions increased unit costs, they said the implications of the ongoing redesign efforts have overshadowed the pandemic's effects. The project has also experienced delays and cost growth due to design changes from the SLS Block 1B vehicle.

Preliminary Schedule



Preliminary Cost

THEN-YEAR DOLLARS IN MILLIONS



Cost and Schedule Status

Since our last report, the ML2 project missed its target date to begin implementation by at least 7 months and expects at least a year delay in holding its critical design review. The project is in the process of setting its cost and schedule baselines, but continues to miss its schedule targets and will likely also incur additional costs.

ML2 officials stated that the main cause for the schedule delays is that the prime contractor misjudged the scope and complexity of the job. According to project officials, the contractor initially underestimated the time and effort involved, resulting in inadequate labor, schedule durations, and the amount of materials—such as steel, critical equipment, wiring, and tubing—needed. Project officials said the contractor adjusted its proposal to account for this, but the updated proposal still underestimated the work necessary. The contractor agreed with that assessment, and further stated that concurrent launch vehicle and launcher design increased inefficiency as well.

In February 2022, the contractor proposed a recovery plan to respond to NASA's letter of concern regarding cost and schedule growth, which NASA officials said stemmed, in part, from the contractor's struggle with the weight aspect of the ML2 design. Weight is important because the Crawler Transporter, the vehicle that carries the ML2 and the integrated launch vehicle—SLS and Orion—to the launch pad, has a weight limit. As of January 2022, the contractor's design was approximately 500,000 pounds over the weight limit.

According to NASA, as a result of collaborative efforts between NASA, the contractor, and industry partners, the team is pursuing a two-pronged approach to overcome the weight issue. First, NASA released 500,000 pounds of margin in the capacity of the Crawler Transporter, enabling the weight limit to be raised by the same amount. Second, the contractor is redesigning the ML2 structure to incorporate 31 weight reduction ideas. Officials said these ideas amount to approximately 570,000 pounds and restore adequate margins for the project. NASA officials said that the contractor committed to submit a recovery plan in May 2022 in response to NASA's letter of concern from December 2021 and subsequent iterations. According to NASA officials, the contractor's planned May 2022 deliverable will update NASA on the potential cost growth and schedule affects, and then NASA will be able to determine the best path forward.

The project has also experienced schedule delays and cost growth due to design changes stemming from the SLS Block 1B vehicle. The ML2 is being developed to launch the taller, heavier, and as yet unbuilt SLS variants. According to project officials, due to the long-lead nature of designing and building the ML2, NASA made the decision to award the ML2 contract before the requirements for the SLS Block 1B's Exploration Upper Stage were finalized. As such, officials said the parallel development of the flight vehicle and ML2 resulted in necessary design changes to safely accommodate the new SLS Block 1B vehicle interfaces, such as design updates to ensure that the ML2 structure could withstand increased loads.

According to officials, current market conditions are affecting material costs, resulting in projected cost growth for the project. In addition, while the project has had some cost growth due to COVID-19, officials said the project's redesign efforts have overshadowed the pandemic's schedule effects.

Other Issues to Be Monitored

As of December 2021, the ML2 project's highest risk was that its schedule did not provide enough time to complete stand-alone and multi-element verification and validation testing. Project documentation of the lessons learned from the existing launch platform and tower multi-element testing suggest that the amount of time allocated for similar ML2 testing may not be sufficient. According to officials, the effect is an increased schedule risk that ML2 may not be ready when it is needed for Artemis IV.

Project Office Comments

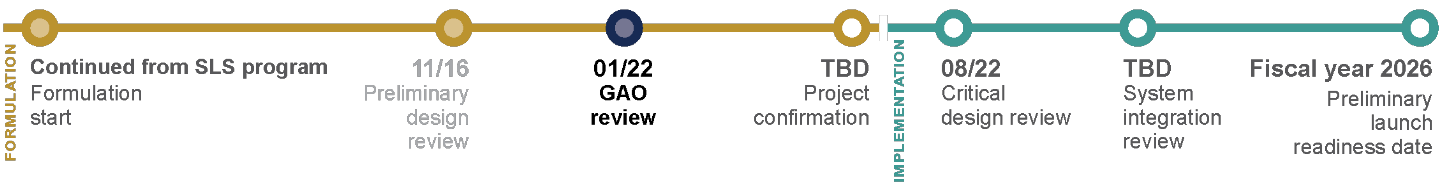
ML2 officials provided technical comments on a draft of this assessment, which were incorporated as appropriate.

Source: NASA. | GAO-22-105212

Space Launch System Block 1B

The Space Launch System (SLS) Block 1B is a planned evolution of the SLS. The SLS Block 1 is intended to be NASA's first human rated heavy-lift vehicle since the Saturn V and is intended to enable deep-space Artemis and Mars missions. The SLS Block 1B will retain the core stage, 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 co-manifested payloads. The EUS on Block 1B will have four RL-10 engines with a total of 97,000 pounds of thrust, which will increase the amount of mass the SLS Block 1B can deliver to the moon and other destinations.

Timeline



TBD = to be determined

Project Information

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**

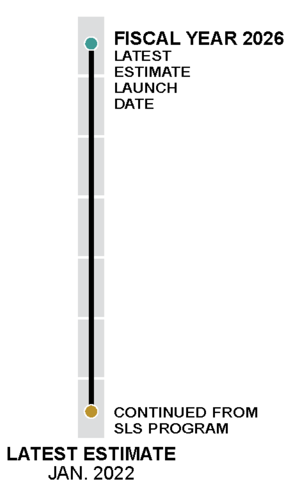
Budget Portfolio: **Deep Space Exploration Systems, Exploration Systems Development**

Project Summary

NASA has not yet established preliminary cost estimates or formal cost and schedule baselines for SLS Block 1B. NASA previously anticipated releasing the SLS Block 1B baselines with the baseline cost and schedule commitments for Mobile Launcher 2—which is required to fly the SLS Block 1B. According to officials, the agency has decoupled these two baselines and is planning to sign the SLS Block 1B baseline in June 2022. In addition, the program is working toward a vehicle-level critical design review (CDR), occurring in summer 2022. However, the program will not complete all component-level reviews before the vehicle-level CDR, which increases the risk of component rework.

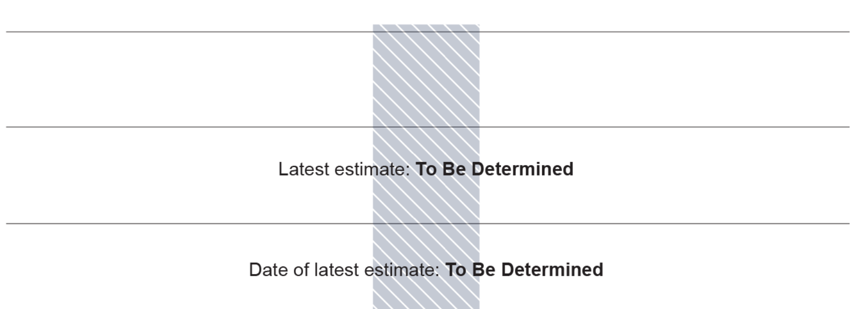
The program completed a manufacturing readiness review in August 2021. At this review, the program identified the integration of a second product line to build the EUS at the Michoud Assembly Facility as a primary area of risk. The program identified its critical path—the portion of the program with the least amount of schedule reserve available—as development of the stage controller required to conduct the green run, or the first full power test, of the EUS.

Preliminary Schedule



Preliminary Cost

THEN-YEAR DOLLARS IN MILLIONS



Cost and Schedule Status

NASA plans to fly the SLS Block 1B for the first time on the Artemis IV, a crewed lunar mission, in fiscal year 2026. NASA, however, has not yet established preliminary cost estimates or formal cost and schedule baselines for SLS Block 1B. In December 2021, NASA's Agency Program Management Council, which is responsible for assessing programs and their respective baselines, reviewed the SLS Block 1B program. Subsequently, NASA leadership decided to withhold releasing the SLS Block 1B baselines until the baseline cost and schedule commitments for Mobile Launcher 2 are approved and released. Mobile Launcher 2 is required to transport SLS Block 1B from the vehicle assembly building to the launch pad. According to officials, the agency has decoupled these two baselines and is planning to sign the SLS Block 1B baseline in June 2022.

SLS Block 1B production and operations costs for Artemis IV and beyond will remain uncertain until NASA is able to finalize negotiations and definitize the terms of the Stages Production and Evolution Contract with Boeing. According to officials, the contract includes materials and production for the Artemis III and Artemis IV missions and Core Stage and EUS materials for Artemis V and Artemis VI missions. Likewise, ongoing and unplanned delays in the execution of Artemis I through Artemis III—other missions in the Artemis program—could delay the SLS Block 1B schedule.

Technology and Design

The program is working toward a vehicle SLS Block 1B CDR, occurring in summer 2022. Under the current schedule, however, the program will not complete CDRs for six components until after the vehicle CDR. While the program established risk mitigation plans for the components that are lagging, completing the vehicle-level CDR before finalizing component designs places the program at increased risk of component rework.

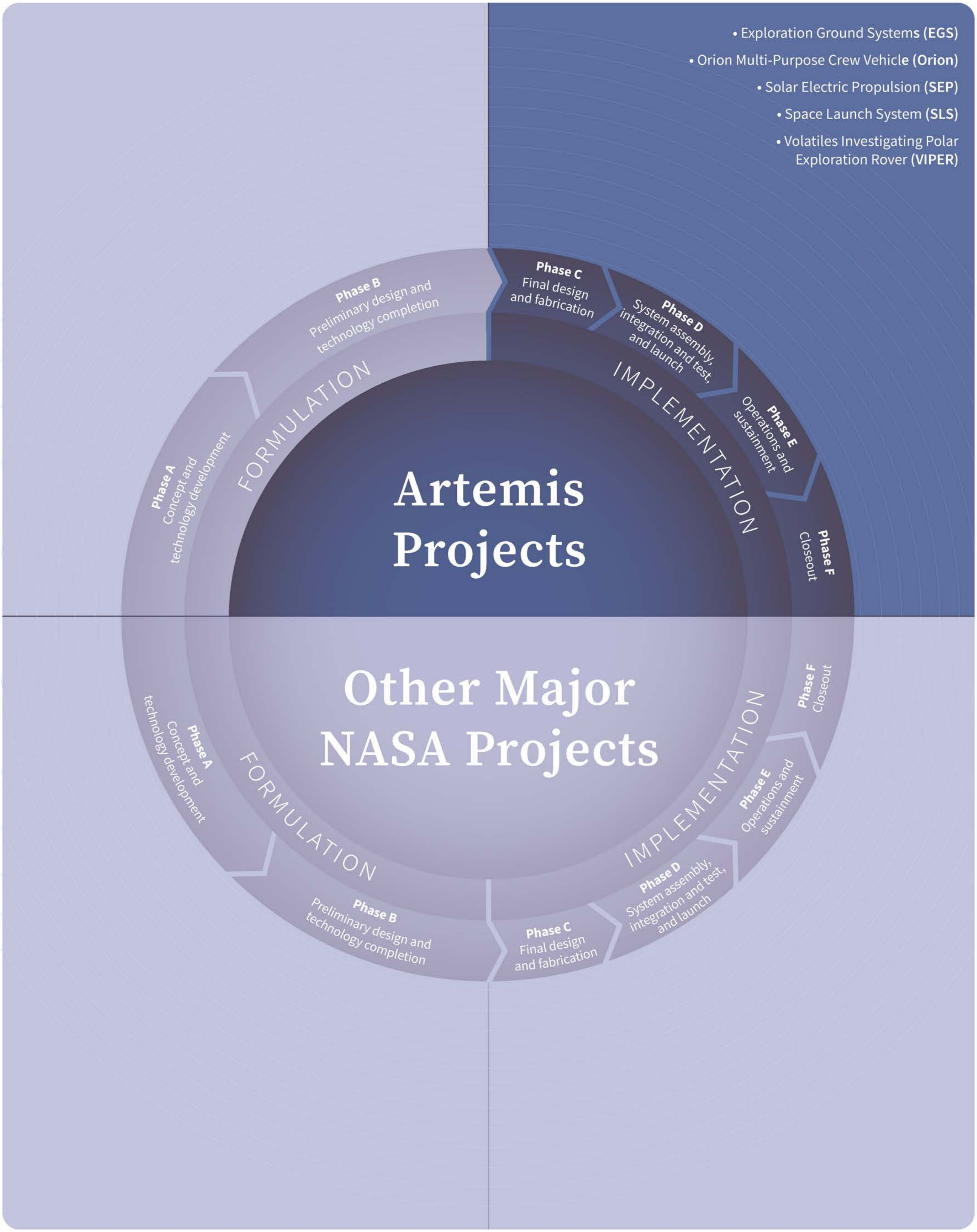
The program held a manufacturing readiness review in August 2021. This review identified the integration of a second product line to build the EUS along with the full-scale production of the core stage at the Michoud Assembly Facility as a primary area of risk. SLS Block 1B officials stated the program is coordinating with the facility to decide the best way to manage resources efficiently.

Other Issues to Be Monitored

Development of the stage controller hardware and software is the program's critical path—the portion of the program with the least amount of schedule reserve available. The stage controller is needed to support the green run, or first full power test of the EUS, currently scheduled for December 2024. According to program officials, the stage controller will provide simulated flight instructions to the EUS during green run testing. These officials indicated that although the stage controller for the EUS green run is 60-70 percent common with the stage controller used for the SLS core stage green run, the program is tracking a risk related to developing the EUS green run stage controller. Program officials indicated this risk could affect the SLS Block 1B schedule and said the risk will be assessed as part of the agency's cost and schedule commitment in June 2022.

Project Office Comments

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



Source: U.S. Government Accountability Office analysis of NASA data. | GAO-22-105212

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Source: NASA. | GAO-22-105212

Exploration Ground Systems

The Exploration Ground Systems (EGS) program is modernizing and upgrading the infrastructure at the Kennedy Space Center. It is also developing software needed to integrate, process, and launch the Space Launch System (SLS) and Orion Multi-Purpose Crew Vehicle (Orion). Additionally, EGS is responsible for recovering Orion after its mission. The EGS program consists of several major construction projects of facilities and ground support equipment, including the Mobile Launcher, Crawler Transporter, Vehicle Assembly Building, and Launch Pad 39-B. All of these projects need to be completed before the first uncrewed exploration mission, Artemis I.

Project Information

NASA Lead Center: **Kennedy Space Center**

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

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

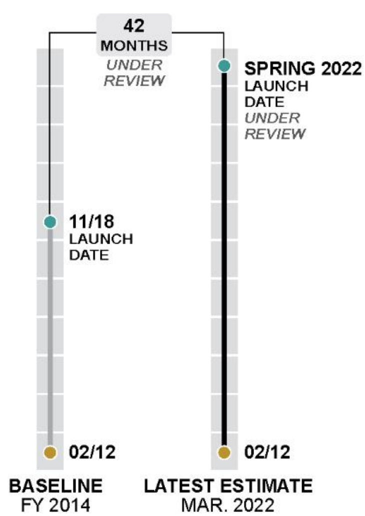
Next Major Project Event: **Launch (spring 2022, under review)**

Current Status

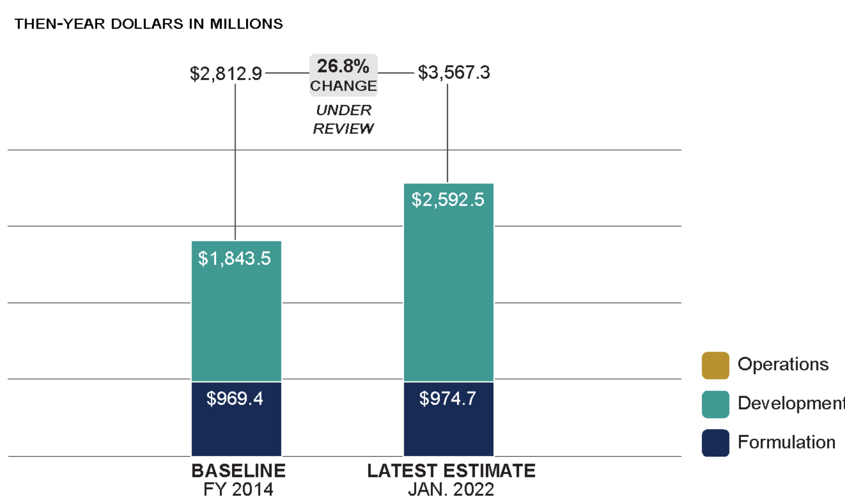
EGS is managing the final integrated tests ahead of Artemis I—the first launch of a SLS rocket carrying an Orion spacecraft. As of March 2022, the Artemis I launch date slipped at least 6 months from November 2021 to spring 2022. EGS attributed the delay to a number of issues, including problems identified during testing and COVID-19 effects. Since our last report, EGS experienced cost growth of $96.2 million, in part, due to this launch delay. EGS officials recognize that the remaining testing schedule is success-oriented and that issues discovered during first time operations and testing could further delay the program's readiness to support Artemis I.

EGS completed stacking and integration of the SLS rocket and Orion spacecraft for Artemis I in the Vehicle Assembly Building at Kennedy Space Center in October 2021 and began final integrated testing. The program encountered some problems during testing. For example, in December 2021, the Countdown-Sequencing Test terminated 4 seconds early due to a data link issue. EGS successfully completed a second run of the same test in January 2022. The final integrated test is the Wet Dress Rehearsal that began in spring 2022. EGS will then return the rocket and spacecraft to the Vehicle Assembly Building for final checkouts and establish a launch date for Artemis I.

Schedule Performance



Cost Performance



Project Office Comments

When commenting on a draft of this assessment, EGS program officials said the launch date remains under review pending completion of the Wet Dress Rehearsal. As of May 2022, NASA was planning for a launch no earlier than August 2022. Program officials also provided technical comments on a draft of this assessment, which were incorporated as appropriate.

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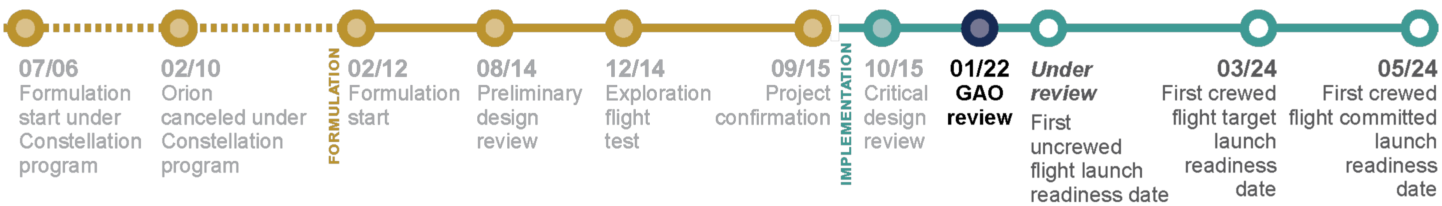
Source: NASA. | GAO-22-105212

Orion Multi-Purpose Crew Vehicle

The Orion Multi-Purpose Crew Vehicle (Orion) is being developed to transport and support astronauts beyond low-Earth orbit and will launch atop NASA's Space Launch System (SLS). The current design includes a crew module, service module, launch abort system, and rendezvous proximity and docking capability. The project plans for one uncrewed and one crewed mission—Artemis I and II, respectively—with Orion. Although not included in the current baseline, NASA plans for Orion to later transport crew for a planned 2025 lunar landing mission called Artemis III. The Orion program is continuing to advance the development of the vehicle started under the canceled Constellation program.

Timeline



Project Information

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**

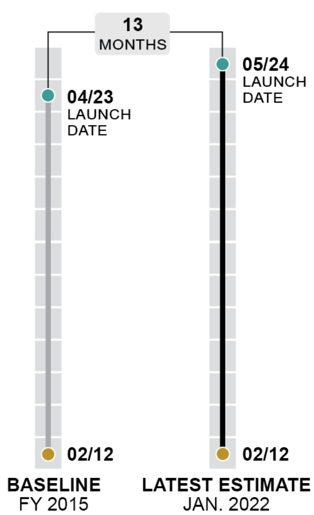
Budget Portfolio: **Deep Space Exploration Systems, Exploration Systems Development**

Project Summary

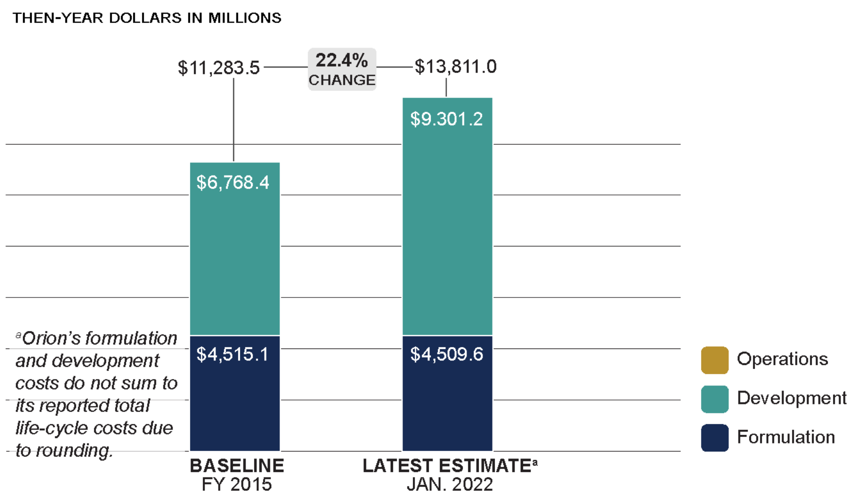
In August 2021, Orion rebaselined, which added $2.5 billion in estimated costs and delayed its launch readiness date. Orion is now working to a committed May 2024 launch readiness date for Artemis II, 13 months later than the original baselined date. The rebaseline included additional scope, a docking capability, as well as almost $480 million for what NASA calls forward uncertainty, which could include future COVID-19 effects. We have previously reported on $888 million of this cost increase, which was attributed to European Service Module (ESM) delays and contractor performance issues. The revised cost estimate also assumes a no later than April 2022 launch date for Artemis I, which is no longer feasible.

The program took delivery of the second European Service Module (ESM-2) in October 2021 and attached it to the crew module adapter in November 2021. This formed the Artemis II service module that is now undergoing testing. The program's docking capability will have limited testing and a demonstration for Artemis II, and will be fully incorporated for Artemis III to allow for docking with the Human Landing System (HLS).

Schedule Performance



Cost Performance



Cost and Schedule Status

Orion entered the system assembly, integration and test, and launch phase in August 2021, at which point the project rebaselined, adding $2.5 billion in estimated costs due, in part, to additional scope.

The addition of the Rendezvous Proximity Operations and Docking (RPOD) capability to support docking operations on future Artemis missions and other new capabilities and requirements is responsible for the largest share of this increase, accounting for almost $1.1 billion. COVID-19 continues to affect the program and contributed to the rebaseline, but, according to program officials, it is a not a primary driver of cost increases or schedule delays. The program's rebaseline also included $145 million in past COVID-19-related costs. In addition, the rebaseline included almost $480 million for what NASA called forward uncertainty. Project officials said that, while this forward uncertainty includes any future COVID-19 effects, other issues, such as delays to Artemis I, could also fall under its umbrella. We have previously reported on $888 million of this cost growth, which was largely due to ESM delays and contractor performance issues.[5]

According to NASA documentation, the project's revised costs are based on an assumption that Artemis I will launch no later than April 2022. While NASA had planned a November 2021 launch for Artemis I, that date is no longer feasible. The delayed launch could increase program costs.

The project is now working to a committed launch readiness date of May 2024 for Artemis II, a 13-month delay from its original baseline. Continued delays to the Artemis I mission and Artemis II spacecraft production issues contributed to this delay. NASA plans to reuse some avionics from the Artemis I crew module—including GPS receivers and antennas—on the Artemis II crew module. The Exploration System Development division estimates that NASA needs about 27 months between the Artemis I and II missions to refurbish and install the used avionics, complete the crew and service module, and complete the ground systems prelaunch processing activities. However, division officials said the minimum time needed between the two missions varies on the amount of risk assumed. Project officials said they have a backup option to use avionics currently earmarked for Artemis III, if necessary, to preserve schedule.

Integration and Test

Orion was stacked, or mounted, on top of the SLS in October 2021 in preparation for launching Artemis I. Since then, Orion underwent integrated vehicle testing with SLS and EGS, end-to-end communication tests, and countdown sequence tests in the lead up to the wet dress rehearsal and launch in spring 2022. These tests ensure that communication works between various systems—such as Orion, SLS, and ground sites—as well as check on how the integrated vehicle performs under countdown procedures.

The project received ESM-2, the European contribution to the Artemis II service module, in October 2021 and joined it to the crew module adapter in November 2021. The combined service module is undergoing leak testing and then is planning to begin power and function testing in May 2022.

Rendezvous Proximity Operations and Docking

NASA added RPOD as a critical subsystem and new capability to Orion in August 2021 as part of its rebaseline. RPOD will allow Orion to dock with other systems, such as the HLS. RPOD accounted for at least $604 million of the increased baseline cost but will not be fully demonstrated until Artemis III. The Orion program's cost and schedule baselines, however, are tied to Artemis II. For Artemis II, NASA plans to demonstrate a limited RPOD capability on the Orion crew capsule, with the crew performing proximity tests to demonstrate the ability of the docking system to line up with a target. The full RPOD capability will be used for Orion to dock with the HLS as part of Artemis III.

In December 2020, we recommended that NASA establish a cost and schedule baseline for RPOD as soon as practicable in advance of its critical design review.[6] NASA officials concurred with this recommendation, but they said that, instead of establishing a separate cost and schedule baseline, they would incorporate RPOD into Orion's August 2021 rebaseline. While the project incorporated RPOD in August 2021, RPOD's costs are not being reported as a distinct cost estimate. The lack of a separate cost and schedule baseline could make it more challenging to evaluate whether RPOD is meeting defined program constraints, such as available resources.

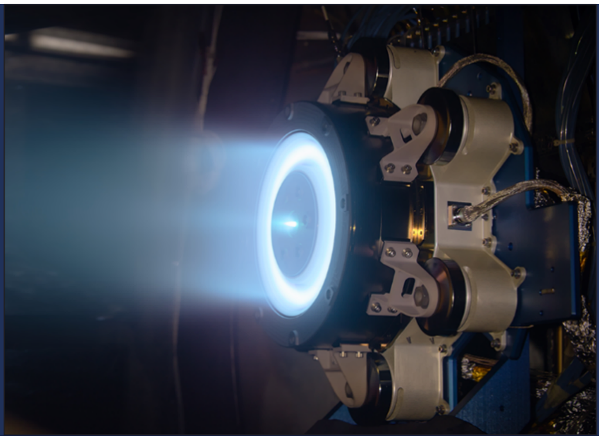
RPOD held a subsystem critical design review in May 2021, followed by an integrated assessment in September 2021. Project officials said this approach was taken to ensure that RPOD and other subsystems were still able to work together.

Project Office Comments

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

[5]GAO, *NASA: Assessment of Major Projects*, GAO-21-306 (Washington, D.C.: May 20, 2021).

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

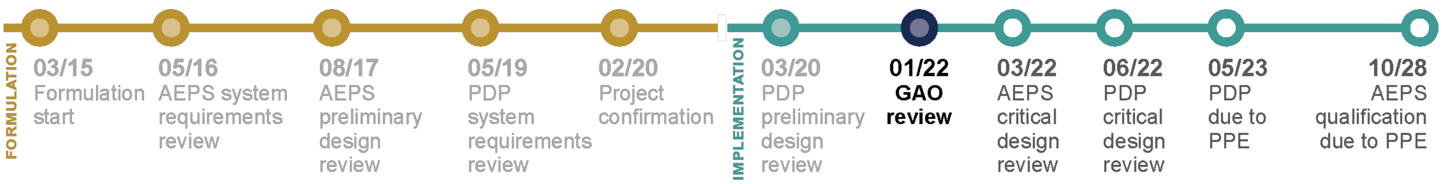


Solar Electric Propulsion

The Solar Electric Propulsion (SEP) project aims to develop high power electric propulsion technologies for NASA exploration and to empower the U.S. space industry. Solar electric propulsion augments propellant with energy from the Sun to reduce the mass of the propulsion system and propellant. Lower mass enables higher fuel efficiency for spaceflight missions beyond low-Earth orbit compared to conventional chemical propulsion systems. The SEP project has two development efforts: (1) the Advanced Electric Propulsion System (AEPS), for which the project will develop and qualify 12 kW thrusters; and (2) the Plasma Diagnostics Package (PDP), which will describe the performance of the electric propulsion system while in space. Both efforts will fly on Gateway's Power and Propulsion Element (PPE).

Source: NASA. | GAO-22-105212

Timeline



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

Project Information

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**

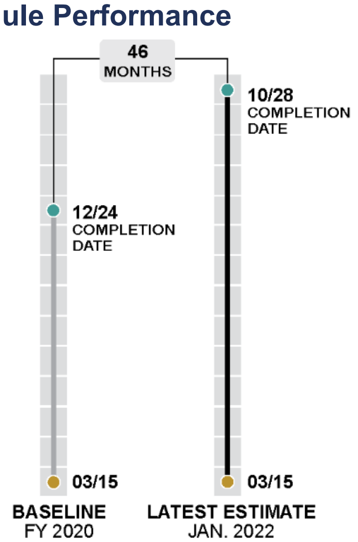
Budget Portfolio: **Space Technology, Technology Demonstration; and Deep Space Exploration Systems, Exploration Research and Development**

Project Summary

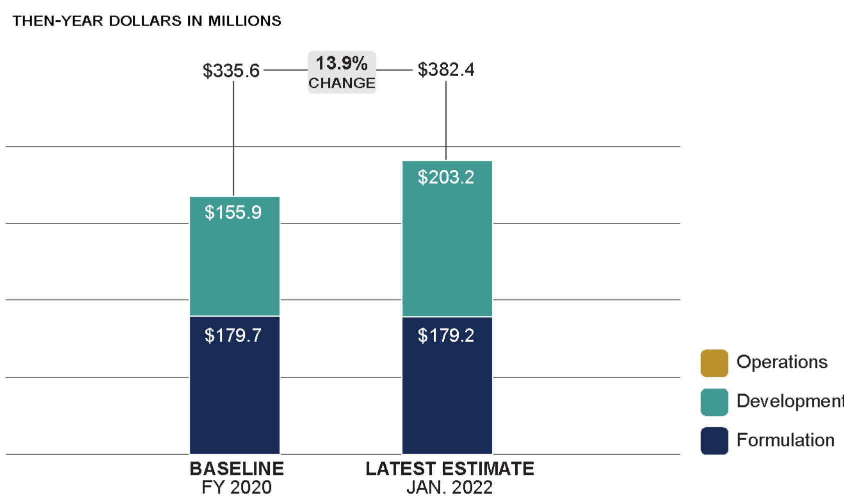
The SEP project rebaselined in March 2022. In July 2021, the project's development costs increased by about $47 million, and the project's completion date was delayed by 46 months to October 2028. Recent rescoping and requirements changes for its thrusters, among other things, resulted in the cost increases and schedule delays. According to officials, revisions incorporated into the new baseline account for additional changes to the project's thruster contract. Project officials said challenges with a component of the PDP drove cost growth at the rebaseline and, along with mass constraints on PPE, are driving NASA to cancel the PDP. Officials said the cancelation will be finalized in June 2022.

The project plans to mature key technologies for its advanced electric propulsion thruster after the thruster flies on the PPE. NASA plans to launch the flight thrusters on the PPE 2 to 3 years before completing key testing to mature the thrusters in 2028. Project officials consider this testing low risk due to NASA's decades of knowledge on the topic.

Schedule Performance



Cost Performance



Cost and Schedule Status

At a key decision point review in July 2021, NASA increased the SEP project's latest estimates to account for cost growth and schedule delays since the project established its baselines in 2020. The latest estimate increased the project's development costs by about $47 million and delayed its project completion date by 46 months, from December 2024 to October 2028. The project attributed the cost increases and schedule growth to multiple factors, such as (1) changes in mission requirements and the PPE project's procurement strategy; (2) contractor performance; (3) the effects of COVID-19; and (4) the addition of testing previously omitted from the baseline, which officials said accounts for about 3 years.

The project completed an official cost and schedule rebaseline in March 2022 to capture additional changes. According to officials, these updates reflect the addition of manufacturing, assembly, testing, and delivery of the three flight thrusters for the Gateway's PPE onto the SEP project's contract. Project officials stated challenges managing a component of the PDP also drove cost growth at the rebaseline and, along with mass constraints on PPE, are driving NASA to cancel the PDP. Officials said the cancelation will be finalized in June 2022.

Advanced Electric Propulsion System. The SEP project previously rescoped its effort to develop and qualify the entire advanced electric propulsion system for the PPE to only develop and qualify the thrusters. NASA officials said they made this change because of continued poor contractor performance and because the PPE project only needs the thrusters. The SEP project now plans to produce five thrusters—two for qualification testing to confirm the thrusters comply with requirements and verify they will function as expected in space, and three flight thrusters for the PPE project. The SEP project added a third flight thruster due to NASA's decision to launch the PPE and HALO together, which increased the vehicle's mass and, thus, the performance requirements for the thrusters.

The SEP project reported significant schedule delays due to modifications to the contract to add the additional flight thruster. To meet the PPE project's integration date for the flight thrusters, SEP project officials explained that the contractor will deliver all three PPE flight thrusters before delivering the second qualification thruster for the SEP project. As a result, the SEP project delayed the start of thruster qualification testing, which resulted in delays to the project's completion date. The SEP project will end when it completes wear testing on the second qualification thruster.

Plasma Diagnostics Package. In December 2021, the project moved the development of its main electronics package in-house due to what NASA described as poor contractor performance. The main electronics package serves as the communication link to the Gateway's PPE and avionics for the PDP's thruster probe assembly. The thruster probe assembly houses sensors that interface with the thrusters on the PPE. Prior to this change, the contractor building the main electronics package experienced a 30 percent cost overrun and an 8-month schedule delay. According to NASA, the contractor reported that it underestimated the hardware's complexity and maturity level and, in August 2021, told NASA it did not have personnel with the necessary skills to continue building the main electronics package.

Technology and Design

Advanced Electric Propulsion System. The SEP project's qualification of the thrusters will help to mature the thruster technologies for the PPE project, but testing will not be completed before the thrusters fly on PPE. SEP officials said they expect the thrusters to be mostly mature by the thrusters' critical design review because all elements of the thrusters, except life qualification testing, should be tested in a relevant environment. Officials explained that the life qualification of the test thrusters will be demonstrated over 4 years of testing, starting in 2024. Based on the current schedule, NASA expects to launch the flight thrusters on PPE between 2025 and 2026, and before life testing is completed in 2028. However, according to NASA officials, at the time of the PPE launch the project will have performed extensive testing on engineering development units, qualification thruster environmental testing in relevant environments, and at least 4,500 of the 23,000 hours of life testing.

The project held a critical design review for the thrusters in March 2022. As of January 2022, the project reported releasing about 88 percent of its design drawings and plans to release close to 100 percent by the review. GAO's best practice 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.

Plasma Diagnostics Package. According to officials, NASA plans to cancel PDP in June 2022.

Project Office Comments

When commenting on a draft of this assessment, SEP project officials told us the project held critical design review for the thrusters in March 2022 with over 90 percent of drawings released. Project officials also provided technical comments, which were incorporated as appropriate.

Source: NASA. | GAO-22-105212

Space Launch System

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

Project Information

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

Mission Duration: **Varied based on destination**

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

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

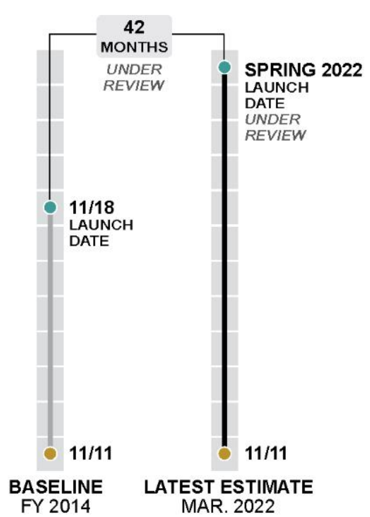
Next Major Project Event: **Launch (spring 2022, under review)**

Current Status

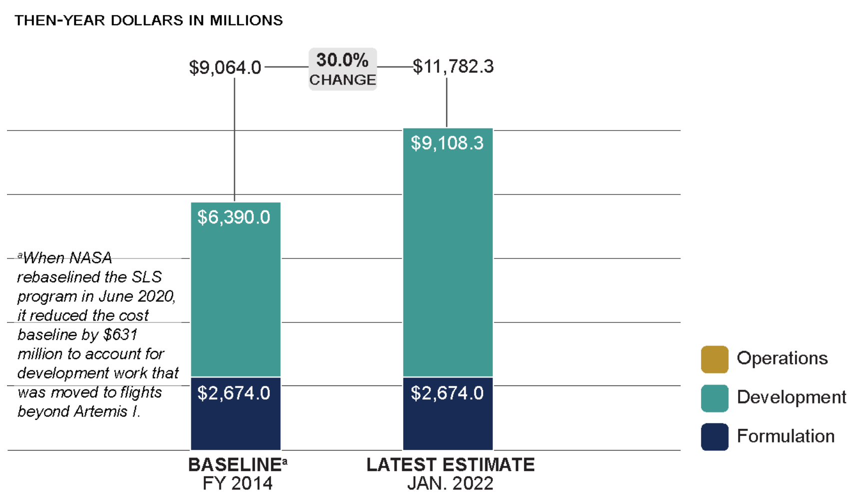
SLS is in the final stages of preparing for Artemis I, its first launch. As of March 2022, the anticipated Artemis I launch date slipped at least 6 months from November 2021 into spring 2022. SLS officials attributed these delays to the time spent addressing various issues discovered during testing.

After completing full-power testing of the SLS core stage in March 2021, the program had to address issues discovered during the test. This included removing and replacing engine valve components, repairing insulation on the engine section, and installing modified tubing. The SLS program delivered the core stage to Kennedy Space Center in April 2021. The Exploration Ground Systems program completed final stacking of the integrated SLS vehicle with the Orion spacecraft in October 2021 and, as of April 2022, had started the final integrated test ahead of the Artemis I launch, the Wet Dress Rehearsal. During integrated testing in November 2021, the program discovered an issue with an engine controller on one of SLS's four RS-25 engines. Removing, replacing, and retesting the engine controller contributed to delays to Artemis I testing.

Schedule Performance



Cost Performance



Project Office Comments

When commenting on a draft of this assessment, SLS program officials said the launch date remains under review, pending completion of the Wet Dress Rehearsal. As of May 2022, NASA was planning for a launch no earlier than August 2022. Program officials also provided technical comments on a draft of this assessment, which were incorporated as appropriate.

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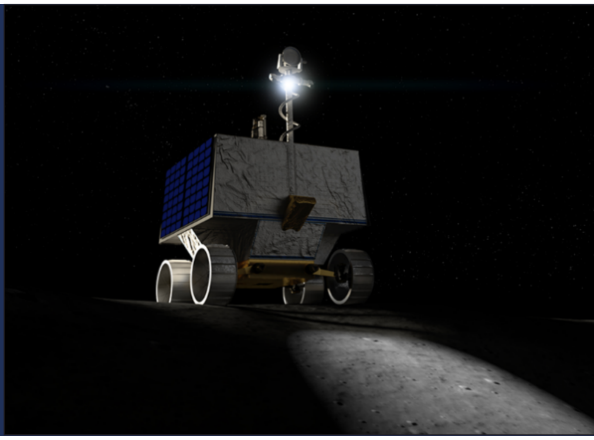


Source: NASA. | GAO-22-105212

Volatiles Investigating Polar Exploration Rover

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

Timeline

FORMULATION
- 10/19 Formulation start
- 04/20 Requirements sync review
- 08/20 Preliminary design review
- 03/21 Project confirmation

IMPLEMENTATION
- 10/21 Critical design review
- **01/22 GAO review**
- 06/22 System integration review
- 07/23 Delivery to Astrobotic
- 11/23 Initial operational capability

Project Information

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)**

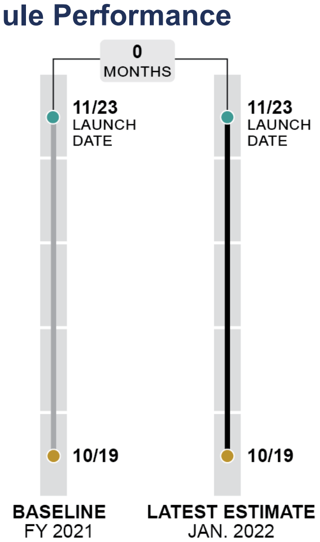
Requirement Derived from: **2011 Planetary Science Decadal Survey**

Budget Portfolio: **Science, Planetary Science**

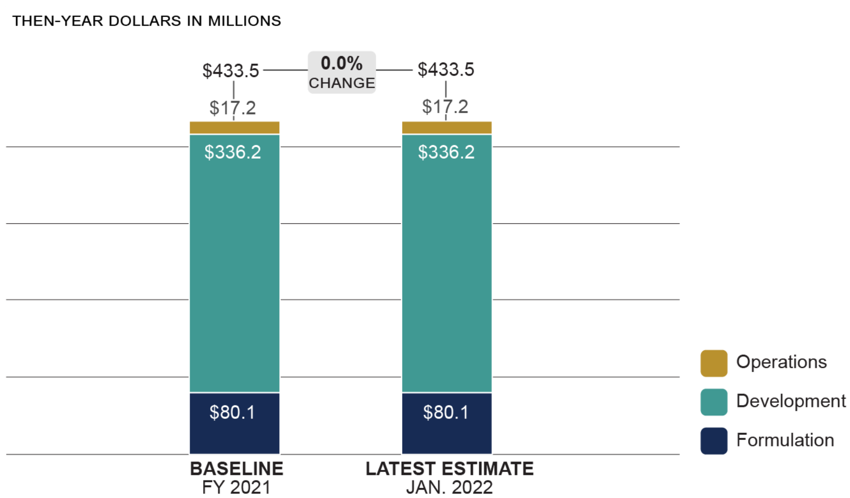
Project Summary

In March 2021, the VIPER project entered the implementation phase and formally established a baseline life-cycle cost of $433.5 million and an initial operational capability date of November 2023. The project continues to operate within its baselines. However, this estimate does not include the cost to transport VIPER to the lunar surface or, according to project officials, development work completed under a prior project. NASA reported awarding a contract to Astrobotic—a Commercial Lunar Payload Services (CLPS) provider—to provide end-to-end commercial payload services between Earth and the Nobile crater region on the moon. These services will provide both a lander and a launch vehicle to deliver VIPER onto the Lunar South Pole. NASA and VIPER have undertaken efforts to reduce project schedule risk. For example, the project used cost reserves to allow for parallel hardware testing, which will save schedule by allowing for multiple pieces of hardware to be tested at the same time. The project held its critical design review (CDR) in October 2021 with 75 percent of its design drawings released, which did not meet GAO's best practice of releasing 90 percent of design drawings by this review.

Schedule Performance



Cost Performance



Cost and Schedule Status

The VIPER project entered the implementation phase and established its cost and schedule baselines in March 2021. NASA set a baseline life-cycle cost of $433.5 million and a November 2023 initial operational capability date. This date is when Astrobotic is expected to deliver VIPER to the lunar surface. To support the baseline date, the project plans to deliver the rover to Astrobotic in July 2023. The project continues to operate within its cost and schedule baselines.

The baseline includes $10.2 million in known COVID-19 effects through January 2021 but does not include future project reserves specifically for COVID-19 effects. According to officials, COVID-19 effects so far include higher labor costs across the aerospace industry and NASA facility constraints. Supply chain delays from the pandemic have been and continue to be tracked as a top issue for the project.

According to project officials, VIPER's baseline also does not include funding for prior development work under the Resource Prospector project or CLPS task order costs. In May 2021, we recommended that NASA include these costs as relevant in the VIPER baseline.[7] 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. CLPS costs for the VIPER project include a task order with Astrobotic valued at $235.6 million to provide end-to-end commercial payload services between Earth and the Nobile Crater region on the moon.

Design

VIPER held its CDR in October 2021, having released 75 percent of its design drawings. This is below GAO's best practice of releasing 90 percent of design drawings at this review. Releasing at least 90 percent of design drawings at CDR lowers the risk of projects experiencing design changes that can lead to cost and schedule growth. Officials attributed the low number to two challenges: 1) the complexity of integrating the rover harnessing design into the overall rover vehicle, and 2) process changes to the drawing release system. According to officials, VIPER is the first project to use the updated system. Officials said that the learning curve for this system, not design immaturity, delayed the project's ability to get drawings in a releasable state. As of January 2022, the project has not released any additional drawings, but officials said they plan to carefully manage design changes moving forward.

In addition, the VIPER Review Team raised multiple concerns at CDR, such as a tight systems integration and testing schedule and potential issues from interdependencies with Astrobotic. The project plans to address these concerns at its next quarterly review.

Astrobotic is maturing its lander design independently while NASA matures the VIPER rover design, which adds complexity to the project. Project officials said there are technical and programmatic challenges inherent in integrating the two different systems to execute a single mission. To account for this, NASA reported that, in February 2021, it pursued a change order for Astrobotic to modify the lander's design to accommodate VIPER's design as VIPER is further along the development process.

The project is also tracking a mass growth risk as it balances 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, compared to plans under Resource Prospector, this will require a bigger battery system and chassis. The rover's mass also increased to accommodate features such as an improved thermal management system. Project officials said that NASA negotiated to purchase additional mass allocation from Astrobotic to mitigate the risk and bring the project into line with Ames Research Center mass margin requirements. Project officials said they intend to request headquarters-held cost reserves in order to support this purchase.

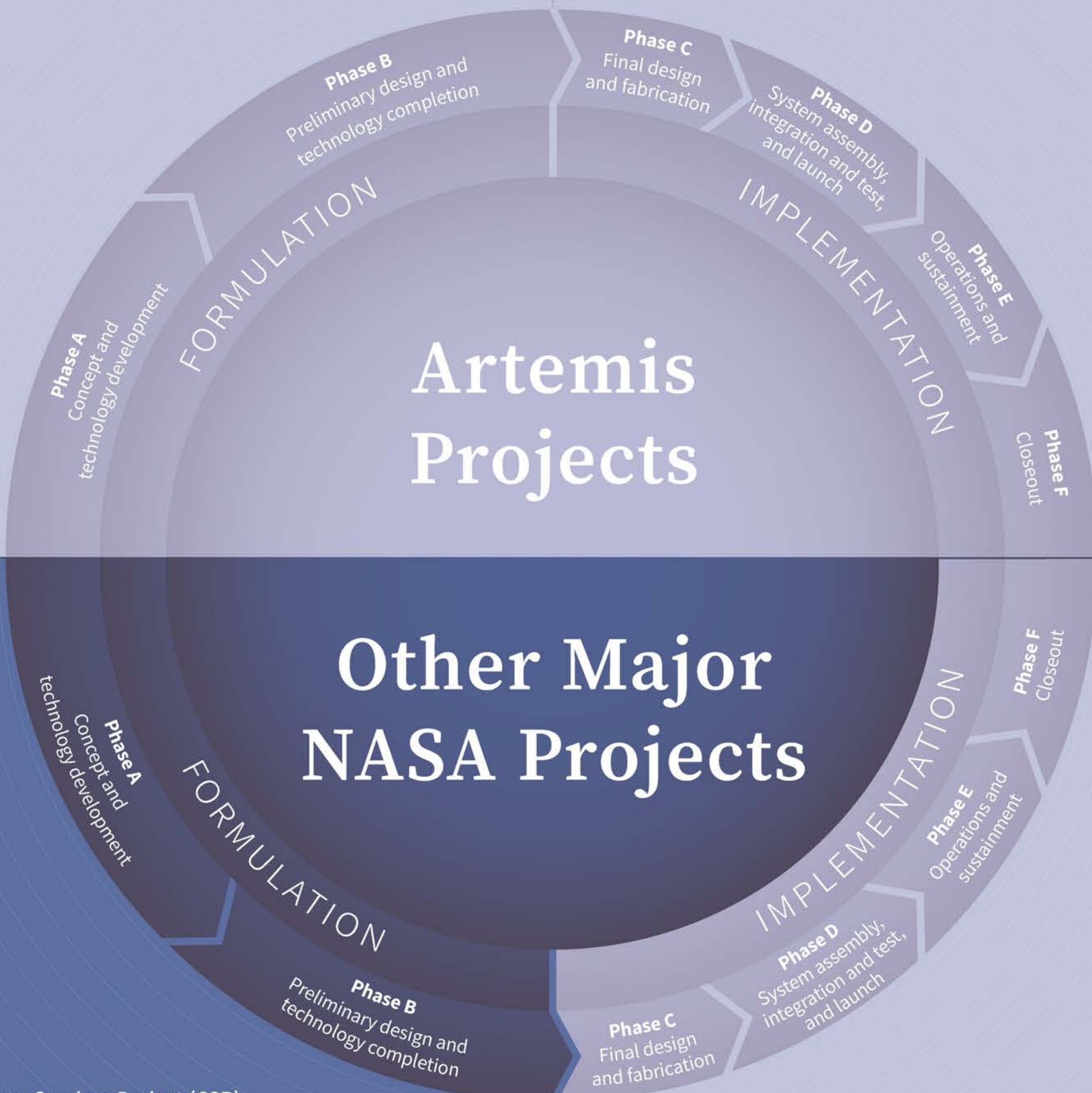
Integration and Test

The VIPER project is working to mitigate schedule risk related to system integration and test. According to project documentation, normal flexibilities in the integration and test schedule were consumed earlier than expected because of pandemic-related supply chain delays. As a result, routine design maturation changes then become a greater threat to the schedule. In November 2021, the project held a summit to address schedule concerns, and then took several steps to reduce schedule risk. For example, to save time the project changed its component installation approach to a parallel format, decided to start integrated vehicle testing earlier than previously planned, and added a second shift for testing. In addition, officials said the project is engaging with vendors to understand key schedule drivers. The project is also evaluating whether to add incentives for early deliveries.

Project Office Comments

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

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



- Communications Services Project (**CSP**)
- Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging (**DAVINCI**)
- Dragonfly
- Electrified Powertrain Flight Demonstration (**EPFD**)
- Geospace Dynamics Constellation (**GDC**)
- Mars Sample Return (**MSR**)
- Near Earth Object Surveyor (**NEO Surveyor**)
- Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy (**VERITAS**)

Source: U.S. Government Accountability Office analysis of NASA data. | GAO-22-105212

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Communications Services Project

The Communications Services Project (CSP) plans to demonstrate the feasibility of acquiring Satellite Communications (SATCOM) services for NASA missions from commercial providers. CSP is following a three-phase approach to transitioning NASA SATCOM users from the current government-owned communication satellites to commercially-provided services. In the first phase, NASA is identifying future mission needs as well as commercial industry capabilities for meeting those needs. In the second phase, selected commercial providers will demonstrate end-to-end SATCOM capabilities. In the third phase, the project will support the acquisition of SATCOM services for NASA users.

Source: W2 Communications, Adobe Stock Image. | GAO-22-105212

Project Information

NASA Lead Center: **Glenn Research Center**

Mission Duration: **4-year development and demonstration period**

Requirement Derived from: **2020 National Space Policy**

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

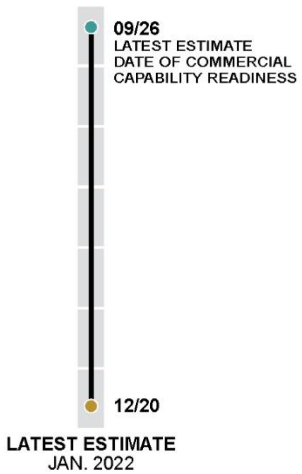
Next Major Project Event: **Space Act Agreement awards (spring 2022)**

Current Status

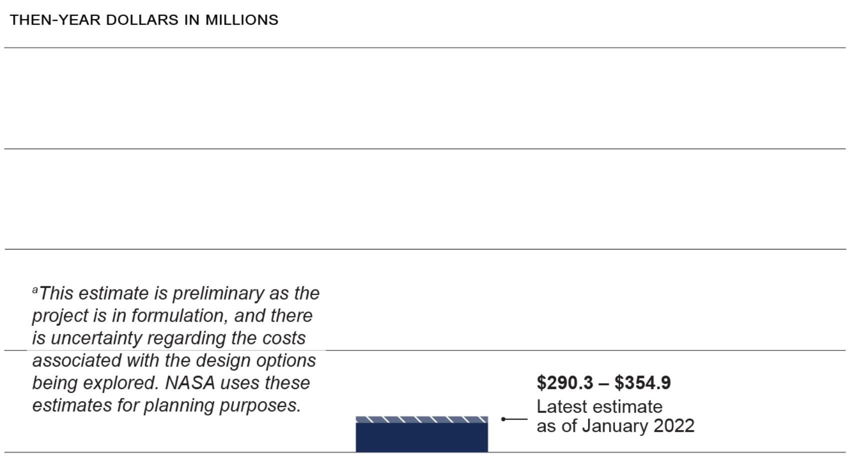
CSP entered the concept and technology development phase in December 2020 and has a preliminary cost estimate range from $290.3 to $354.9 million. The project's preliminary schedule is to complete multiple commercial capability demonstrations by September 2026, though officials said the final schedule will be determined by the Space Act Agreements. In July 2021, the project issued an announcement for proposals from industry to provide a demonstration of commercial satellite communication capabilities for use with NASA missions in the near-Earth orbit. The project is currently assessing proposals and plans to award multiple Space Act Agreements in spring 2022. As part of the demonstrations, project officials said industry partners will provide the hardware and software necessary to provide satellite communications.

The project is tracking a risk that selected systems will not be able to work together across vendors. To mitigate this risk, the project plans to conduct an interoperability assessment to ensure systems can work together. Officials said that making multiple awards may also help the project avoid being locked into a single vendor.

Preliminary Schedule



Preliminary Cost



[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

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

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Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging

Source: NASA/Goddard Space Flight Center. | GAO-22-105212

The Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging (DAVINCI) mission consists of a spacecraft that will fly by Venus twice to measure clouds and surface composition before it delivers an entry probe with an internal descent sphere to enter Venus's atmosphere. The measurements obtained will inform an understanding of how the planet formed and evolved and provide new data to help determine whether the planet ever had surface oceans of liquid water. DAVINCI will acquire high-resolution pictures of one of Venus's highland regions, which could provide clues about whether Earth-like mountain-building processes involving water ever occurred on Venus.

Project Information

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

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

Requirement Derived from: **Discovery Program Announcement of Opportunity 2019**

Budget Portfolio: **Science, Planetary Science**

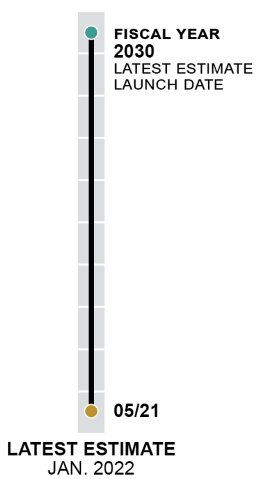
Next Major Project Event: **Mission requirements review (March 2023)**

Current Status

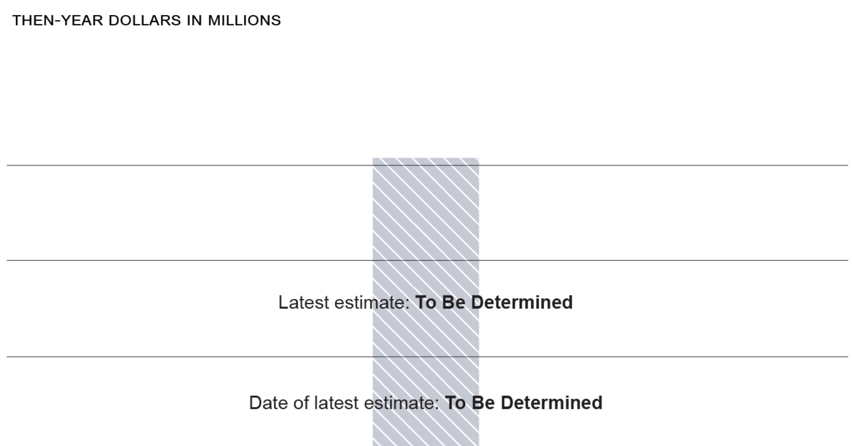
The DAVINCI project was selected in May 2021 as part of the Discovery Program and entered the preliminary design and technology completion phase. After selection, NASA directed the project to revise its cost and schedule estimates to support a later launch readiness date of fiscal year 2030 due to budget constraints in fiscal years 2021 and 2022. As of December 2021, the project proposed a June 2029 launch readiness date to NASA. The project plans to use the time provided by a later launch to analyze ways to optimize the scientific information the mission will provide and conduct risk reduction activities. For example, recent risk reduction activities simulated the Venus environment to test the descent sphere's thermal protection. Other activities will qualify and test the seal of the descent sphere's Sapphire Window, which allows cameras inside the sphere to take images of Venus, during the descent.

The project identified risks that include the potential late delivery of the Venus Mass Spectrometer, which will measure noble gases while the descent sphere descends. The spectrometer must be completed before the descent sphere because it resides inside the sphere. As part of its mitigation strategy, the project plans to conduct risk reduction activities as well as allocate additional schedule margin for the instrument.

Preliminary Schedule



Preliminary Cost



Project Office Comments

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

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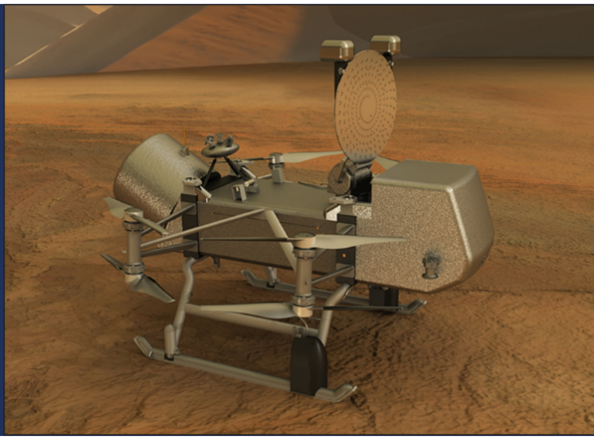


Dragonfly

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. Dragonfly will explore Titan, from organic dunes to the deposits of an impact crater, where liquid water and complex organic materials key to life once existed together for possibly tens of thousands of years, as well as investigate how far prebiotic chemistry has progressed. This mission is the first time that NASA will fly an eight-bladed rotorcraft. The flight will 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.

Source: Johns Hopkins University Applied Physics Laboratory. | GAO-22-105212

Timeline

Project Information

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**

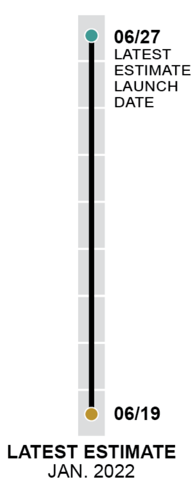
Requirement Derived from: **2011 Planetary Science Decadal Survey**

Budget Portfolio: **Science, Planetary Science**

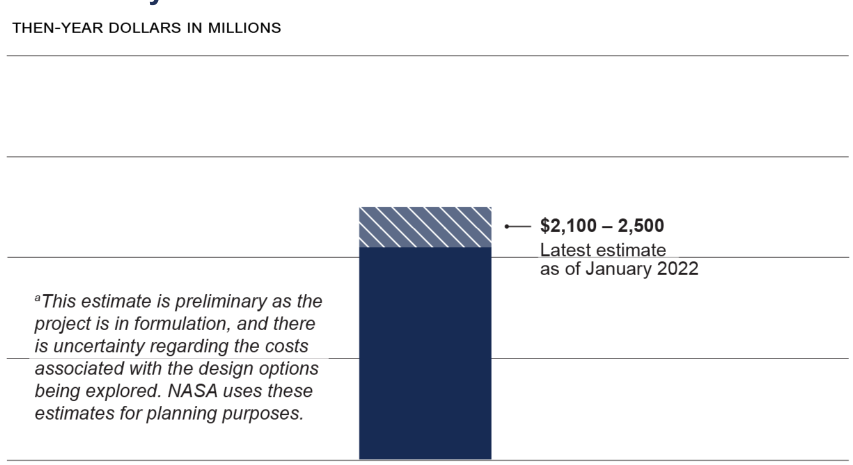
Project Summary

In January 2022, NASA officials increased the project's preliminary life-cycle cost estimate range by approximately $200 million to a range from $2.1 billion to $2.5 billion. This change was to accommodate NASA's decision to plan for a June 2027 launch date. Since its selection, Dragonfly revised its plans three times. Project officials said this allowed the project to accommodate NASA funding restrictions and factors external to the project, including COVID-19's effects on the Planetary Science Division's budget. Dragonfly is progressing to preliminary design review (PDR), planned for October 2022, by finalizing requirements and detailed aspects of its design. Dragonfly has five critical technologies that are not yet matured to technology readiness level (TRL) 6, but the project expects to achieve TRL 6 before PDR. In June 2021, NASA decided to pursue a launch vehicle capable of achieving the project's proposed high-energy trajectory option. The high-energy vehicle will result in a shorter cruise to Titan that will allow Dragonfly to start doing science earlier. Project officials said that the simpler trajectory and shorter cruise will reduce the mission operations costs by about $50 million.

Preliminary Schedule



Preliminary Cost



Cost and Schedule Status

In January 2022, NASA increased the project's preliminary cost estimates to a range from $2.1 to $2.5 billion to support a June 2027 launch date. According to NASA documentation, when preliminary estimates were set in March 2021, the launch date was notional and the funding profile for the listed date was not executable. Subsequently, NASA directed the project to plan for a June 2027 launch date. NASA increased the preliminary estimates by approximately $200 million to accommodate the later launch date.

According to officials, the project is holding minimal cost reserves for fiscal year 2022 but already identified a possible need for the reserve funding. This would leave the project with limited, if any, reserves to address issues that may arise during the remainder fiscal year 2022. Officials said that, if they need more reserves than planned in fiscal year 2022, they would try to move work to later fiscal years to accommodate the added expenses.

NASA directed the project to revise its cost and schedule plans three times since selecting it to proceed with the preliminary design and technology completion phase in 2019. According to project officials, these revisions allowed the project to accommodate NASA funding restrictions and factors external to the Dragonfly project, including COVID-19's effects on the Planetary Science Division's budget. COVID-19 has also affected the project. For example, building the Titan thermal test chamber was delayed due to COVID-19, but the project was able to reorder activities and accommodate that delay in its new schedule. According to project officials, as of August 2021, the level of activity at the Applied Physics Laboratory, where Dragonfly is being developed, had almost returned to normal levels. Project officials said that future cost and schedule effects from COVID-19 will depend on the duration and extent of new activity restrictions.

Technology and Design

Dragonfly is progressing toward its PDR scheduled for October 2022. The project is working on finalizing its requirements and detailed design. For example, it is working on finishing the interfaces and accommodations for the mechanical, electrical, and thermal systems. Project officials said they want to complete preliminary designs and build prototype assemblies by PDR.

As of January 2022, Dragonfly has five critical technologies that are not yet matured to TRL 6, but the project expects all technologies to achieve this before PDR. Currently, all achieved TRL 5, and two previously flew on missions to Mars but need to be qualified for the Titan environment. For example, the Dragonfly Mass Spectrometer (DraMS)—an instrument that will study the chemical complexity and diversity of Titan's solid surface—was qualified for a Mars environment, which has lower atmospheric pressure than Titan. As part of qualifying DRaMS, the project is adapting the instrument to accommodate the Titan pressure environment and allow most of the instrument design to remain unchanged and operate as though it would on Mars.

The Dragonfly Gamma-ray Neutron Spectrometer (DraGNS)—an instrument used to determine elemental composition beneath the lander without requiring sampling—is being redesigned due to a change in its neutron generator. The generator will produce neutrons to stimulate gamma rays to detect the chemical elements on Titan. The new design will reduce mass and complexity by removing valves and hardware associated with the previous approach. Officials said that changing the design changed the needed delivery date for the generator, and DraGNS has subsequently moved off the project's critical path.

Launch Vehicle

In April 2021, NASA decided to pursue a launch vehicle capable of achieving a high-energy trajectory for Dragonfly. This will require a heavy-lift launch vehicle that NASA will provide. The change to a high-energy trajectory, which has implications on mission design, will result in a shorter cruise to Titan that will allow the Dragonfly to start doing science earlier and lower component degradation. Despite plans to launch 6 months later than originally planned, the spacecraft will arrive earlier than if it had launched in January 2027. The simpler trajectory reduces cruise operations planning and execution, eliminates a planned Venus flyby, and reduces the Earth flybys from three to one. According to project officials, the simpler trajectory and shorter cruise will reduce the mission operations costs by about $50 million.

NASA's Launch Services Program provided the project with performance information on the candidate heavy-lift launch vehicles: Falcon Heavy, Vulcan 6s, and New Glenn. The project is working with NASA to see if it can accelerate the procurement of the Coupled Loads Analysis (CLA) for the candidate launch vehicles to reduce the risk of having to alter Dragonfly's designs. A CLA is a dynamic loads analysis for a launch vehicle and its payload coupled together. According to officials, the project's design will need to use the worst-case scenario for all possible launch vehicles that might be used, and if the CLA is not completed before 6 months prior to critical design review, it may require a redesign of the nuclear generator mounting or other structures.

Project Office Comments

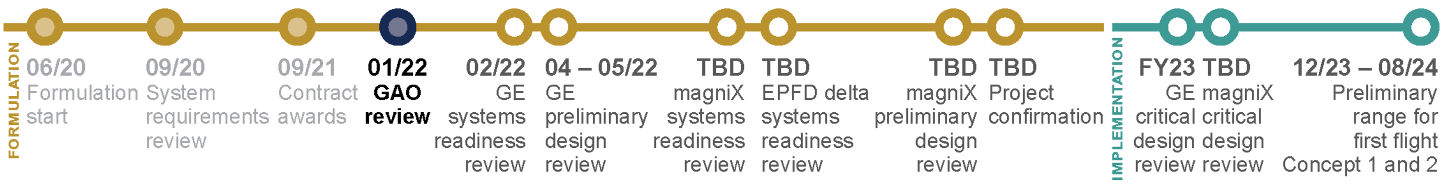
When commenting on a draft of this assessment, Dragonfly project officials noted that all of the project's cost and schedule revisions were directed by NASA because of issues with funding availability and were not to accommodate project-related issues or delays. Project officials also provided technical comments, which were incorporated as appropriate.

Electrified Powertrain Flight Demonstration

The Electrified Powertrain Flight Demonstration (EPFD) project is a technology demonstration of hybrid electric-powered aircraft. It will 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 and emissions. The EPFD project intends to reduce risks to maturing EAP technologies and address specific gaps in regulations and standards associated with introducing electrified propulsion into commercial aircraft.

Source: GE Aviation for the SAAB aircraft, magniX for the de Havilland Dash-7 aircraft. | GAO-22-105212

Timeline



GE = GE Aviation FY = Fiscal year TBD = to be determined

Project Information

NASA Lead Center: **Virtual Project Office**

International Partners: **None**

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

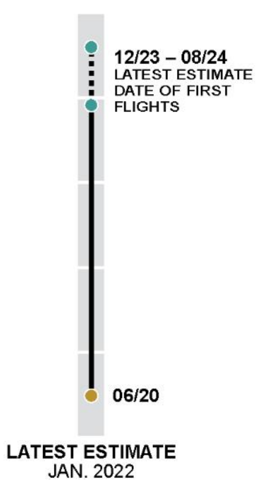
Budget Portfolio: **Aeronautics, Aeronautics**

Project Summary

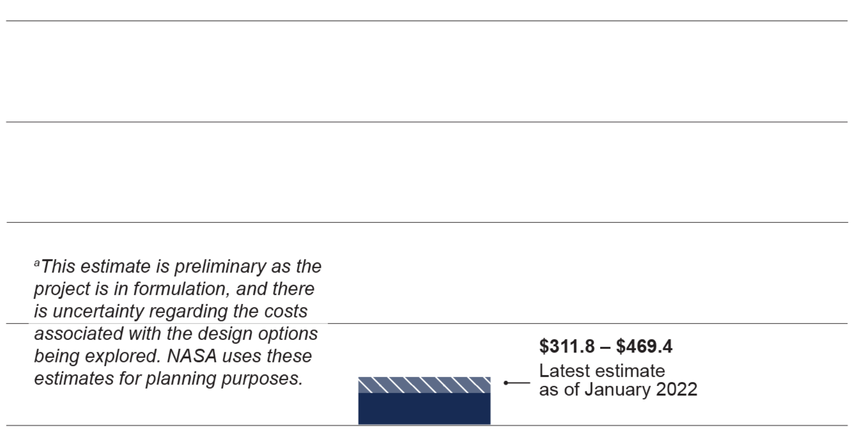
The EPFD project is in the preliminary design and technology completion phase and is operating within its preliminary life-cycle cost and schedule estimates. In September 2021, the project awarded two contracts to industry partners totaling $253.4 million. These contracts were awarded to GE Aviation and magniX. The project could also award additional contracts to industry partners through August 31, 2022. GE Aviation is focused on the development of a megawatt-class powertrain system for the single-aisle aircraft market, which includes aircraft that can carry approximately 150 passengers. magniX is focused on the development of a commuter, or more regional, hybrid turboprop aircraft meant to transport 45 passengers.

Through these partnerships, the EPFD project is working to address and retire risks that pose challenges or barriers to developing EAP technology. Project officials said the top risk is the integration of the megawatt-class powertrain with the aircraft system.

Preliminary Schedule



Preliminary Cost



[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

In November 2020, the EPFD project entered the preliminary design and technology completion phase. At that time, it established a preliminary life-cycle cost estimate range from $311.8 million to $469.4 million and a first flight date range between December 2023 and August 2024. The project is operating within these preliminary cost and schedule estimates.

On September 30, 2021, the project awarded two hybrid firm-fixed-price, cost-share contracts that total $253.4 million—$179 million to GE Aviation and $74.3 million to magniX. The contracts are firm-fixed-price until GE Aviation and magniX conduct critical design reviews, at which point a cost-sharing mechanism is added. According to NASA, the contract awarded to GE Aviation includes a partnership with Boeing.

While two awards have been made, NASA reported additional awards to other industry partners may be made through August 31, 2022. Project officials said that, as of December 2021, they were still finalizing schedules with the selected partners, but that they intend to hold project confirmation in the first quarter of fiscal year 2023, after the two industry partners hold preliminary design reviews.

Technology and Design

Officials said the EPFD project's aim is to build an integrated megawatt-class powertrain system and conduct flight demonstrations. GE Aviation and magniX are each developing aircraft that use a parallel hybrid architecture, which is a type of EAP system that uses both electrical and fuel-based energy storage to improve efficiency during flight.

GE Aviation and Boeing are developing an EAP system for the single-aisle aircraft market, which includes aircraft that can carry approximately 150 passengers. GE Aviation will fly a turboprop aircraft that will serve as the platform for the integration of the megawatt-class powertrain. According to officials, after the conclusion of the EPFD project, the megawatt-class powertrain will need to be integrated with a turbofan on a single-aisle aircraft for GE product integration

According to program documentation, prior to the recent award, GE Aviation and Boeing held risk reduction contracts with the project, during which they assisted the project in lowering the risks of their relevant technologies. For example, GE Aviation and Boeing addressed risks that pertained to battery systems. Officials said GE Aviation conducted tests of subscale battery performance and safety that are key for the future build of a battery that could store electricity for a parallel hybrid system. In addition, they said Boeing conducted research that will assist it in producing a future battery that will meet certification requirements.

magniX is focused on the development of a commuter, or more regional, aircraft meant to transport 45 passengers. In terms of technical development, magniX's EAP system is the furthest along in introducing the hybrid electric technology to turboprop planes. For example, magniX has flown electric propulsion units with lower power capability on existing aircraft, demonstrating its ability to integrate these types of systems. magniX plans to use the same vehicle for testing its EAP system as it plans to use for its long-term application of the system. In addition, project officials said the magniX aircraft does not require direct integration between the electrical engines and the turboprop engines, which may result in fewer challenges to aircraft integration and certification.

The EPFD project is addressing technical and integration barriers to EAP technology and has identified six barrier risks. Addressing and retiring these barrier risks could enable U.S. industry to bring to market the next generation of EAP commercial transport and inform standards and regulations gaps. Officials said they are most concerned about the barrier risk involving the aircraft system integration of the power system with the gas turbine engine because a megawatt EAP system has never been deployed on an aircraft. The project's risk reduction contracts helped the project understand these risks better. As the selected partners move forward with development, the project hopes to further address these barrier risks.

Project Office Comments

When commenting on a draft of this assessment, EPFD project officials said the first flight estimated date range has shifted to be no earlier than August 2024, with the flight test campaign expected to complete by September 2025. Officials said the schedule will continue to be refined during formulation as the project approaches project confirmation. They also provided technical comments, which were incorporated as appropriate.

Geospace Dynamics Constellation

The Geospace Dynamics Constellation (GDC) project will use multiple spacecraft to collect simultaneous multipoint observations to explore Earth's ionosphere-thermosphere (I-T) system and how it responds to, processes, and redistributes external energy inputs from the Sun and Earth's magnetosphere. The I-T system is comprised of the ionosphere and thermosphere layers of Earth's upper atmosphere. GDC will provide the first global scale measurements of the I-T system and allow a better understanding of the fundamental nature of Earth's atmosphere, as well as how other planetary atmospheres behave. GDC will provide information on the mechanisms that drive space weather effects, such as communication and navigation disruptions and enhanced orbital drag.

Source: NASA. | GAO-22-105212

Project Information

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

Mission Duration: **3 years**

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

Budget Portfolio: **Science, Heliophysics**

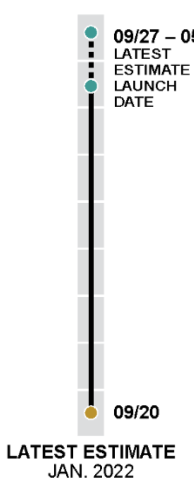
Next Major Project Event: **System requirements/mission definition review (to be determined)**

Current Status

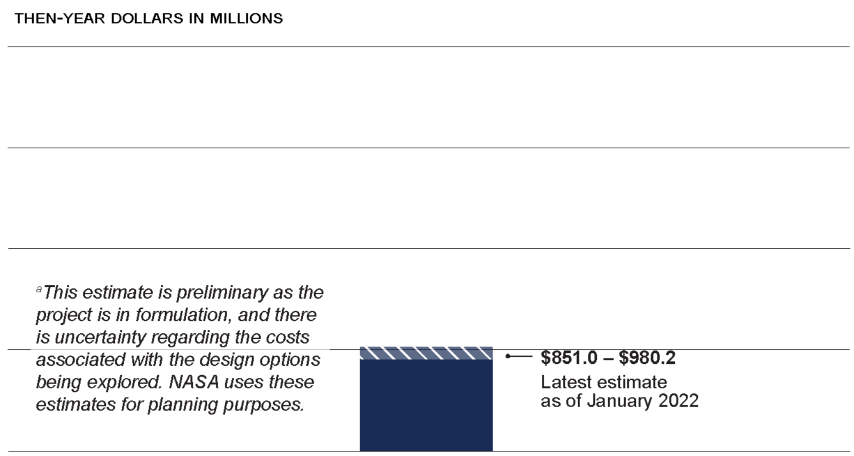
The GDC project entered the concept and technology development phase—phase A—in September 2020, with a preliminary cost estimate range from $851 to 980.2 million and a launch readiness date range from September 2027 to May 2028. The project planned for this phase to be longer than usual due to instrument and spacecraft needs. For example, officials said GDC plans to use six spacecraft, each equipped with approximately seven instruments. NASA plans to select the instruments first and then select a spacecraft model once instrument needs are better defined. According to NASA, this approach reflects lessons learned from the Europa Clipper project, and presents the lowest amount of risk because it will allow the project to avoid costly spacecraft modifications for instrument changes. NASA released a solicitation for science investigations and instruments in August 2021 and expects to make selections in April 2022.

While GDC planned for the extended duration of phase A, officials said that it may be extended further due to projected funding constraints. In September 2021, NASA asked GDC to revise its cost and schedule estimates due to lower than planned projected funding for fiscal year 2024 and subsequent years. NASA is proceeding with the instrument selection process, but officials said the project's schedule is under review and will be based on fiscal year 2023 funding.

Preliminary Schedule



Preliminary Cost



Project Office Comments

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

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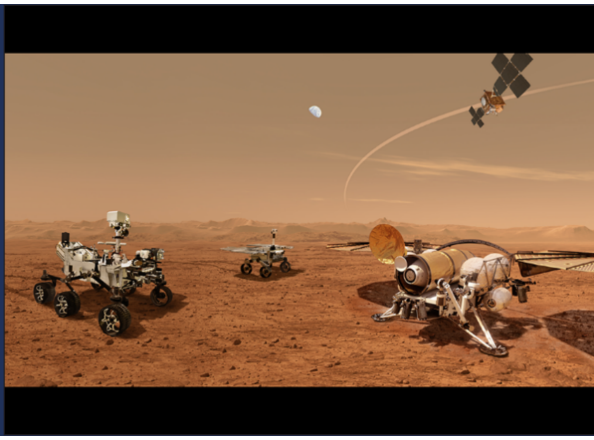


Mars Sample Return

The Mars Sample Return (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 additional study and analysis. The MSR program includes a NASA-managed Sample Retrieval Lander element that will contain an ESA Sample Fetch Rover, ESA Sample Transfer System, NASA Orbiting Sample container, and the NASA Mars Ascent Vehicle (MAV). It also includes an ESA-managed Earth Return Orbiter that contains a NASA Capture Containment and Return System and a NASA Earth Entry System. This mission will be the first launch from the surface of another planet and the first international, interplanetary relay effort.

Source: NASA. | GAO-22-105212

Project Information

NASA Lead Center: **Jet Propulsion Laboratory**

Mission Duration: **5 years**

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

Budget Portfolio: **Science, Planetary Science**

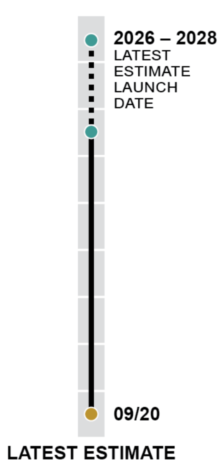
Next Major Project Event: **Key decision point B (June 2022)**

Current Status

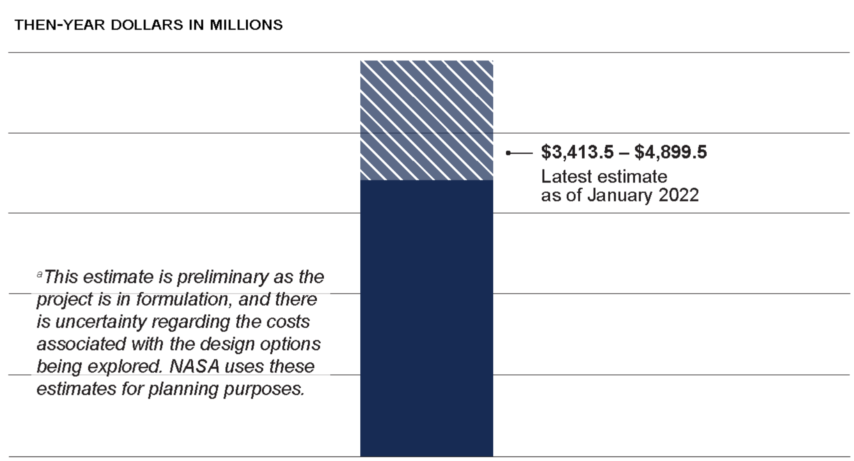
The MSR program entered the concept and technology development phase in December 2020, with a preliminary cost estimate range from $3.4 to $4.9 billion and a launch readiness date range from 2026 to 2028. The preliminary costs include all NASA-managed or NASA-contributed elements, such as the Sample Retrieval Lander and its associated components and the Capture Containment and Return System, which will be included on the ESA-contributed Earth Return Orbiter. NASA will reassess its estimates no earlier than June 2022 when it enters the preliminary design and technology completion phase.

The program is in the process of completing trade studies and working through early design decisions. The project extended its concept and technology development phase by over 6 months to close out trade studies. For example, one study involves deciding between a large single or smaller dual lander architecture. The large single lander approach would accommodate the MAV and Sample Fetch Rover on one lander and would require a Space Launch System-class launch vehicle. The alternatives are to accommodate the MAV and Sample Transfer System on a NASA-provided lander and pursue either a commercial option or international partnership to provide the lander for the Sample Fetch Rover. In addition, in February 2022, NASA announced it awarded a contract to Lockheed Martin Space to build the MAV.

Preliminary Schedule



Preliminary Cost



Project Office Comments

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

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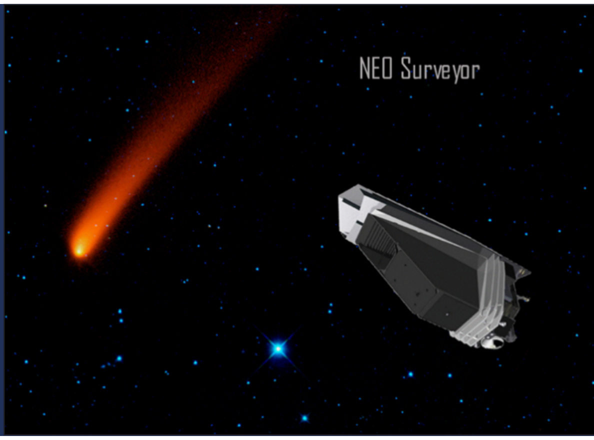


Source: University of Arizona. | GAO-22-105212

Near Earth Object Surveyor

The Near Earth Object (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 the 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.

Timeline

FORMULATION	06/20	Formulation start
	09/20	System requirements/ mission definition review
	01/22	**GAO review**
	09/22	Preliminary design review
	11/22	Project confirmation
IMPLEMENTATION	11/23	Critical design review
	01/25	System integration review
	02 – 06/26	Preliminary launch readiness date

Project Information

NASA Lead Center: **Jet Propulsion Laboratory**

International Partners: **None**

Launch Location: **To be determined**

Launch Vehicle: **To be determined**

Mission Duration: **5 years**

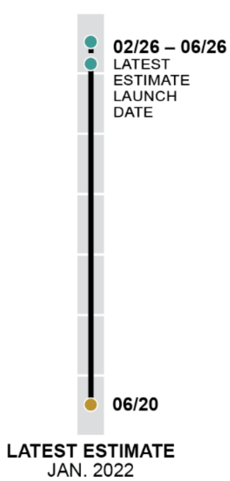
Requirement Derived from: **The George E. Brown, Jr. Near Earth Object Survey Act, Pub. L. No. 109-155, § 321 (2005)**

Budget Portfolio: **Science, Planetary Science**

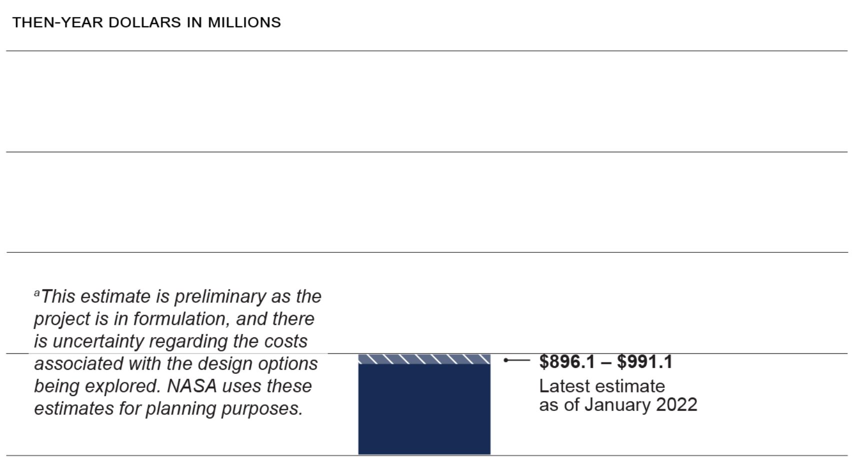
Project Summary

In June 2021, the NEO Surveyor project entered the preliminary design and technology completion phase, and set a preliminary life-cycle cost estimate range from $896 to $991 million. The project entered this phase 7 months later than it originally planned because NASA needed more time to assess budgetary resources considering potential COVID-19 effects. NASA's budget in fiscal year 2021 did not provide the project's requested funding, so this phase was extended and the project's preliminary schedule estimate is later than previously planned. As the project proceeds with formulation, it is currently updating its time frames to support an earlier preliminary design review (PDR), which was moved up by 2 months to September 2022. In addition, the project has taken steps to reduce risk for the telescope. For example, the project will manufacture the telescope at the Jet Propulsion Laboratory (JPL). The project is also working to address risks with its long-wave and mid-wave infrared detectors, which sense the infrared wavelengths that the project is measuring to detect NEOs, and with the aperture deployable release cover.

Preliminary Schedule



Preliminary Cost



[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 NEO Surveyor project entered the preliminary design and technology completion phase in June 2021. The project established a preliminary life-cycle cost estimate range from $896 million to $991 million and an estimated launch readiness date between February 2026 and June 2026. The project entered this phase—also known as phase B—7 months later than originally planned because NASA needed more time to assess budgetary resources considering potential COVID-19 effects.

The project is planning for phase B to last 20 months rather than the original estimate of 12 months due to the project receiving less funding than it requested in fiscal year 2021. Officials said the reduced funding was a result of NASA's budget constraints. According to NASA officials, the extended phase B and resulting later launch readiness date will increase costs for the project. No COVID-19 effects were included in the project's preliminary cost and schedule estimates. However, as of January 2022, the project was working with NASA to move planned funding from phase C into phase B to move up multiple procurements and activities because of COVID-19 supply chain issues. The project does not anticipate that the shift in funding will affect the overall estimated life-cycle cost.

Technology and Design

The NEO Surveyor project is currently updating its time frames to support an earlier PDR, which was moved up by 2 months to September 2022. The spacecraft inheritance review was held in August 2021 to assess which components have prior flight history. The review identified seven spacecraft components with flight history and confirmed that heritage, or mature, components could be used for them. Officials told us this results in a more mature spacecraft, which reduces implementation risk.

After the project's September 2020 system requirements review—a life-cycle review that occurs early in development—the project brought telescope manufacturing in-house to JPL. This decision was made to take a lower risk approach to telescope implementation. According to officials, the original vendor encountered schedule difficulties and conflicts with other work that made it unlikely the vendor would be able to meet the project's technical and schedule needs. Project officials said that they checked other vendors' ability to produce the telescope, but other vendors were unavailable or uninterested. Project officials said that because JPL was available to take on the effort, they determined that their best course of action was to move development to JPL.

NEO Surveyor requires four long-wave and four mid-wave infrared detectors to measure the infrared wavelengths to detect NEOs. According to officials, the detectors are similar to those used in other NASA missions but have been slightly modified to detect longer infrared wavelengths while still being optimized for looking into cold space. The detectors are integrated into two Sensor Chip Assemblies (SCAs) that transfer data to the project's Sensor Control Electronics (SCE) component, then through the instrument and spacecraft to Earth. The project classified SCAs and SCEs as critical technologies and both are already at a technology readiness level 6 well in advance of the project's PDR. GAO's best practice work has shown that reaching this level of maturity by PDR can minimize risks for systems entering product development.

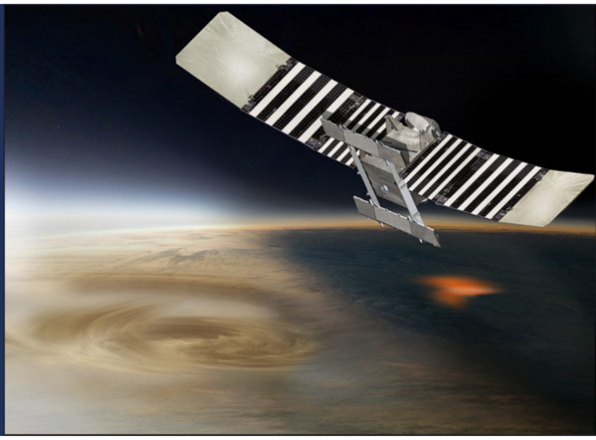
According to officials, the detectors are an essential part of NEO Surveyor and can be difficult to develop since each lot produced is slightly different. As a result, the project is tracking the manufacturability of detectors as a top risk. Specifically, officials are tracking whether the vendor will be able to produce enough viable SCAs on schedule. The project is performing a number of mitigation activities to address this risk, including starting procurement for SCAs early in phase B. Officials said that the project intentionally started the build process early to keep the detectors off of the project's critical path.

The project is also tracking a top risk that its aperture cover will fail to deploy. While this risk has a low likelihood, if realized the mission would fail. Officials said that the aperture cover release device is important to minimize contaminants during telescope operations. The project has taken steps to mitigate this risk, including reviewing and updating the cover's heritage design. It also completed an analysis to ensure that the aperture cover does not generate excessive loads to the device holding it down during launch, which could damage the device. The project continues to develop a test plan and work with independent review boards in advance of its PDR and critical design review.

Project Office Comments

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

Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy



Source: Corby Waste. | GAO-22-105212

The Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy (VERITAS) project will use two instruments and the telecommunications system on an orbiting spacecraft to map Venus's surface and interior to understand why it developed differently than Earth. One instrument will assess Venus' tectonic and volcanic history. Another instrument will determine if volcanoes are active and releasing water vapor into the atmosphere. A gravity science investigation will determine if Venus' core is liquid or solid and provide other data and maps. VERITAS will also host an atomic clock technology demonstration.

Project Information

NASA Lead Center: **Jet Propulsion Laboratory**

Mission Duration: **To be determined**

Requirement Derived from: **Discovery Program Announcement of Opportunity 2019**

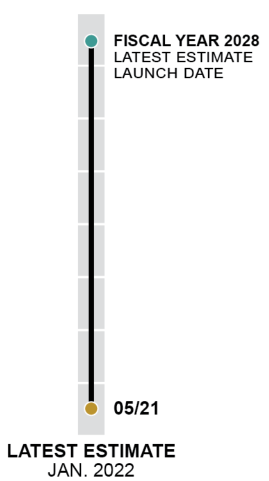
Budget Portfolio: **Science, Planetary Science**

Next Major Project Event: **Mission definition review (October 2023)**

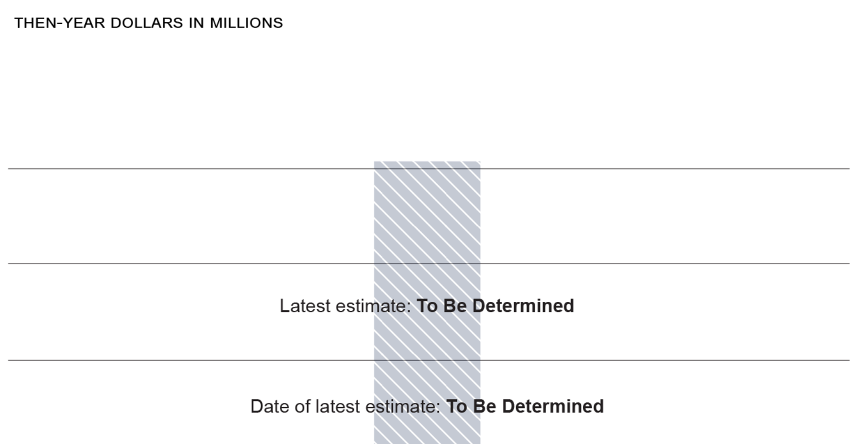
Current Status

The VERITAS project was selected in May 2021 as part of the Discovery Program and entered the preliminary design and technology completion phase. After selection, NASA directed the project to revise its cost and schedule estimates to support a later launch readiness date in fiscal year 2028 due to budget constraints in fiscal years 2021 and 2022. As of January 2022, the project proposed a November 2027 launch readiness date to NASA. Project officials said they plan to use the added time to focus on addressing the project's potential technical challenges. For example, they are performing risk reduction activities for the Venus Interferometric Synthetic Aperture Radar—the instrument that will measure ground-surface displacement. One activity involves obtaining the processor used in the Digital Electronics Subsystem, which does the onboard radar processing in order to test the algorithms. In addition, VERITAS has three international partners: the Italian, German, and French Space Agencies. As part of its risk reduction strategy, the project is working with these partners to ensure the partners have the support needed so their contributions can proceed and be delivered on schedule. Lastly, officials said that they are interacting with industry early to procure electronic parts because they are seeing delivery of electronic parts taking longer due to COVID-19.

Preliminary Schedule



Preliminary Cost



Project Office Comments

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

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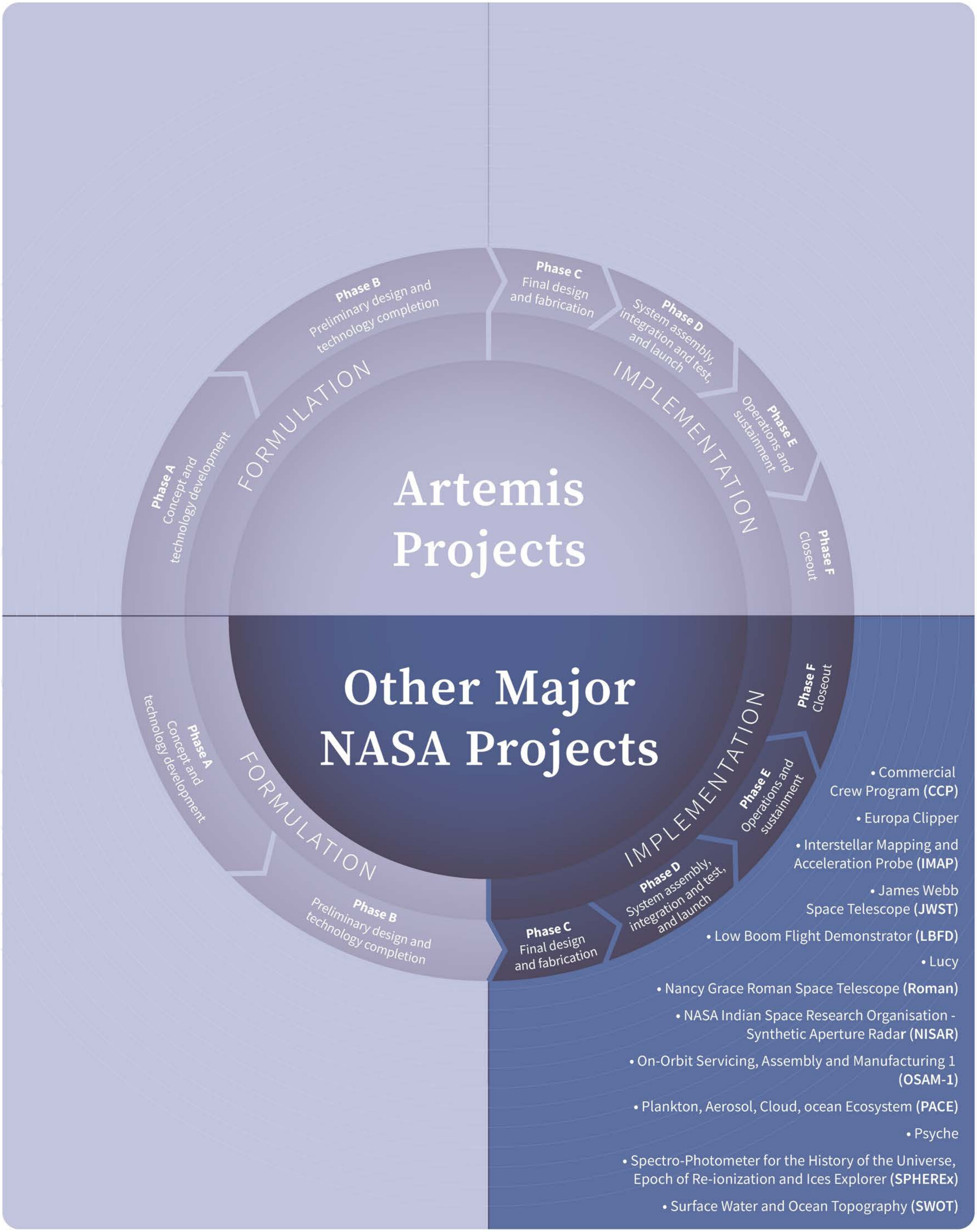

Source: U.S. Government Accountability Office analysis of NASA data. | GAO-22-105212

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Commercial Crew Program

The Commercial Crew Program (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 the commercial 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-22-105212

Timeline

- 09/14 Transportation Capabilities phase contract awards
- 03/19 SpaceX uncrewed test flight
- 12/19 Boeing uncrewed test flight-1
- 05/20 SpaceX crewed test flight
- 11/20 SpaceX final certification and first post-certification flight
- **01/22 GAO review**
- **No earlier than 05/22** Boeing uncrewed test flight-2
- ***Under review*** Boeing crewed test flight
- ***Under review*** Boeing final certification
- **2020 – 2028** Post-certification operational missions

Project Information

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**

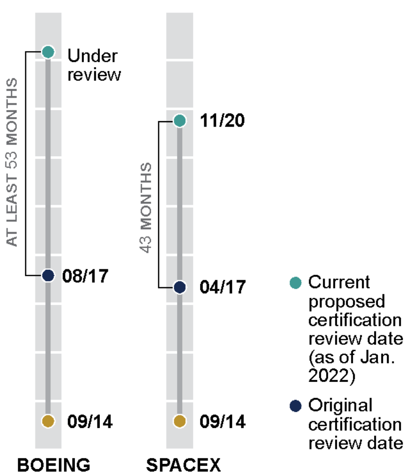
Requirement Derived from: **NASA Strategic Plan**

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

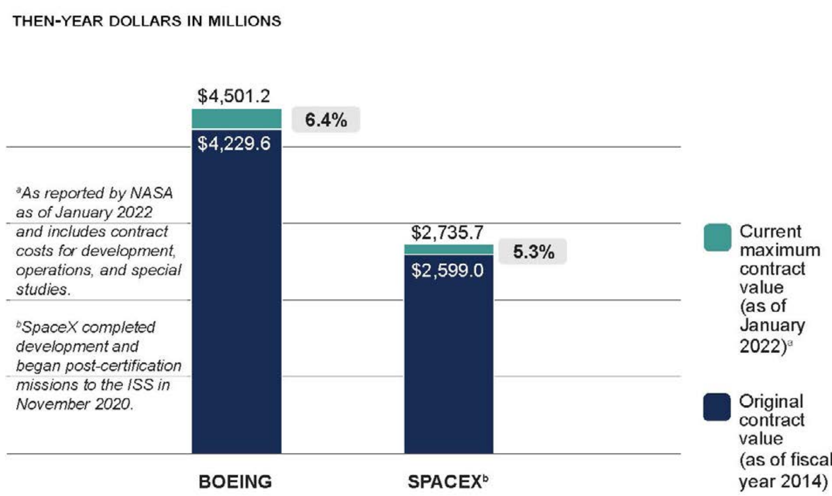
Project Summary

CCP and Boeing are working to complete two flight tests required for certification, but significant work remains. For example, CCP and Boeing spent at least 6 months investigating the mechanical failure of service module valves that caused Boeing to postpone its second uncrewed flight test in August 2021. The program is continuing to support SpaceX's near term crewed missions to the ISS. SpaceX is launching post-certification or service missions approximately every 6 months and may fulfill its current contract to provide six of these missions to the ISS by 2023. To ensure continued access to the ISS, in February 2022, NASA announced that it awarded three additional missions to SpaceX. The CCP program manager said the program is also exploring whether to expand the number of providers that can transport crew given the President's decision to extend the ISS through 2030.

Schedule Performance



Cost Performance



Cost and Schedule Status

CCP is balancing SpaceX's near-term crewed missions with Boeing's development. While SpaceX was certified to provide crewed transportation to the ISS in November 2020, Boeing has not yet completed two flight tests that are, among other things, needed before its certification review. Boeing's certification review has been delayed at least 4 years. After Boeing's first uncrewed flight test did not reach the planned orbit or dock with the ISS, Boeing planned to conduct a second uncrewed flight test in August 2021. However, NASA and Boeing delayed the test after detecting an anomaly with the service module's oxidizer valves and rescheduled the test pending the results of an investigation and corrective action. They plan to reattempt this flight test as early as May 2022.

To ensure access to the ISS, SpaceX is launching post-certification, or service, missions approximately every 6 months and may fulfill its current contract to provide six of these missions to the ISS by 2023. In February 2022, NASA announced that it awarded three additional missions to SpaceX to maintain access to the ISS. These missions may begin at the end of 2023.

Given the President's decision to extend the use of the ISS through 2030, NASA will continue to rely on SpaceX and eventually Boeing for crewed transportation. The program manager said the program was exploring whether to expand the number of providers that can transport crew.

Integration and Test

Uncrewed Flight Test-2. CCP and Boeing are close to remedying the anomaly in the service module valves that caused Boeing to postpone its second uncrewed flight test in August 2021. The service module provides propulsion on-orbit and in abort scenarios, radiators for thermal control, and solar panels to charge batteries. A team of staff from NASA's CCP, Boeing, and Boeing's suppliers performed an investigation and testing into the root cause of the valve anomaly. According to NASA, the team continues to believe that oxidizer leakage was the probable cause and the presence of moisture was a contributing factor.

After a test revealed continued issues with the valves of service module 2, CCP and Boeing decided not to reuse it for the uncrewed flight test-2, as originally planned. Instead, Boeing will fly the service module originally planned for its later crewed flight test. Boeing plans to salvage parts from service module 2 and use them on future flights, such as reusing the solar arrays and batteries on the upcoming uncrewed flight test-2. CCP and Boeing will also implement hardware changes for uncrewed flight test-2 to mitigate this issue. For example, the project plans to add environmental seals and a valve purge system to the service module.

CCP and Boeing must complete other tasks before they attempt uncrewed flight test-2. According to Boeing officials, about 10 percent of both of their certification products must be updated and resubmitted for CCP review and approval as a result of the valve anomaly. Boeing will also fly a modified service module design for the first time on the uncrewed flight test-2, which must be approved by NASA.

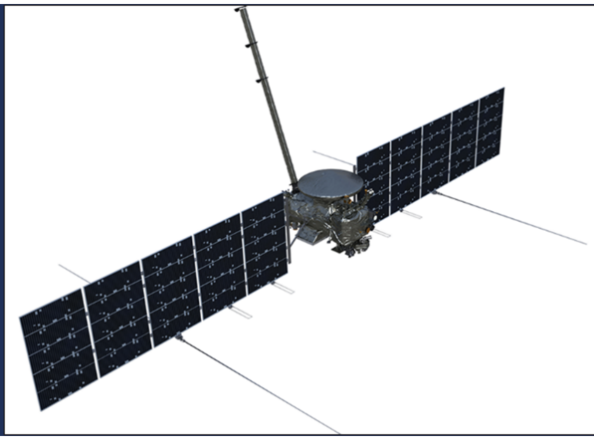
Crewed Flight Test. CCP and Boeing have multiple items to complete to be ready for the crewed flight test. While launch vehicle components have been delivered and Boeing requested a launch window, the service module production will be a key schedule driver. Boeing will fly the service module originally slated for its first service mission on its crewed flight test. CCP and Boeing's readiness for the crewed flight test will be determined by how quickly they complete the significant certification work that remains. The CCP program manager said the program approved 50 percent of Boeing's certification products for the crewed flight test as of January 2022. However, because the program limited the scope of uncrewed flight test-2 to reduce the program's certification workload, the program manager said the remaining certification work for the crewed flight test includes challenging items such as Boeing's parachutes, landing loads, and abort systems.

In addition, the CCP and ISS programs are concerned that operational staff may not be able to safely operate Boeing's crewed spacecraft if there are any issues with Boeing's flight software. CCP reported that Boeing's approach to software development and testing created a significant backlog of software problem reports. Program officials said the operations team is being trained on operational workarounds to complete functions manually that software would normally automate. Several teams reported little capacity to safely accommodate additional operational workload that may be needed if there are any problems with Boeing's flight software. To mitigate this issue, CCP plans to provide operational teams 6 months of training time with released software and closely monitor workload.

One of CCP's top risks for the crewed flight test is that quality issues with hardware may pose unknown risks to the mission or to crew safety. CCP had previously discovered deficiencies in Boeing's quality management of its suppliers. Boeing made changes to its quality management processes, which NASA determined to be sufficient through multiple audits. However, CCP plans to conduct technical assessments of certain systems to better understand the risk level to the mission or crew safety.

Project Office Comments

When commenting on a draft of this assessment, CCP officials said that, since certification, SpaceX performs regular missions to rotate NASA astronauts to the ISS. They said NASA and Boeing continue work to certify Boeing's crew transportation system and plan to conduct two flight tests prior to certification. Once certified, officials said NASA plans to alternate missions between the providers. Officials also provided technical comments, which were incorporated as appropriate.

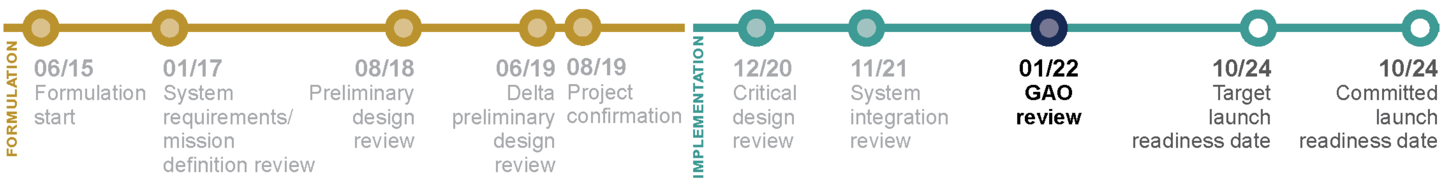


Europa Clipper

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. We did not assess the proposed mission to land on Europa, which NASA is managing as a separate project in pre-formulation.

Source: NASA/Jet Propulsion Laboratory-California Institute of Technology. | GAO-22-105212

Timeline



Project Information

NASA Lead Center: **Jet Propulsion Laboratory**

International Partners: **None**

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

Launch Vehicle: **Falcon Heavy**

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

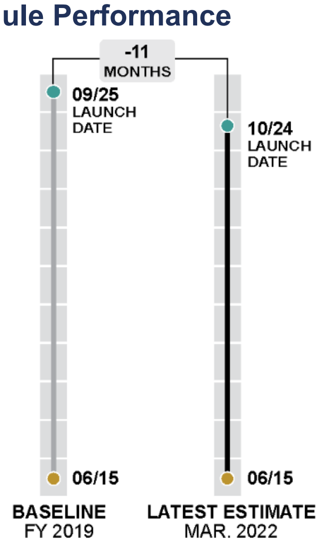
Requirement Derived from: **2011 Planetary Science Decadal Survey**

Budget Portfolio: **Science, Planetary Science**

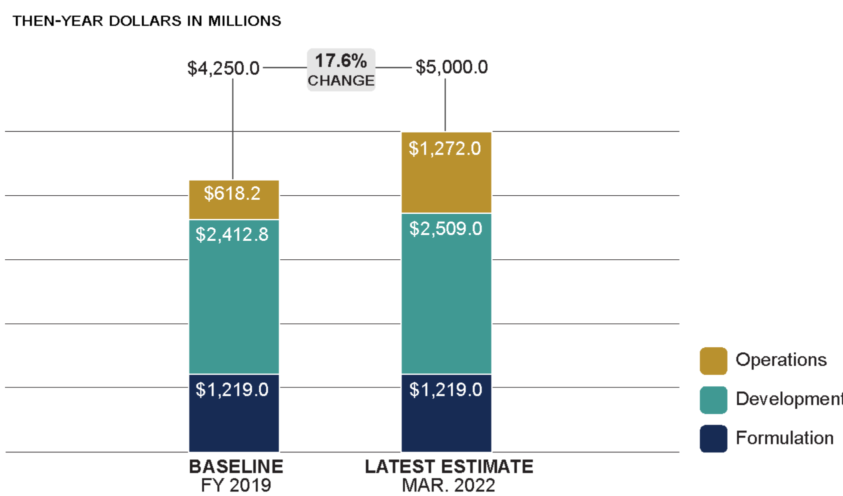
Project Summary

The Europa Clipper project is executing to a new life-cycle cost estimate of $5.0 billion and a launch readiness date of October 2024, which is almost one year earlier than the project's original baseline. The increased life-cycle cost includes $96.2 million in development cost growth above the cost baseline, which the project attributed to COVID-19 and late launch vehicle selection, among other issues. The project is also reporting an over 100 percent increase to operations costs due to errors and omissions in an earlier estimate, design maturations, and a longer flight time from the recently selected Falcon Heavy launch vehicle. In addition, the project's schedule is currently at risk due to late hardware deliveries for several subsystem and instruments, which have been delayed due to technical issues and COVID-19. The project is considering several options to mitigate schedule concerns. In addition, the project is monitoring its solar arrays, which are at risk of being delivered later than planned. To mitigate the potential delay, officials are developing plans to install the arrays at the launch site.

Schedule Performance



Cost Performance



Cost and Schedule Status

The Europa Clipper project is executing to a new life-cycle cost estimate of $5.0 billion and is planning to launch in October 2024, almost one year earlier than its original committed launch readiness date of September 2025. The project had previously moved $66 million from development to operations. However, it recently added $162.2 million in development costs to replenish the $66 million and add $96.2 million to cover effects from COVID-19, the late launch vehicle selection, and associated trajectory implications. The increased costs also restored the project's cost reserves. In addition, the project recently increased operations costs to approximately $1.3 billion, which is over 100 percent higher than the original 2019 baseline. The project attributes this growth to errors and omissions in an earlier estimate, design maturations, and a longer flight time to reach Europa on the project's selected launch vehicle.

Development of the project's instruments consumed about $72 million of the project's cost reserves from January to August 2021. Project officials stated that the Mapping Imaging Spectrometer for Europa instrument had the most significant cost growth due to late hardware deliveries. According to officials, the Mass Spectrometer for Planetary Exploration (MASPEX) and Europa Imaging System (EIS) instruments were also cost-growth drivers. NASA previously reviewed all three of these instruments for descoping due to previous cost growth. As a result of that process, the MASPEX and EIS instruments received cost caps that will trigger another descoping review if breached. Project officials said that they do not expect either instrument to breach its cost cap, but, even if one of the instruments were to do so, they would recommend against descoping it because the potential cost growth would not be large enough to justify the science losses.

Integration and Test

Hardware deliveries for several subsystems and instruments continue to be delayed due to technical issues and COVID-19—threatening the project's schedule. To mitigate potential delays to starting and progressing through Assembly, Test and Launch Operations (ATLO), project officials stated they are undertaking several efforts. For example, the project is assessing whether to combine two planned system thermal vacuum tests into a single test. Officials stated they also plan to use engineering models for some electronic elements, allowing the project to begin integration and testing activities despite the delays.

A further complication, according to project officials, is that many of the spacecraft's and instruments' sensitive electronics have to be sealed in a radiation-protected vault early in the ATLO process. However, delivery delays are anticipated for three of the nine instruments' electronics, so the project is planning to potentially seal the vault without these instruments' electronics. The project would then proceed with integration and testing and reopen the vault later in the ATLO process when the late hardware is delivered. According to officials, this mitigation option would require the project to retest equipment, and it increases the risk of potentially damaging the already-integrated hardware.

In addition, one of the project's top concerns is the possible late delivery of the solar arrays due to COVID-19, design complexity, and quality issues. To mitigate the potential delay, officials are developing plans to install the arrays on the spacecraft at the launch site. Officials said that although the solar arrays build off hardware from another Jupiter orbital mission, Europa Clipper's arrays will host antennas, which will require changes to how they are stowed on the spacecraft compared to the other mission's hardware. The project is continuing to explore how this late installation would affect design and testing activities. According to officials, these activities were going to be used to validate models of the arrays in the new stowed position.

During the system integration review (SIR) in November 2021, the project's Standing Review Board acknowledged the project's risks and recommended the addition of two status update meetings to help address them—one after the start of ATLO, planned for early 2022, and the second around the time of the planned vault closure.

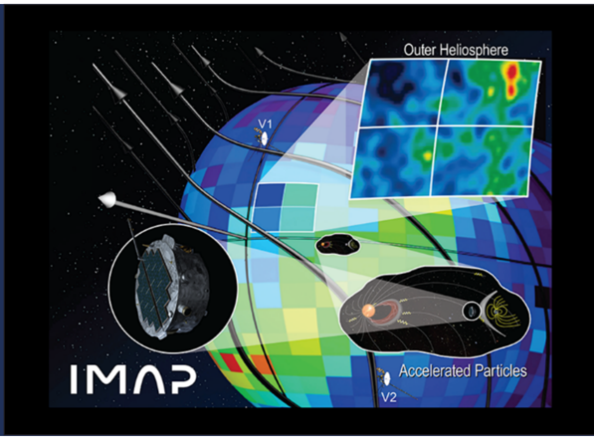
Launch Vehicle

NASA reports that it awarded a contract valued at $178 million to SpaceX in July 2021 to provide launch services for Europa Clipper on a Falcon Heavy launch vehicle. Officials said the contract value is $230 million less than the project budgeted for a launch vehicle. However, the late launch vehicle decision led the project to delay its internal launch date. In addition, compared to the baselined launch vehicle, the Space Launch System, the Falcon Heavy will add almost 4 years of flight operations to reach Europa. Officials said the launch vehicle cost savings offset the cost of the longer cruise.

Launching on a Falcon Heavy during the project's target launch date of October 2024 will require that Europa Clipper fly first around Mars and Earth—leveraging the planets' gravities to increase the spacecraft's speed in a maneuver known as a gravity assist—before entering Jupiter's orbit in April 2030. If the project does not meet the target launch date, the next launch opportunity begins in October 2025. This later date would require Europa Clipper to execute two Earth and one Mars gravity assists before entering Jupiter's orbit in July 2031.

Project Office Comments

When commenting on a draft, Europa Clipper project officials said they generally agreed with this assessment. They said the project has continued to make excellent progress since its SIR in November 2021 and continues to adjust plans to accommodate delivery delays of key flight hardware elements while making progress and reducing risk. Officials said the recent NASA decision to restore project reserves provides the necessary resources to resolve potential upcoming challenges. Project officials also provided technical comments, which were incorporated as appropriate.



Interstellar Mapping and Acceleration Probe

The Interstellar Mapping and Acceleration Probe (IMAP) is a spinning spacecraft that will help researchers better understand the boundary where the heliosphere 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: Princeton University, Johns Hopkins University/Applied Physics Laboratory, Southwest Research Institute. | GAO-22-105212

Timeline

Project Information

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

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

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

Launch Vehicle: **Falcon 9**

Mission Duration: **2 years**

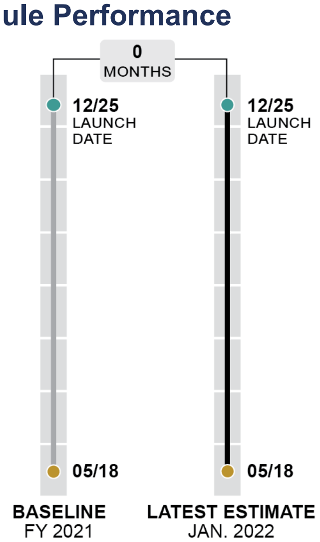
Requirement Derived from: **2013 Heliophysics Decadal Survey**

Budget Portfolio: **Science, Heliophysics**

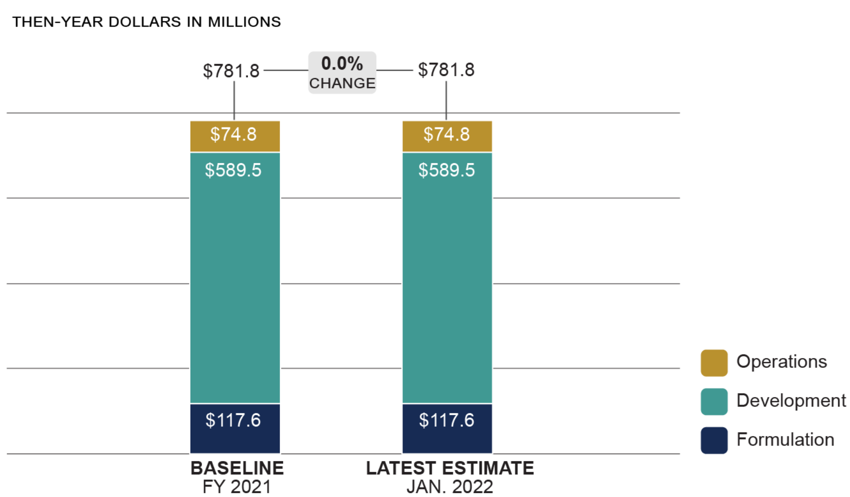
Project Summary

IMAP entered the implementation phase in July 2021 and established cost and schedule baselines of $781.8 million and December 2025, respectively. These estimates are $5.5 million above the project's preliminary cost estimate and 12 months later than its preliminary schedule estimate. According to program documentation, the project is maintaining cost and schedule reserves within requirements. IMAP successfully passed its preliminary design review in May 2021. It reported having no critical technologies, as its 10 instruments are based on mature heritage designs, but faces several challenges in developing, testing, and integrating the instruments. In particular, the project is tracking risks related to complexity of its IMAP-Lo and Compact Dual Ion Composition Experiment (CoDICE) instruments. The project is developing engineering models to mitigate these concerns. It is also modifying spacecraft components that did not meet strength requirements. Additionally, the project is tracking risks related to contamination concerns introduced by secondary payloads, also known as rideshares.

Schedule Performance



Cost Performance



Cost and Schedule Status

IMAP entered the implementation phase and established its cost and schedule baselines in July 2021. NASA set a baseline life-cycle cost of $781.8 million and a December 2025 launch date. This is $5.5 million above the top end of the project's preliminary cost estimate and 12 months later than its preliminary schedule estimate. The baseline includes COVID-19-related effects already incurred, such as an almost 4-month postponement of the project's preliminary design review, as well as an additional $25 million for potential future COVID-19-related cost effects. According to project documentation, the project is currently maintaining cost and schedule reserves within requirements.

Technology and Design

The project passed its preliminary design review in May 2021. IMAP reported that the project has no critical technologies, or no technologies used in a new or novel way. However, one of the top challenges facing the project will be developing, testing, and integrating its 10 instruments, most of which need to be updated in some fashion.

The project is tracking several risks related to its instruments. For example, one of the project's top risks is related to the development complexity of the IMAP-Lo instrument, which will measure interstellar atoms to improve understanding of the composition and properties of interstellar medium. Performance of this instrument is required for the mission to be considered a success. According to the project manager, IMAP-Lo is the most complex instrument on the spacecraft due to its high voltage requirements and the number of required interfaces to other components. Further, the instrument is being modified to add a pivot platform to the heritage instrument IMAP-Lo is based on. The modification is expected to increase the measurements taken by the instrument. The project is developing an engineering model to mitigate the risk that the complicated design of the instrument will require more time or personnel to complete and increase project schedule or cost.

In addition, the project is tracking a schedule risk related to the complexity of the CoDICE instrument, which will measure solar wind, among other requirements. According to the project manager, CoDICE has the least heritage elements of all the instruments. The project is building and testing an engineering model of the instrument to mitigate the risk of potential redesigns. Testing of the engineering model is expected to run through early 2022.

Spacecraft

In January 2021, the project discovered at the mechanical subsystem preliminary design review that clips on the spacecraft did not meet strength requirements. However, this issue was not communicated properly to project management until after the mission preliminary design review in May 2021. The project conditionally approved updated designs at a follow-up design review with independent reviewers in December 2021. The project expects to complete the design by February 2022 and noted that implementing the modifications will consume schedule reserves.

Other Issues to Be Monitored

The project is tracking two risks related to potential contamination of IMAP's instruments. One risk stems from four planned secondary payloads, also known as rideshares, that will be launched with IMAP. According to NASA program documentation, in September 2020, NASA made an early launch vehicle contract award for IMAP to SpaceX to allow additional time to mitigate risks regarding contamination control and other concerns before and after launch. Additionally, IMAP continues to coordinate with its rideshare partners, the project's Standing Review Board, launch site officials, and SpaceX to mitigate these concerns. However, per NASA's rideshare policy, if the secondary payloads fail to meet contamination requirements or schedule milestones, they can be descoped and replaced with a mass simulator.

Additionally, the project is tracking a risk related to maintaining access to the instruments after IMAP is placed inside the launch vehicle to address potential contamination concerns. According to project officials, launch vehicle processing for Falcon 9 occurs in a horizontal rather than vertical position, which creates some unique concerns related to airflow and potential contamination. The project is conducting a trade study to evaluate options for accessing the instruments within the launch vehicle.

Project Office Comments

When commenting on a draft of this assessment, IMAP project officials said that the IMAP critical design review and system integration review are delayed and under review to incorporate and fully consider changes to the spacecraft structure and the IMAP-Lo pivot platform. They also provided technical comments on a draft of this assessment, which were incorporated as appropriate.

Source: NASA. | GAO-22-105212

James Webb Space Telescope

The James Webb Space Telescope (JWST) is a large, infrared-optimized telescope designed to help understand the origin and destiny of the universe, the creation and evolution of the first stars and galaxies, and the formation of stars and planetary systems. It will also help further the search for Earth-like planets. The JWST has a large primary mirror composed of 18 smaller mirrors and a sunshield the size of a tennis court. Both the mirror and sunshield were folded for launch and gradually opened over a period of weeks following the December 2021 launch. The JWST resides in an orbit about 1 million miles from the Earth.

Project Information

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

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

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

Budget Portfolio: **Science, Astrophysics**

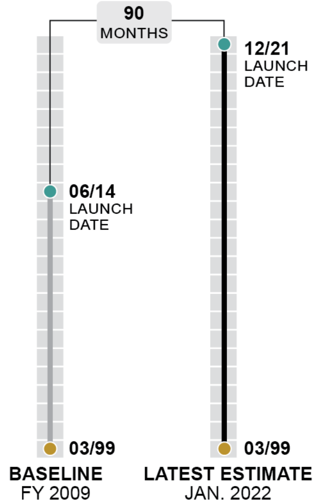
Next Major Project Event: **Completion of Commissioning (June 2022)**

Current Status

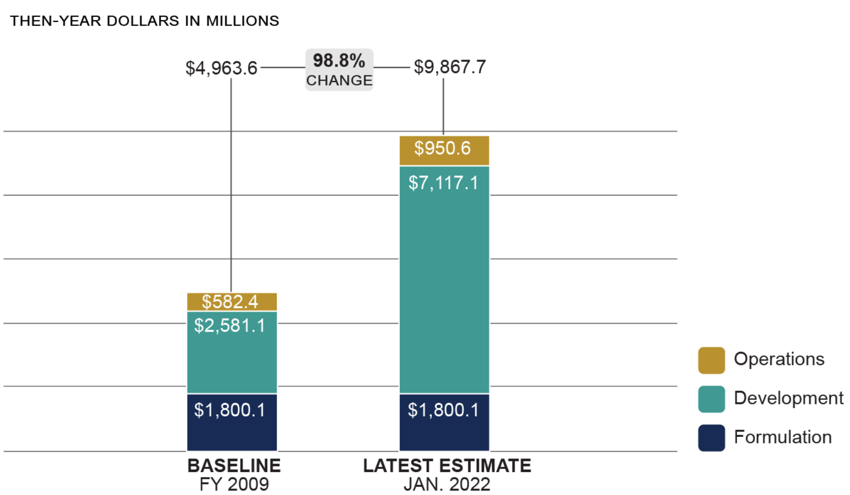
After more than 20 years of development and testing, NASA and its international partners successfully launched the JWST into space aboard an Ariane 5 launch vehicle in December 2021. NASA completed spacecraft and mirror deployments following the launch and then inserted the observatory into its orbit 30 days after launch, as planned. NASA will continue to align mirrors and activate scientific equipment over the next several months while the observatory cools to the required temperature for full operations. In January 2022, the project continued to manage 23 risks to the mission and anticipated closing all but eight by the time the observatory is operational. These risks include events NASA assessed to be unlikely, such as failure of certain mechanisms that could prevent the mission from meeting its goals.

In the months preceding the JWST's launch, the project consumed all of its reserves to address technical issues and COVID-19-related delays and expenses. In addition, launch vehicle and other technical issues required NASA to delay the launch readiness date from October 2021 to December 2021. NASA reallocated funds planned for observatory operations to development in order to cover the $115 million cost associated with this delay. NASA plans to restore these operational funds in its budgets for fiscal years 2026 and 2027.

Schedule Performance



Cost Performance



Project Office Comments

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

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Source: Lockheed Martin Aeronautics. | GAO-22-105212

Low Boom Flight Demonstrator

The Low Boom Flight Demonstrator (LBFD) is a flight demonstration project that plans to show that noise from supersonic flight—sonic boom—can be reduced to levels acceptable to the public for commercial use in overland supersonic flight paths. The LBFD project plans to generate data to inform the development of internationally accepted standards, which are needed to open the market to supersonic flight. After airworthiness certification and acoustic validation, the project plans to transfer the flight demonstration aircraft for use by the Commercial Supersonic Technology project. This will provide an opportunity to gather community responses to the flights and to create a database to support development of international noise standards for supersonic flight.

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 Project confirmation

IMPLEMENTATION
- 09/19 Critical design review
- **01/22 GAO review**
- 12/22 First flight date
- 11/23 System acceptance review
- 08/24 Aircraft transfer review

Project Information

NASA Lead Center: **Virtual project office**

International Partners: **None**

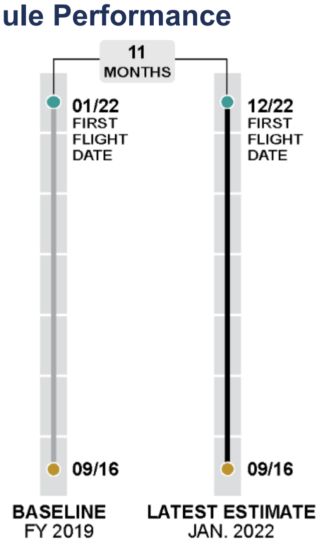
Requirement Derived from: **Aeronautics Research Mission Directorate Strategic Implementation Plan**

Budget Portfolio: **Aeronautics, Aeronautics**

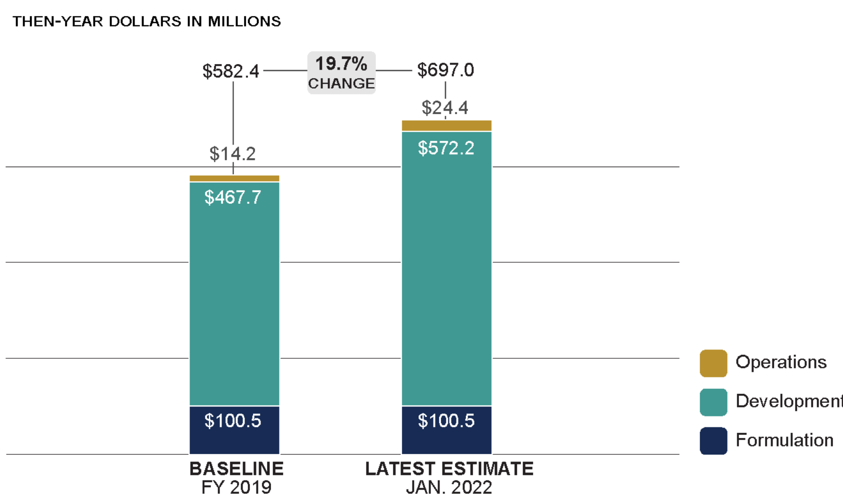
Project Summary

In December 2021, NASA approved a replan for the LBFD project that incorporated about 20 percent in cost increases and 11 months of schedule delays. The project's revised life-cycle costs are $697 million and the new first flight date of December 2022 is 11 months later than the original committed first flight date. Project officials stated that the primary cause of the cost increase is funding the contractor for a longer period than previously planned. In December 2021, the aircraft was shipped to Texas for ground testing. Following these tests, the aircraft will return to California for final processing and first flight. The project continues to track a risk that the takeoff weight of the aircraft will exceed targets. Project officials said they could mitigate this risk by reducing the fuel used during first flight—which could affect mission performance by reducing the aircraft's range. The risk will remain until the final weight of the aircraft is determined. Finally, the LBFD project will continue to monitor risks beyond first flight that the sonic boom performance may be too loud to meet the minimum success criteria.

Schedule Performance



Cost Performance



Cost and Schedule Status

In December 2021, NASA approved a replan for the LBFD project that incorporated cost increases and schedule delays. The project's revised life-cycle costs are $697 million, which is 19.7 percent higher than the original cost target and includes an additional $104.5 million in development costs. The new first flight date of December 2022 is 11 months later than the original committed first flight date. Since our last report, the LBFD project added $40 million to development costs and 6 months to its first flight date from June 2022 to December 2022. According to NASA's replan documentation, the recent increase from the project's baseline is the result of COVID-19 effects, contractor performance issues, and future unknowns.

According to project officials, the primary cause of the project's cost growth is the cost of funding the contractor for a longer period than previously planned. While COVID-19 effects such as quarantines and reduced working efficiencies contributed to cost increases, project estimates show that the replan would have happened regardless of the pandemic's effects. For example, project officials said staffing continues to be a challenge for the contractor given the volume of work compared to the available staff. In addition, project officials said that the contractor's historically optimistic scheduling created challenges for the NASA team, such as making it harder to accurately estimate required cost and schedule reserves.

Integration and Test

In December 2021, the aircraft was shipped to Texas for critical ground testing—5 months later than previously planned. The project plans to reassess its reserve posture now that the aircraft shipped, but officials said they did not expect to need additional headquarters-held reserves for the remaining work. During the testing in Texas, the project will ensure the aircraft can withstand the loads and stresses that typically occur during flight and the team will calibrate and test the fuel systems. Project officials expect these activities to take 2 months before returning the aircraft to California for more tests and final processing before first flight.

The project will use the time of the Texas-based testing to plan and prepare for previously deferred work that will now be done after the aircraft's return to California. For example, the project may address any remaining parts shortages, ensure the availability and serviceability of the required ground support equipment, and create plans to close open quality issues. However, there is a risk that the scope of work planned to be conducted during the final processing period is greater than the project anticipates due to the possibility of discovering issues late in the development process.

Technology

The project continues to track a key technical risk that the aircraft will exceed weight targets, jeopardizing mission performance. The actual weight of several payload components came in below predicted values, which helped bring the project's estimated maximum takeoff weight below the aircraft's acceptable limit. However, some threats will remain until the aircraft is complete and actual weight data can be received. Threats to the total takeoff weight include the weight of the fuel tank sealant, installed electrical power systems, and external paint.

Project officials said they can use performance margins to mitigate additional weight increases. For example, they explained that the model that calculates estimated takeoff weight assumes engine performance based on an engine that is at the end of its life. But, the actual engine being used is brand new. As a result, officials said performance could be better, which would potentially free up mass margins. In addition to these mitigation efforts, project officials said they can decide to reduce the fuel used during first flight to lower the weight of the aircraft at takeoff. However, the reduction in fuel may affect mission performance by reducing the aircraft's flight range.

Other Issues to Be Monitored

The LBFD project expects to continue tracking several risks beyond first flight related to the aircraft's sonic boom, which occurs when the aircraft flies faster than the speed of sound. The aircraft is designed to reduce the loudness of the sonic boom, but there are risks that the aircraft may be too loud to meet success criteria and that predicted boom levels do not match the real aircraft. According to project officials, the project will continue to track related risks until it can measure the actual performance of the aircraft at the speeds and altitudes needed, which will be about 9 months after first flight.

Project Office Comments

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

Source: NASA. | GAO-22-105212

Lucy

Lucy will be the first mission to investigate the Trojans, a population of never-explored asteroids orbiting the Sun in tandem with Jupiter. The project aims to understand the formation and evolution of planetary systems by conducting flybys of these remnants of giant planet formation. The Lucy spacecraft will first encounter an asteroid in the main belt—located between the orbits of Mars and Jupiter—and then will travel to the outer solar system, where the spacecraft will encounter seven Trojans over an approximately 12-year mission. The spacecraft has two solar arrays that are stowed for launch but are deployed in space. The mission's planned measurements include asteroid surface color and composition, interior composition, and surface geology.

Project Information

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

Mission Duration: **11.6 years**

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

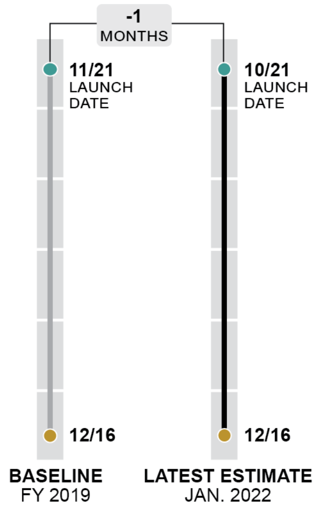
Budget Portfolio: **Science, Planetary Science**

Current Status

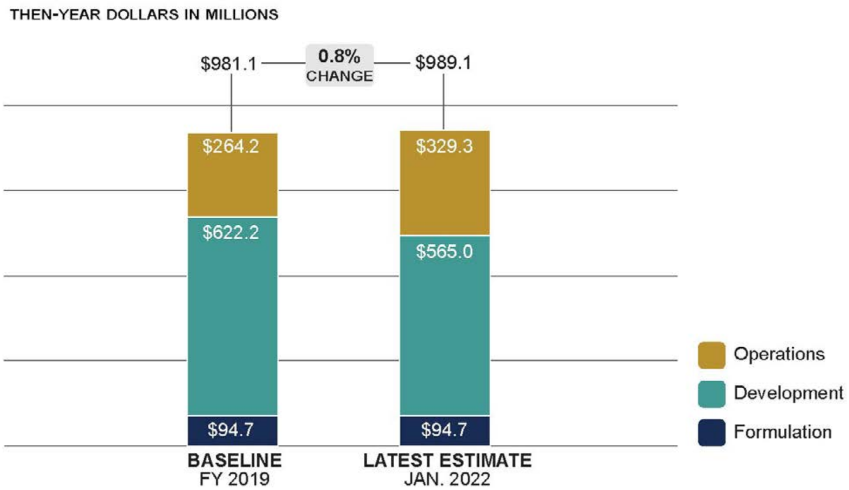
Lucy successfully launched 1 month early in October 2021, overcoming late launch vehicle concerns. After launch, one of the spacecraft's solar arrays failed to fully open, deploying only 350 of the planned 360 degrees. To deploy the arrays, a lanyard attached to each array is pulled by a motor and wraps around a spool as it retracts before latching securely. Project officials said one array did not fully deploy because the lanyard did not spool properly when the array was unfurling. NASA is investigating two paths moving forward: the use of a secondary motor to finish pulling the lanyard and potentially latch the array, or leaving it as is. Project officials said that, if left as is, it could affect the project's ability to achieve the full science objectives of the mission, but the project is expected to meet the minimum science requirements regardless of which path is pursued.

When the project entered the operations and sustainment phase in October 2021, it reported an increase in estimated operations costs that was largely offset by development cost underruns. NASA attributed the underruns to excellent project management. As of February 2022, the project estimated the array issue could cost about $20 million; however, officials said that existing cost reserves could likely cover the costs.

Schedule Performance



Cost Performance



Project Office Comments

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

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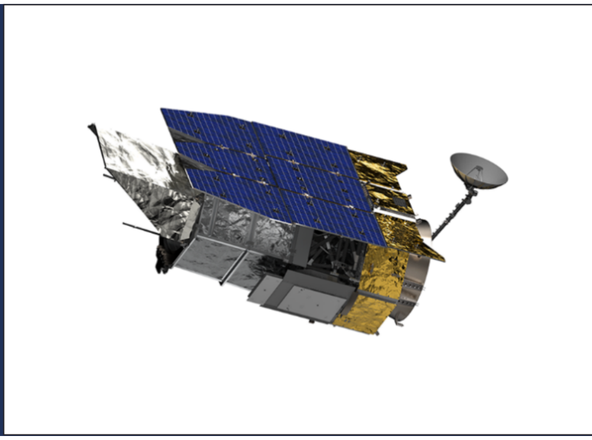


Source: NASA/Goddard Space Flight Center. | GAO-22-105212

Nancy Grace Roman Space Telescope

The Nancy Grace Roman Space Telescope (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. Roman 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 the Earth. The project is also planning a guest observer program in which the project may provide observation time to academic and other institutions.

Timeline

Project Information

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, FL/ Eastern Test Range**

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

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

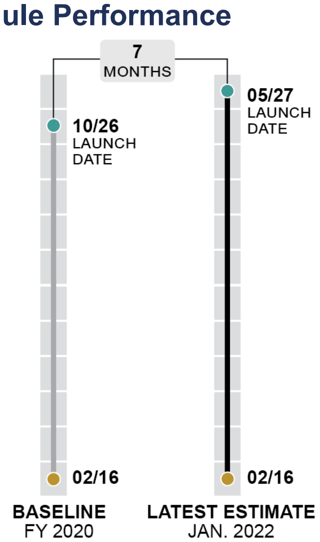
Requirement Derived from: **2010 Astrophysics Decadal Survey**

Budget Portfolio: **Science, Astrophysics**

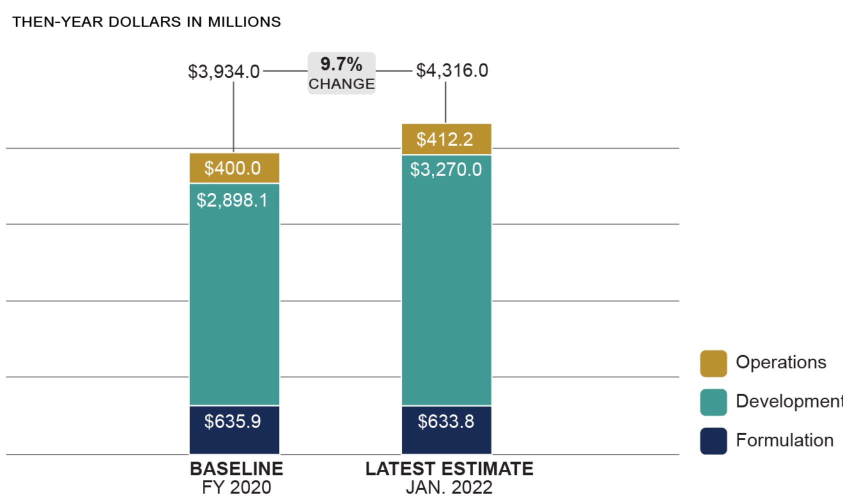
Project Summary

In June 2021, the Roman project replanned its cost and schedule due to COVID-19. The replan increased its life-cycle cost by $382 million or 9.7 percent, and delayed the project's committed launch readiness date by 7 months to May 2027. While the replan restored reserves to pre-pandemic levels, it did not address any technical issues. In February 2022, NASA released approximately $240 million in headquarters-held reserves to improve the project's reserve posture and changed the project's target launch readiness date to October 2026 to provide the project additional schedule margin. The project passed its critical design review (CDR) in September 2021 with 72 percent of its design drawings released, which did not meet GAO's best practice of releasing 90 percent of design drawings by CDR. The project's optics have been coated and meet specifications, but the project faces ongoing issues with the Optical Telescope Assembly (OTA) Primary Mirror Assembly. In addition, the project is working through a review of its spacecraft restraint release actuators after multiple failures, and is evaluating redesign options and potential schedule implications.

Schedule Performance



Cost Performance



Cost and Schedule Status

In June 2021, NASA approved a replan for the Roman project that incorporated schedule delays and cost increases from COVID-19. The project's revised life-cycle cost is $4,316 million or 9.7 percent higher than the baseline. The new launch readiness date of May 2027 is 7 months later than the original committed launch readiness date of October 2026. The replan also included added funding for operations and for the Coronagraph Instrument (CGI). COVID-19 started 1 month after the project entered implementation. According to officials, its effects included prolonged disturbance of supply chains, restrictions at NASA and contractor sites, and staffing challenges. The project was able to mitigate some delays prior to the replan, but officials said that the tools used to recover the schedule, such as placing expedited orders, were not an option due to supply chain disruptions, leading to a need for additional time and funding.

While the replan restored reserves to pre-pandemic levels, it did not address any technical issues or improve the reserves for non-COVID-19-related issues. For example, project officials said they used cost reserves to conduct unplanned additional testing and to address higher costs from vendors. In February 2022, NASA released $240.5 million in headquarters-held reserves, $236.5 million for Roman to restore project-held reserves and fund a delay to the target launch readiness date, and $4.0 million for CGI. NASA also changed the project's target launch readiness date to October 2026 from July 2026 to provide the project additional schedule margin.

Technology and Design

In September 2021, Roman passed its CDR and released 72 percent of its design drawings. This is below GAO's best practice, which is to release at least 90 percent of design drawings at CDR because it lowers the risk of projects experiencing design changes and subsequent cost and schedule growth. A project official said that the project's drawings evolve to flight design drawings from engineering test unit drawings, which typically only involves minor changes. Therefore, final released drawing numbers can increase quickly as the test unit hardware is completed. As of January 2022, the project had released 80 percent of its design drawings.

Four of the five technologies that were not matured to technology readiness level (TRL) 6 at the project's preliminary design review achieved TRL 6 by the project's CDR. However, GAO's best practice for technology maturity states that critical technologies should achieve a TRL 6 by the preliminary design review to minimize risks when entering product development. Project officials said that delivery delays for the Wide Field Instrument optical prism slowed the project's ability to mature the prism. Development and testing of the prism is ongoing, and officials said the project plans for the prism to be at TRL 6 when the protoflight unit completes environmental testing in early 2022.

Roman is also experiencing delays in the delivery of the instrument carrier structure due to manufacturing issues. The optics of the OTA have been coated and meet specifications. However, a bonding gap was discovered in the OTA Primary Mirror Assembly composite structure. The gap was filled and inspected, but, in order to mitigate the possibility of failure on launch, the project plans to perform a strength regression test. As of November 2021, the project was still preparing for the regression testing.

The project had multiple failures of the spacecraft restraint release actuators and is working through a review of the actuator failure. The project has not yet determined the failure's root cause. Roman project officials brought in a technical expert with experience working on actuators to assist in the investigation. The project is evaluating redesign options for the actuator and schedule implications from resolving the issue.

Coronagraph Instrument

CGI is a technical demonstration mission designed to perform high contrast imaging and spectroscopy of nearby exoplanets. It is managed separately from the Roman observatory, which officials said needs some performance of CGI in order to meet its science requirements. CGI completed its CDR in April 2021 and is currently building its flight hardware components and subsystems. Roman and CGI officials said that, while they participated in each other's CDRs, CGI's design maturity was not evaluated at the Roman mission-level CDR. Moving forward, a top risk for CGI is that its performance cannot be fully verified until it is integrated and tested. Project officials said that CGI has more than 80 percent margin on its performance requirements and that conducting incremental performance verification and development of software capabilities will help to mitigate some of the risks.

Other Issues to Be Monitored

NASA previously directed the project to incorporate Starshade capability into its design. But, in early 2020, NASA deferred further work on Starshade compatibility, pending completion of the decadal survey in 2021. A Starshade is a device that is launched with or separately from an observatory and positioned between it and the star being observed to block out the starlight while allowing the light emitted by the planet through. In November 2021, NASA decided that, based on the 2020 Astrophysics Decadal Survey, Roman does not need to be Starshade compatible.

Project Office Comments

When commenting on a draft of this assessment, Roman officials said that the mission, including CGI, is making strong progress. Officials said programmatic pressures at CDR were addressed in February 2022. They also said the 2020 Astrophysics Decadal Survey affirmed the project's alignment with national science priorities. They also provided technical comments, which were incorporated as appropriate.

NASA ISRO – Synthetic Aperture Radar

The NASA Indian Space Research Organisation (ISRO) – Synthetic Aperture Radar (NISAR) is a joint project between NASA and ISRO that will study the solid Earth, ice masses, and ecosystems. It aims to address questions related to global environmental change, Earth's carbon cycle, and natural hazards such as earthquakes and volcanoes. The project will include 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 the 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: © California Institute of Technology/Jet Propulsion Laboratory. | GAO-22-105212

Timeline

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

IMPLEMENTATION
- 10/18 Critical design review
- 10/20 System integration review
- **01/22 GAO review**
- ***Under review*** Target launch readiness date
- ***Under review*** Committed launch readiness date

Project Information

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**

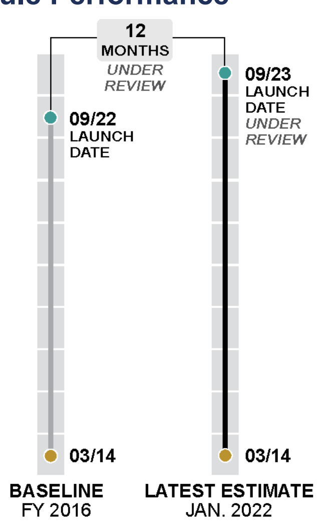
Requirement Derived from: **2007 Earth Science Decadal Survey**

Budget Portfolio: **Science, Earth Science**

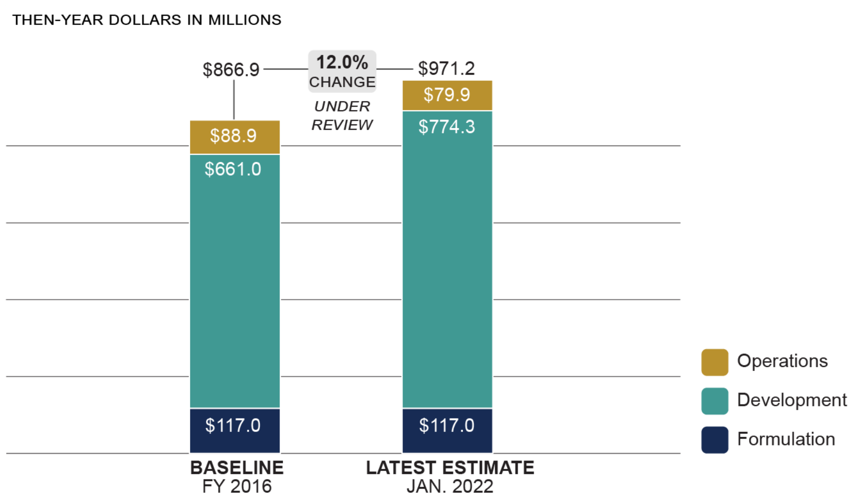
Project Summary

In April 2021, the NISAR project replanned its cost and schedule baseline, increasing its cost target by 12 percent and delaying its schedule by a year. The replan set a new life-cycle cost of $971.2 million and committed launch readiness date of September 2023. This incorporated $113.3 million in additional development costs. The project attributed its recent cost and schedule growth to COVID-19 and issues with hardware development and delivery delays of NASA- and ISRO-provided hardware. Following the April 2021 replan, further issues emerged, primarily with the ISRO-provided radar, which will further delay the project and increase costs. For example, during the integration and test of both radars, the project discovered electromagnetic interference (EMI) susceptibility and faulty hardware on the ISRO radar, and a calibration issue on the NASA radar.

Schedule Performance



Cost Performance



Cost and Schedule Status

In April 2021, NASA approved a replan for the NISAR project that incorporated cost increases and schedule delays. The increased life-cycle cost is $971.2 million, which is 12 percent higher than the original cost target and includes an additional $113.3 million in development costs. The new launch readiness date of September 2023 is a year later than the original committed launch readiness date. The project attributed its recent cost and schedule growth to COVID-19, issues with hardware development, and delivery delays on both the NASA- and ISRO-provided hardware. For example, project officials said the ISRO radar was delivered to NASA in March 2021—16 months later than originally planned—due to late hardware deliveries. In addition, the NASA radar experienced technical issues with its cabling that required additional time to resolve.

Furthermore, since the replan occurred, the project is continuing to experience hardware issues and delays—predominantly with the ISRO radar—that are exacerbated by COVID-19. The project anticipates additional cost and schedule growth beyond the replanned estimates established in April 2021. Project officials said they are waiting to finalize their cost and schedule estimates until they finalize plans to deliver the integrated radar payload, which includes both the ISRO- and NASA-provided radars, to ISRO for integration onto the spacecraft. This delivery was previously planned for March 2022, but the project now estimates it will be 10 months later in January 2023. This delay shifts the anticipated launch date to late fall 2023, which is in the middle of eclipse season. The project plans to avoid launching during eclipse season. According to officials, eclipse season is when the Earth experiences shadow events, which could cause NISAR's system to experience extreme thermal cycles that would affect the project's radar antenna deployment operations. As a result, the project anticipates its launch readiness date slipping to February 2024. According to project documentation, the cost growth associated with these delays may push total development cost growth above 30 percent, which would require the project to rebaseline.

Integration and Test

The NISAR project completed the first portion of its integration and test activities, including completing construction of the NASA- and ISRO-provided radars. NASA is currently integrating and testing the two radars. Following the completion of this testing, the radars will be shipped to India for integration with the spacecraft and launch.

Issues with the ISRO radar will delay the project's committed launch date. During the initial testing of the integrated radars, the NASA- and ISRO-provided radars were operated simultaneously, which officials said was the plan for eventual operations. However, the ISRO radar experienced EMI, and the project subsequently discovered that the ISRO radar did not meet the agreed-upon design specifications for EMI susceptibility. As a result, the ISRO radar experienced data loss when the NASA radar was operating. ISRO replaced a controller computer to resolve the issue, and the NISAR project added shielding to connectors and harnesses in the radar to mitigate EMI. In addition, one of the ISRO radar's transmit-receiver modules showed performance degradation during testing and required replacement. ISRO continues to investigate the root cause of the degradation to ensure that no other modules need replacement. The project replaced the transmit-receiver module while it was replacing hardware to resolve the EMI issues. Initial testing indicates that both of these issues are resolved, but, according to officials, the project will not retire the risks until testing is complete in spring 2022.

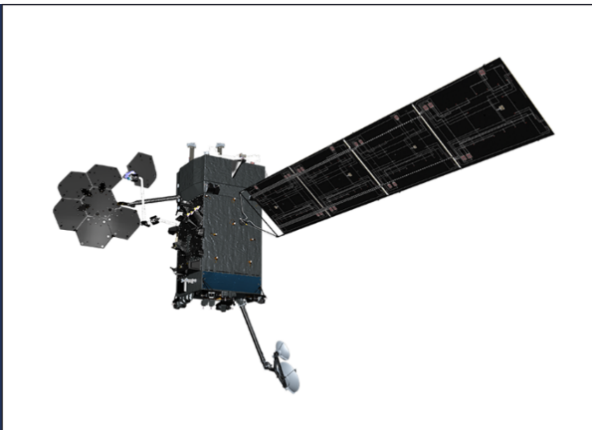
Also during testing, an issue was discovered with the hardware used to process the radar signals on the NASA-provided radar, and addressing the issue consumed schedule margin. The project replaced the hardware, which testing shows resolved the issue, but continues to investigate its root cause. The project is also building spare hardware as an additional contingency.

Launch Vehicle

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 two of the criteria. During an August 2021 launch, the upper stage did not ignite and the launch vehicle failed to accomplish its mission. Despite the failure, NASA officials said this mission satisfied a criteria regarding successful fairing deployment. According to NASA officials, ISRO has a number of other Geosynchronous Satellite Launch Vehicle Mark II launches planned that could satisfy the remaining criteria before NISAR launches.

Project Office Comments

When commenting on a draft of this assessment, NISAR officials said the NASA-ISRO partnership is a key NASA strategic objective, and that the experience gained on NISAR will strengthen future NASA-ISRO collaborations. They said ISRO delivered all necessary hardware for the Jet Propulsion Laboratory to complete radar payload integration, and overcame pandemic travel difficulties to support integration and test. In addition, officials said that joint mission operations demonstrated ISRO and the Jet Propulsion Laboratory's maturity to support the mission. Officials also provided technical comments, which were incorporated as appropriate.



Source: Maxar Technologies. | GAO-22-105212

On-Orbit Servicing, Assembly, and Manufacturing 1

The On-Orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1) project plans to demonstrate a capability to autonomously refuel and extend the life of on-orbit satellites. NASA is transferring OSAM-1 technologies to commercial entities as well. 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 DExterous Robot (SPIDER) payload to demonstrate on-orbit assembly and installation of an antenna and manufacturing of a beam.

Timeline

Project Information

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

International Partners: **None**

Launch Location: **To be determined**

Launch Vehicle: **To be determined**

Mission Duration: **12 months**

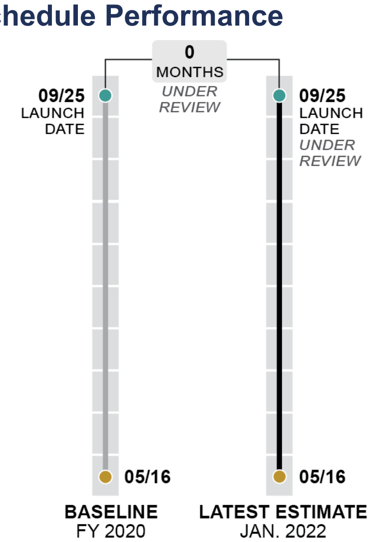
Requirement Derived from: **Consolidated Appropriations Act, 2016**

Budget Portfolio: **Space Technology, Technology Demonstration**

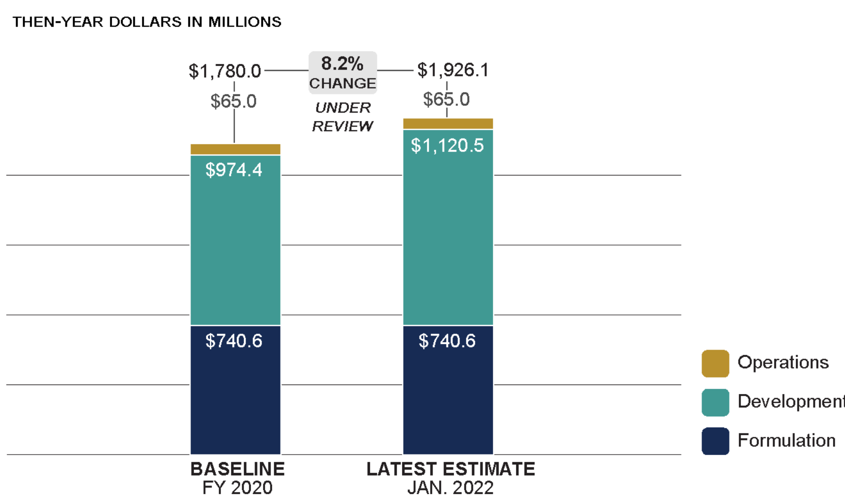
Project Summary

The OSAM-1 project estimates it will exceed its cost baseline and is reevaluating both its schedule and associated costs due to COVID-19, technical issues, and vendor delays. According to NASA documentation and officials, the project's development costs will increase to at least $1.12 billion, increasing the total estimated life-cycle cost by 8.2 percent to $1.93 billion. As of January 2022, the project's replan was still under review. Technical issues involve problems with OSAM-1's servicing and SPIDER payloads. The payloads contain motors that are supplied by a vendor and are delayed. In addition, analysis determined that cameras on the servicing payload could not meet relative performance requirements without modification. The SPIDER payload's flight assembly joint, which interfaces between the SPIDER antenna and boom, also experienced challenges and is being redesigned. Finally, the project continues to track a risk that, before OSAM-1 can service the Landsat 7 satellite, the satellite will have a hardware failure and OSAM-1 will be unable to complete its technology demonstration.

Schedule Performance



Cost Performance



Cost and Schedule Status

The OSAM-1 project estimates it will exceed its cost baseline and is reevaluating both its schedule and associated costs due to COVID-19, technical issues, and vendor delays. According to NASA documentation and officials, the project's development costs will increase by at least 15 percent to $1.12 billion, increasing the total estimated life-cycle cost by 8.2 percent to $1.93 billion. As of January 2022, the project's replan was still under review.

According to officials, the replan is largely driven by COVID-19 effects. When the pandemic began, OSAM-1 was in the middle of hardware activities, and was affected by on-site work stoppages and restrictions. In addition, COVID-19 contributed to delays of the project's critical design review, which was previously planned for September 2020 and is now planned for February 2022. However, officials said the project also experienced cost growth and schedule delays due to technical issues with the servicing payload, test bed development and operations, and spacecraft development.

Technology and Design

Project officials reported that, from project confirmation in June 2020 to January 2022, the servicing payload and SPIDER payload motor deliveries slipped approximately 2 years and 1.5 half years, respectively. According to officials, these late deliveries are affecting the project's target launch readiness date because the servicing payload is a key schedule driver. Goddard Space Flight Center is building the servicing payload that will attempt to grasp, refuel, and extend the life of Landsat 7. A contractor is providing the SPIDER payload, which is meant to assemble seven elements that form an antennae and manufacture a beam. Officials confirmed that both components require motors provided by the same vendor to operate robotic arms. This vendor experienced issues related to COVID-19, such as facility closures and supply chain issues.

The vendor supplying the motors to OSAM-1 also experienced technical and workforce-related issues. For example, in July 2021 the project reported the vendor stopped and restarted work due to insufficient quality inspections, and, according to NASA documentation, was issued a corrective action request by NASA's contractor. Issues with this vendor are ongoing, and, in January 2022, the project reported additional delays due to its use of nonconforming parts. In addition, the vendor experienced staffing shortages. Due to these challenges, NASA officials said they have taken several actions. For example, they placed NASA and contractor staff on-site with the vendor to gain greater insight into vendor activities and they increased engagement between vendor management and NASA. While motor delays are a top issue for the project, officials anticipate the ongoing replan will mitigate the issue by adding sufficient margin to the schedule.

The project also experienced technical issues with the cameras that will help OSAM-1 operate when in proximity to its client satellite. Officials said that, during a proximity operations simulation, the cameras on the servicing payload did not meet performance requirements. As a result, the project is redesigning two camera lenses, repositioning the cameras, and adding two cameras that were previously planned to be used as hardware spares. As of January 2022, officials said they are still assessing cost effects, but that the issue has minimal schedule effects and will not affect the project's technical risks.

The project also recently experienced a technical issue with the SPIDER payload's flight assembly joint. According to officials, this joint interfaces between the SPIDER antenna and boom, and, after vibration testing, the joint did not separate with the required force. The contractor is redesigning part of the joint and is considering use of a robot arm to assist with separation. As of January 2022, the project was in the process of assessing the issue's cost and schedule effects.

In addition, the project continues to track a risk that before OSAM-1 can service the Landsat 7 satellite, the satellite will fail and OSAM-1 will be unable to complete its technology demonstration. NASA conducted a study that identified other satellites as servicing alternatives, but officials said none of these alternatives have been approved, and the project is still working toward servicing Landsat 7. According to officials, Landsat 7's viability is dependent on its propulsion system being able to continue functioning at a reasonable level. Officials said Landsat 7 will use its propulsion system to enter the orbit in which it will be serviced in spring 2022, and that this risk will be reduced significantly at that time.

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

Plankton, Aerosol, Cloud, ocean Ecosystem (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-22-105212

Timeline

FORMULATION
- 06/16 Formulation start
- 01/17 System requirements/ mission definition review
- 06/19 Preliminary design review
- 08/19 Project confirmation

IMPLEMENTATION
- 02/20 Critical design review
- **01/22 GAO review**
- 08/22 System integration review
- 01/24 Target launch readiness date
- 05/24 Committed launch readiness date

Project Information

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**

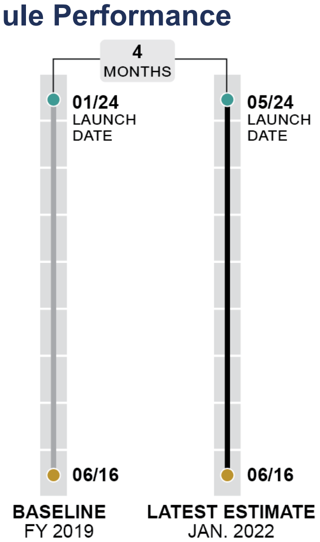
Requirement Derived from: **2007 Earth Science Decadal Survey**

Budget Portfolio: **Science, Earth Science**

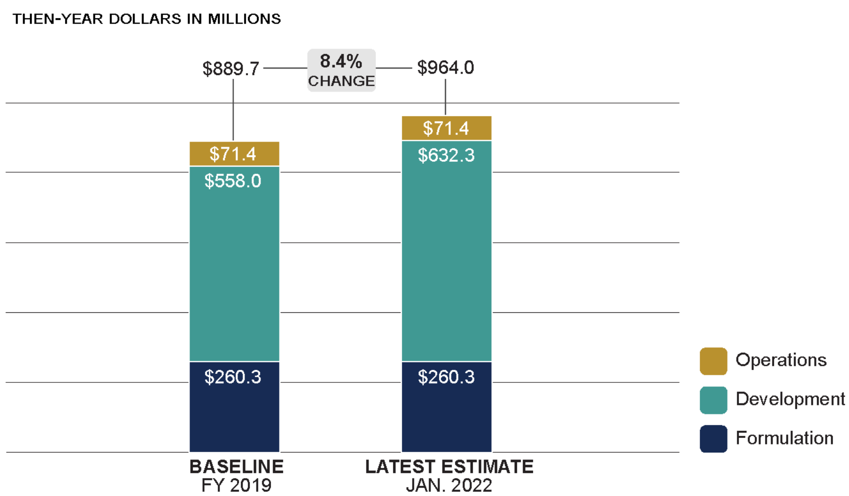
Project Summary

The PACE project experienced cost and schedule growth, increasing its cost target by 8.4 percent and delaying its committed launch date by 4 months from January 2024 to May 2024. The new life-cycle cost for the project is $964 million and incorporates an additional $74.3 million in development costs. The cost and schedule growth are attributed to COVID-19 and technical issues. The project is mitigating a risk related to moisture contamination of the spacecraft's reaction wheel bearings, which officials said occurred during long-term storage. Reaction wheels point the spacecraft in the desired direction, and the bearings help rotate them. In addition, both polarimeters on the spacecraft experienced delays, but officials said neither delay negatively affected the project's mission-level schedule. The polarimeters measure how sunlight changes as it passes through clouds, aerosols, and the ocean. The Ocean Color Instrument (OCI) and spacecraft are in system-level integration, and the project is in the process of assembling the OCI flight unit. In addition, the project experienced an anomaly with its communications box during vibration testing. As of January 2022, the project completed the necessary rework for this anomaly.

Schedule Performance



Cost Performance



Cost and Schedule Status

The PACE project is executing to a new life-cycle cost estimate of $964 million and a committed launch readiness date of May 2024. The revised cost estimate is 8.4 percent higher than the original cost target and includes an additional $74.3 million in development costs. The new launch readiness date of May 2024 is 4 months later than the original committed launch readiness date. NASA attributed the recent cost and schedule growth to COVID-19 and technical issues, including technical issues that occurred prior to the start of the pandemic. For example, prior to the start of the pandemic, the project experienced issues with parts that were contaminated during long-term storage, which led the project to procure replacements. Other issues occurred after the start of the pandemic, such as when a part installed within the communications box was unstable during vibration testing.

NASA attributed the majority of the project's cost and schedule growth to COVID-19. Prior to the pandemic, the project was working to a target launch readiness date of March 2023, which has been delayed to January 2024. Of that 10-month delay, 9 months were due to COVID-19. The pandemic began when the project was at the peak of flight build, or in the middle of developing hardware at Goddard Space Flight Center that was on the project's critical path. Because the center closed for 4 months, the project could not perform on-site work. NASA also reported that inefficiencies associated with the gradual return to work contributed to cost and schedule growth.

Technology and Design

The project is tracking a risk to the reaction wheel bearings on the spacecraft. Reaction wheels are used to point the spacecraft in a desired direction, and the bearings sit inside an axle that allows the reaction wheels to rotate freely. Officials said they originally planned to use bearings from former NASA projects that were held in storage. However, upon inspecting them, the project found some of the bearings were corroded due to moisture contamination. When the project noticed the contamination, it started an investigation and initiated procurements for new bearings through three different vendors. The bearing procurements have been delayed due to difficulty in obtaining materials but are now expected in early 2022. The project is attempting to clean the existing bearings as a back-up option but has not yet approved the existing bearings for use.

The PACE project encountered delays with its two polarimeters, which augment the project's primary science objectives by measuring how sunlight changes as it passes through clouds, aerosols, and the ocean. These polarimeters are contributed by the Netherlands Space Office and the University of Maryland, Baltimore County. The polarimeter contributed by the Netherlands Space Office was delivered to the project in March 2021—5 months later than planned due to the pandemic. This polarimeter is in storage and officials said that the late delivery did not have a significant effect on schedule because of other project delays. The polarimeter from the University of Maryland, Baltimore County experienced delays due to technical issues. For example, a prism that was glued to a structure in the polarimeter was attached incorrectly and came loose, which officials said was due to a contaminated surface and too much stress on a strap that transfers heat. Officials said the necessary rework was completed to address this issue, and the polarimeter is still on track to be delivered months before it is needed.

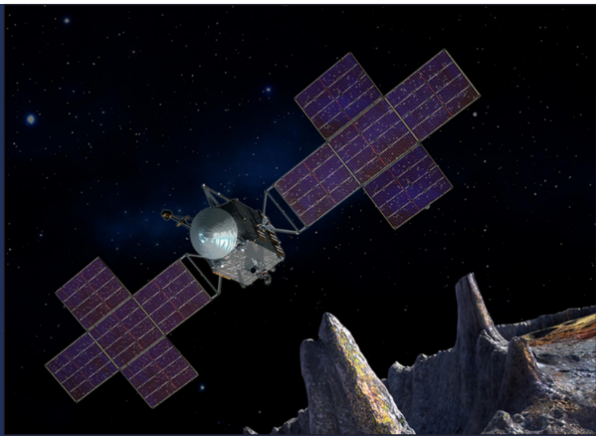
Integration and Test

The project's primary instrument—the OCI—and its spacecraft are both in system-level integration. The OCI will measure properties of light that will help to better understand the complex systems that drive ocean ecology. Project officials said the OCI became a driver of COVID-19-related cost and schedule effects because work on the instrument stopped when Goddard Space Flight Center shut down. The project mitigated OCI schedule delays by finding alternative sources for critical parts and using remote monitoring equipment in areas where social distancing limited progress. NASA recently integrated the OCI's flight electronic control mechanism and is in the process of assembling the flight unit. In addition, the instruments that collect photons from Earth and translate them to the optical system for processing have been installed.

In addition, the project recently experienced an anomaly with its communications box during vibration testing. According to officials, a part installed within this component was unstable. To resolve this issue, the failure review board determined that a shim, or spacer, would help stabilize the parts when they go through vibration testing. As of January 2022, the project had completed rework from this issue and vibration testing and was preparing for thermal vacuum testing. Project officials said they used reserves to address the cost of the rework, and schedule delays were mitigated by using the component's engineering test unit instead of the flight unit as a surrogate during spacecraft-level integration. Using the surrogate unit allowed the project to maintain its testing schedule without waiting for the project to resolve the issue with the final hardware.

Project Office Comments

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

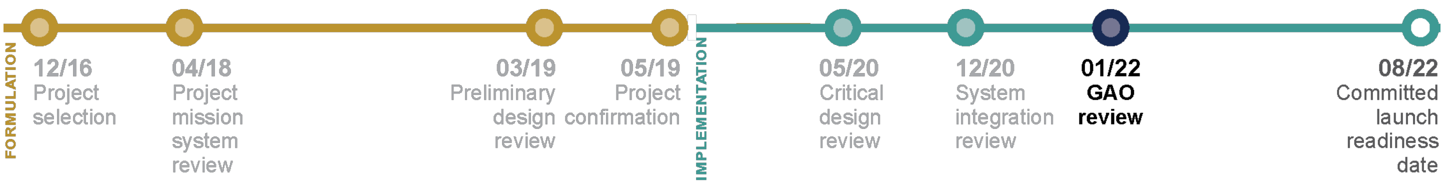


Psyche

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-22-105212

Timeline



Project Information

NASA Lead Center: **Jet Propulsion Laboratory**

International Partners: **None**

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

Launch Vehicle: **Falcon Heavy**

Mission Duration: **21-month science operation**

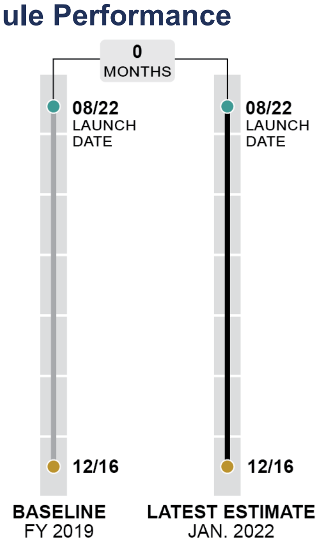
Requirement Derived from: **Discovery Program Announcement of Opportunity 2014**

Budget Portfolio: **Science, Planetary Science**

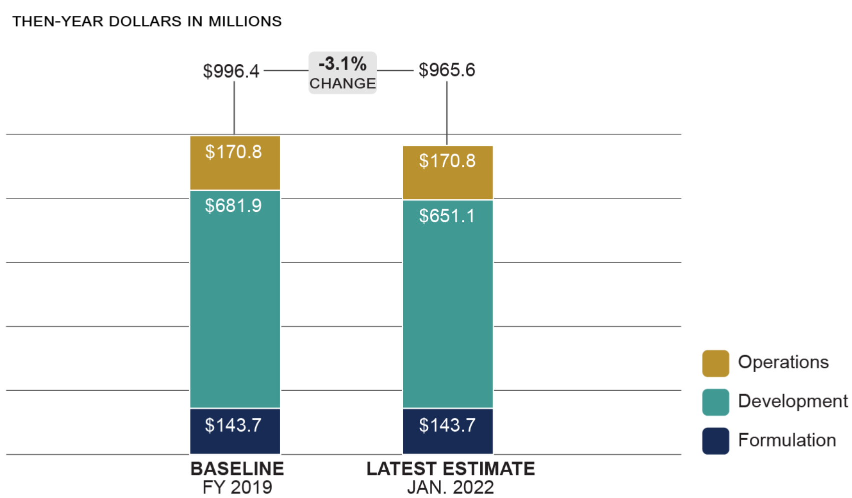
Project Summary

Psyche continues to operate within its cost and schedule baselines but experienced cost growth over the last year. In August 2021, the project's life-cycle cost estimate increased by $8 million due to COVID-19 effects. Psyche also experienced technical challenges with its specialized imagers or cameras. Continuing delays could affect the project's ability to meet its committed launch readiness date in 2022. If so, the next launch window would likely be in 2024. The project started preparing a different project's cameras as backups to mitigate potential future delays. In addition, the project experienced issues with its reaction wheels, which help orient and stabilize the spacecraft. As of spring 2022, officials told us the issues with the imagers and reaction wheels have been resolved, but they continue to address technical challenges.

Schedule Performance



Cost Performance



Cost and Schedule Status

Psyche continues to operate within its cost baseline but experienced cost growth over the last year. In November 2020, NASA reduced the project's life-cycle cost by about $39 million to incorporate cost savings from selecting a launch vehicle. Shortly thereafter, the project entered the system assembly, integration and test, and launch phase. In August 2021, however, the project's life-cycle cost estimate increased by $8 million due to COVID-19 effects. The project has experienced technical issues and continued COVID-19 effects, which consumed both project- and headquarters-held cost reserves. In February 2022, the project received $14.6 million in headquarters-held reserves to address pandemic effects, and the project continues to track COVID-19 as a risk.

Psyche has project-held cost reserves of about 3 percent as of February 2022. According to Jet Propulsion Laboratory documentation, this is lower than the amount typically held by projects at this stage of development. Project officials said the risk from carrying less reserves is partially mitigated by the project's use of fixed-price contracts. However, the project has no additional headquarters-held reserves for development. As of February 2022, the project anticipated that additional funding would be necessary to meet its planned launch readiness date.

Psyche is also continuing to work toward its committed launch readiness date of August 1, 2022, but recently extended its possible launch period through October 9, 2022. The project is experiencing delays due to technical issues and COVID-19 effects that could affect its ability to meet its extended launch period. Officials said that, if Psyche is unable to launch within this period in 2022, the next best option would be in 2024.

Technology and Design

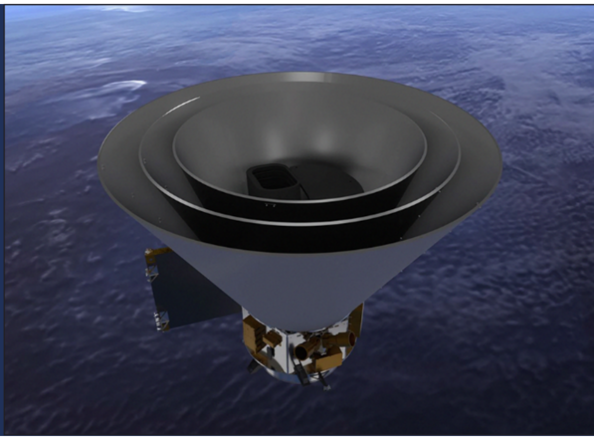
Psyche uses two specialized cameras, or imagers, for science imaging and spacecraft navigation. The imagers include parts such as a telescope and camera electronics. The imagers continue to face technical challenges, and one is further in development than the other. The fundamental problem is the sensitivity of the primary mirror within the telescope to distortions in the mirror's surface caused by external stresses over temperature. For example, the structure and bond materials that hold the mirror in place could distort the surface of the mirror, resulting in poor performance. In addition, one imager did not behave the way models predicted. Because of these issues, the telescopes had to be disassembled and reassembled several times. The project is working to mitigate these issues by replacing hardware and using different materials and bonding techniques.

As of February 2022, delivery of both imagers was delayed and jeopardizing the project's committed launch readiness date as they are on the project's critical path. The project started preparing cameras that were originally developed for NASA's Mars 2020 mission as a backup if there are further delivery delays or issues with one or both imagers. The Mars 2020 cameras were built by the same vendor as Psyche's flight imagers and, according to NASA, would be relatively straightforward to accommodate while still meeting the project's success criteria. Project officials said the imager issues have since been resolved, and they have been installed on the spacecraft.

Psyche also experienced issues with the project's reaction wheels, which help orient a spacecraft without the use of thrusters and keep the spacecraft stable. Psyche has four reaction wheels, all of which were found to have issues. Officials said one issue was that some ball bearings inside the wheels appeared to have raised metal instead of being smooth, which resulted in indentations in the wheel during testing. The project removed all the wheels from the spacecraft and shipped them back to the vendor. After the vendor reworked and tested the wheels, two of the four were returned to the project in December 2021. The other two wheels exhibited unexpected behavior and, as a result, went through additional testing at the vendor prior to being returned to the project in February 2022. Project officials said they rearranged the project's testing schedule to accommodate the delay, and the reaction wheels have been installed on the spacecraft.

Project Office Comments

When commenting on a draft of this assessment, Psyche project officials said that the issues with the flight imagers and reaction wheels have been recently resolved and no longer pose a schedule risk to the 2022 launch date. Officials said the project continues to have technical challenges with its Flight Software development and Guidance Navigation and Control verification and validation, both of which threaten the project's launch date. Project officials also provided technical comments, which were incorporated as appropriate.



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

The Spectro-Photometer for the History of the Universe, Epoch of Re-ionization and Ices Explorer (SPHEREx) mission will use a telescope to probe the origin and destiny of the universe, explore whether planets around 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-22-105212

Timeline

Project Information

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**

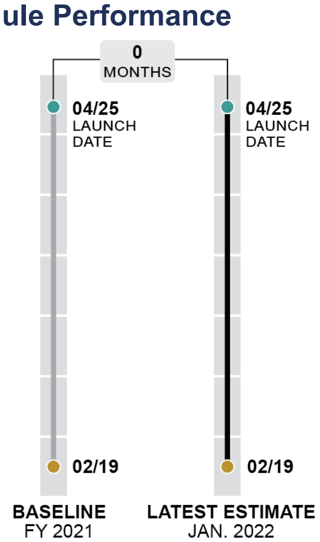
Requirement Derived from: 2010 **Astrophysics Decadal Survey**

Budget Portfolio: **Science, Astrophysics**

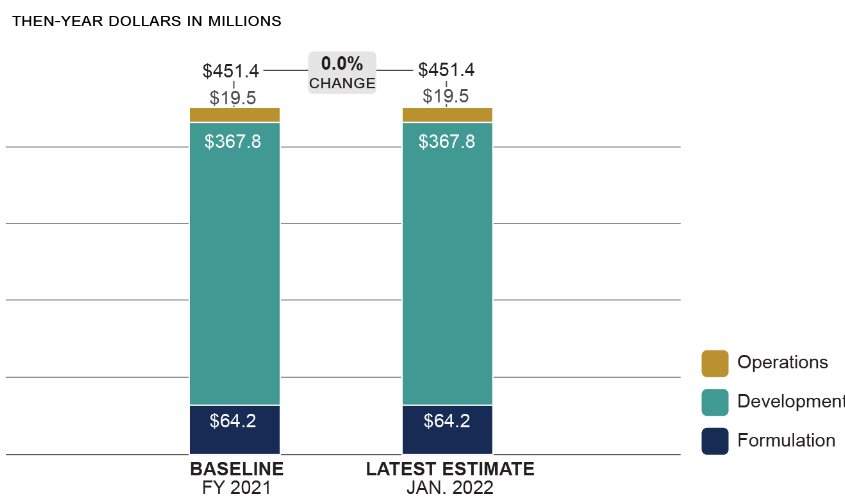
Project Summary

The SPHEREx project continues to operate within its cost and schedule baselines and completed its critical design review (CDR) in January 2022. As part of this review, the project requested headquarters-held reserves to cover COVID-19 effects. The project is also working with NASA to shift its target date out by several months, but it would still be earlier than its committed launch readiness date. We did not assess design stability at CDR because the project uses models rather than design drawings to assess design stability. As of January 2022, the project's top technical risk is that satellites may obscure the data seen by the telescope. In addition, the project was not able to procure a photon shield, which protects the telescope from stray light, after failing to receive offers from vendors. The project is now designing the photon shield in-house with a vendor providing specialized manufacturing services. Finally, in November 2021, the Polarimeter to Unify the Corona and Heliosphere (PUNCH) project was added as a secondary payload to the SPHEREx mission.

Schedule Performance



Cost Performance



Cost and Schedule Status

The SPHEREx project continues to operate within its cost and schedule baselines despite operating at reduced efficiency due to COVID-19. When setting its baselines in January 2021, the project included $8.2 million for COVID-19 effects that were incurred during formulation, and $9.5 million in cost reserves to cover anticipated continued COVID-19 inefficiencies through June 2021. However, because of continued COVID-19 cost and schedule effects, the project requested headquarters-held cost reserves following its CDR in January 2022. Project officials said they would not have requested headquarters-held reserves at this point if it were not for COVID-19.

At CDR, the SPHEREx project proposed a launch date of February 2025, 5 months later than its targeted launch readiness date but earlier than its committed launch readiness date. As of February 2022, NASA had not approved this delay. The project estimates that the delayed launch date is primarily due to COVID-19 effects such as vendor delays, limited access to labs, and personnel outages. For example, the lab limitations delayed the build and test of engineering models. Project officials said they built engineering models in their homes when the project moved to remote work, which added inefficiency to the schedule because of the additional time needed to transport model components between different locations. However, technical issues contributed as well, such as the redesign of the mounting for the telescope's mirror.

Technology and Design

The project held CDR in January 2022. This was 4 months later than planned due to the redesign of the telescope mirror's support structure after launch loads analysis showed the mirrors would break off their mounts. The redesign contributed to the delay as a result of the sequencing of subsystem reviews and the need to have all items complete their design and analyses prior to the mission CDR. In addition, project officials said COVID-19-related vendor delays exacerbated the schedule delays from the mirror redesign work. According to officials, the redesign work was completed in September 2021 and subsequently reviewed, including at peer reviews and subsystem CDRs that preceded the mission CDR.

We did not assess whether the project met GAO's best practice for design stability at its CDR because this metric relies on design drawings. This project does not use design drawings as a metric of design stability. For instance, the project does not track whether a percentage of total drawings is released at CDR. Officials said they track the maturity of their models instead as the models are built to requirements, and the project tracks progress against those requirements.

As of January 2022, the project's top technical risk was that the number and brightness of satellites in orbit around Earth may compromise the scientific data collected by the project. According to officials, the telescope views objects in infrared and the satellites are hot. As a result, satellites appear as streaks, which obscure the data. The project is planning to mitigate this risk by processing the satellite streaks out of the data, but officials said this could result in the project collecting less scientific information than planned. Officials said using this method to address this issue is well established but may require more computing power, which would cost more money.

COVID-19 Effects

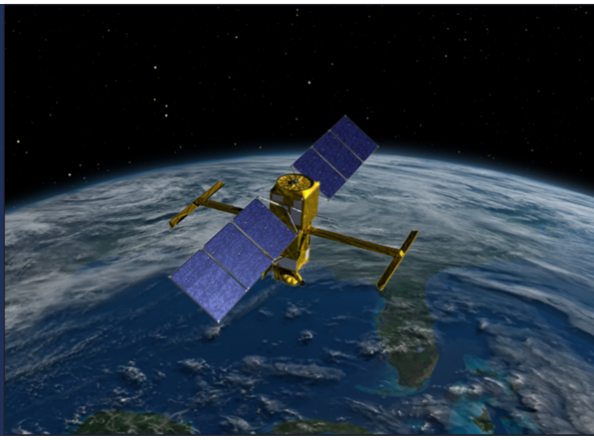
The project experienced issues with the procurement of the project's photon shield, which protects the telescope from stray light from the Earth and moon. According to project officials, the manufacturing process for the photon shield requires specialized equipment, which few machine shops have. The project identified two vendors with the capability to build the shield but received no offers. Project officials said this was partially due to the vendor's uncertainty around COVID-19. For example, according to NASA officials, the vendor was concerned that pandemic-related supply chain delays in procuring materials would delay manufacturing. Project officials said they addressed this concern by procuring key materials so the vendor did not carry the risk of late material deliveries. According to NASA, the vendor was also concerned about having sufficient staff, in part because of a boom in demand. As a result, the project shifted the engineering work in-house. After making these changes, the project was able to secure a vendor for the manufacturing of the photon shield. The project is also pursuing alternate vendors to mitigate COVID-19-related risks. Officials said they are still negotiating with the second vendor they identified while communicating with other possible vendors to maintain backup manufacturing options.

Launch

In September 2021, the SPHEREx project conducted an analysis of the PUNCH project and determined it is compatible to launch together with SPHEREx. According to project officials, this potential rideshare will not affect SPHEREx's design or maturity. NASA signed an agreement for PUNCH to be a secondary payload with SPHEREx in December 2021. According to officials, NASA's Launch Services Program will work with the launch vehicle provider on a contract modification to add the secondary payload.

Project Office Comments

When commenting on a draft of this assessment, SPHEREx project officials said NASA approved delaying the project's target launch readiness date by 5 months to February 2025. Project officials also provided technical comments, which were incorporated as appropriate.

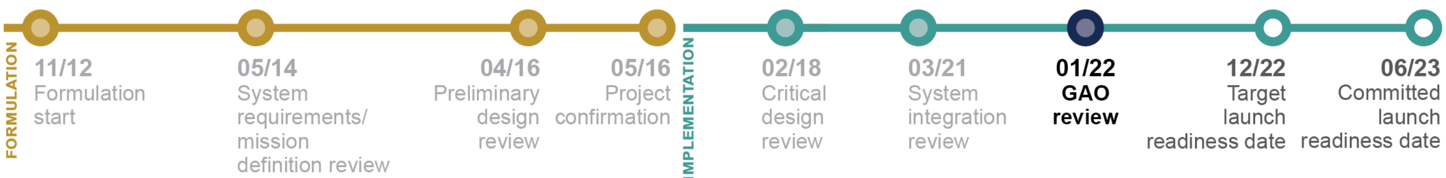


Surface Water and Ocean Topography

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

Source: California Institute of Technology/Jet Propulsion Laboratory (artist depiction). | GAO-22-105212

Timeline



Project Information

NASA Lead Center: **Jet Propulsion Laboratory**

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

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

Launch Vehicle: **Falcon 9**

Mission Duration: **3 years**

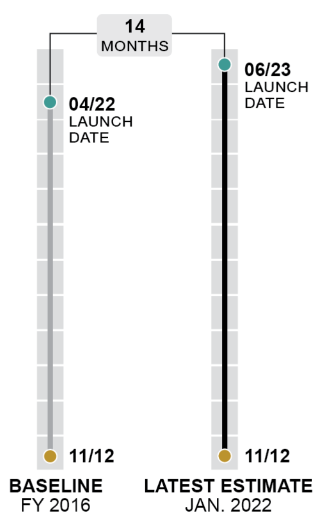
Requirement Derived from: **2007 Earth Science Decadal Survey**

Budget Portfolio: **Science, Earth Science**

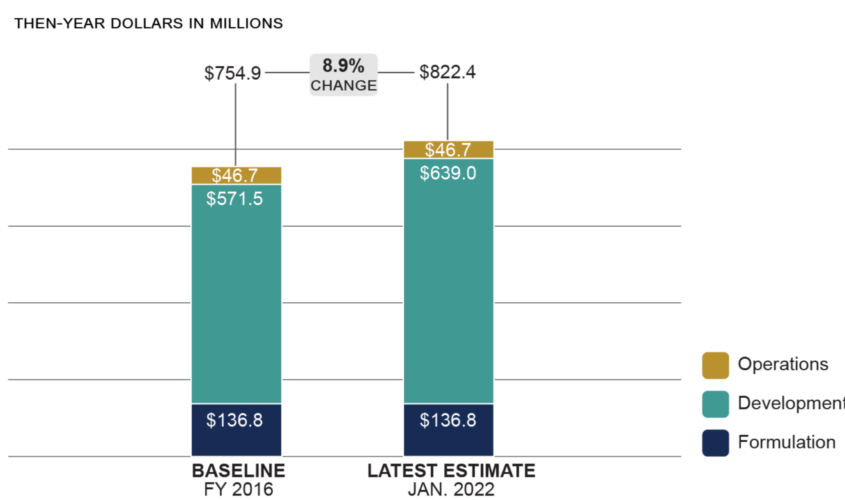
Project Summary

In June 2021, the SWOT project replanned its cost and schedule baseline, increasing its cost target by 8.9 percent and delaying its schedule by 14 months. Project officials said the replan was due to COVID-19 and technical issues. The replan set a new life-cycle cost of $822.4 million and committed launch date of June 2023. This incorporated $67.5 million in additional development costs and delayed the project's baseline launch readiness date by 14 months. However, the project is working toward an earlier internal launch readiness date of November 2022. The project entered the system assembly, integration and test, and launch phase in April 2021. Soon after, the project shipped its payload module to France for observatory integration and test activities. Integration and test activities are being affected by COVID-19 and project officials expressed that the pandemic could continue to affect testing moving forward. Project officials said they plan to bring the spacecraft to Vandenberg Space Force Base in fall 2022 to begin the project's launch campaign.

Schedule Performance



Cost Performance



Cost and Schedule Status

In June 2021, NASA approved a replan for the SWOT project that incorporated cost increases and schedule delays. The increased life-cycle cost is $822.4 million, which is 8.9 percent higher than the original cost target and includes an additional $67.5 million in development costs. The new launch readiness date of June 2023 is 14 months later than the original committed launch readiness date of April 2022. The project attributed the majority of its recent cost and schedule growth to COVID-19. Effects of the pandemic included shut-down periods, travel limitations restricting the number of on-site CNES (French space agency) staff at NASA's Jet Propulsion Laboratory (JPL) to complete payload integration and test activities, and facility constraints due to safety protocols. In addition, the project increased its workforce to reduce continued schedule effects.

The SWOT project experienced technical issues prior to and during the pandemic that contributed to the project's replan. Prior to the pandemic, the project received headquarters-held reserves that officials intended to use for technical issues concerning the Ka-Band Radar Interferometer, but these reserves were consumed to mitigate COVID-19 costs. The project also experienced technical issues with the execution of ground support equipment and the protective blanket for the spacecraft that added cost growth. Project officials stated that they underestimated how long the setup of the ground support equipment operations and test would take because it had never been done before. They also said the protective blanket made for the spacecraft was reworked because it interfered with the project's ability to achieve proper alignment with the ground support equipment while conducting deployment activities.

The SWOT project's schedule margin and cost reserves were replenished in the recent replan. The project is working to an internal launch readiness date of November 2022, which results in 1 month of schedule margin to the project's target launch readiness date and 7 months of margin to its committed launch readiness date. In addition, NASA headquarters is specifically holding $15 million in cost reserves to cover additional COVID-19 uncertainties. As of January 2022, the project reported COVID-19 effects on observatory integration and test schedules as a top concern.

Integration and Test

In March 2021, the SWOT project completed its system integration review. At this review, project officials said the Standing Review Board requested documentation that identified whether JPL or CNES would make the decision to execute an unplanned controlled reentry, if necessary. When the SWOT spacecraft completes its mission, it is planned that it will reenter Earth's atmosphere in a controlled reentry to ensure the spacecraft does not damage life or property upon its descent. However, an unplanned reentry to Earth could be necessary if a subsystem needed for reentry is lost or if the fuel supply becomes too low. If an uncontrolled reentry becomes necessary, the decision to execute it will be a joint one between JPL and CNES. Project officials stated they had always planned to create this type of documentation and will close this request at the project's operations readiness review, planned for July 2022.

The SWOT project entered the system assembly, integration and test, and launch phase in April 2021. In June 2021, the project shipped its payload module to France to complete observatory integration and test activities. Project officials said observatory integration and test activities will be completed by individuals who will travel back and forth between the U.S. and France, as well as a small team of JPL staff who will reside in France as long-term residents. According to officials, the project's replan assumes these activities will be completed without using remote operations. However, the project is currently testing remote operations as a contingency plan and is preparing a hybrid on-site/remote support plan for upcoming test activities. The project is closely monitoring any further travel or other safety constraints from COVID-19.

Project officials stated that once observatory integration and test is complete, CNES will ship the spacecraft, flight system, and supporting equipment to Vandenberg Space Force Base where the project will conduct its launch campaign in fall 2022. Project officials said the launch campaign involves unpacking the spacecraft and completing a stand-alone checkout of the spacecraft. Once the checkout is complete, the spacecraft will be fueled and joined with the launch vehicle.

Project Office Comments

When commenting on a draft of this assessment, SWOT project officials said that the project experienced significant COVID-19 effects, particularly on critical path activities for the integration and test of both the science instrument payload module and observatory. They said the project prepared and implemented a replan in 2021, incorporating lessons learned and mitigations. In addition, officials said that, since the replan, the project has successfully completed the system integration review and NASA approved the project to enter the system assembly, integration and test, and launch phase. They said JPL successfully completed all testing of the payload module and shipped it to France, and observatory integration began in August 2021 with the successful mating of the payload module and spacecraft bus. According to officials, integration and testing of the observatory are ongoing in preparation for a November 2022 launch.

Appendix II: Objectives, Scope, and Methodology

This is our 14th 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 up 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, 2021. The objectives of our review were to assess (1) the cost and schedule performance of NASA's portfolio of major projects and (2) the development and maturity of technologies and progress in achieving design stability. We also described the status and assessed the risks and challenges faced by 33 of the 37 major NASA projects. We did not complete an individual assessment for four projects—Landsat 9, Laser Communications Relay Demonstration (LCRD), the Space Network Ground Segment Sustainment (SGSS), and Double Asteroid Redirection Test (DART)—because they launched or completed development during our review. We did include assessments for two other projects that launched during our review—the James Webb Space Telescope (JWST) and Lucy—to follow-up on significant events that occurred after launch.

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

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 21 projects in the implementation phase during our review to previously established development cost and schedule baselines. The Commercial Crew Program has a tailored project life cycle and project management requirements, so it was excluded from these analyses. All cost and schedule data provided by NASA based on our questionnaires were as-of January 2022. However, three projects provided updated data after those questionnaires were received. SLS and EGS provided an updated launch readiness date and Europa Clipper provided a preliminary decision memo in March 2022. We took additional steps to assess the quality and reliability of data. All cost and schedule original baseline data are from estimates documented at each project's confirmation review, with the exception of the Space Launch System (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 six other projects—JWST, SGSS, LCRD, EGS, Orion, and SEP—have rebaselined. We use the original baseline data when calculating cumulative overruns for purposes of our analyses. 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 2013 and 2022. The portfolio's cost and schedule performance data for each year are in each of our annual reports which 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 if 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 data collected from NASA early in the calendar year. All cost information in this report is presented in nominal then-year dollars for consistency with budget data. We did not assess the cost and schedule performance of projects in formulation because they have not yet established baselines.

To determine the effects of COVID-19 on the cost and schedule performance of NASA's portfolio of major projects in development, we reviewed project documentation—including monthly status reports that include schedules and risk assessments, and major project review documentation— and interviewed project officials. We identified projects that experienced increases to their cost or schedule estimates beyond their established baselines as a result of COVID-19.

To review the various factors—including project performance and COVID-19—NASA considers when it makes portfolio management decisions, we met with the NASA Associate Administrator and Program Management Improvement Officer as well as officials in NASA's mission directorates, Office of the Chief Financial Officer, and Office of the Chief Engineer. We reviewed acquisition decisions outlined in memoranda and briefings and discussed the factors that led to making these decisions with relevant officials from the mission directorates as well as from the individual project offices. We also reviewed NASA guidance and policies on NASA's governance structure and strategic management processes. In addition, we examined documents relating to the agency's lessons-learned and ongoing initiatives in portfolio management from NASA corrective action reports, GAO's high risk series and priority open recommendation reports, the NASA Program Management Improvement Officer's annual fiscal year 2020 briefing to the OMB, the Science Mission Directorate Large Mission Study Report, and a related NASA Inspector General report.

To assess technology maturity, we used questionnaire data that provided the technology readiness levels (TRL) of each of the project's critical technologies at various stages of project development, including at the preliminary design review (PDR). Originally developed by NASA, TRLs are measured on a scale of one to nine, beginning with paper studies of a technology's feasibility and culminating with a technology fully integrated into a completed product. See appendix VI for the definitions of TRLs.

For the 15 projects that identified critical technologies and held their PDR, we compared the TRLs of those projects' reported critical technologies against our technology maturity best practice to determine the extent to which these projects met the best practice. We took steps to assess the reliability of the project office-supplied data on the number of critical technologies and associated technology readiness levels. 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 development.[1] 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 the 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

[1]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).

critical technologies, we only compared this year's results with data after that change, which included data from 2021.

Our analysis of technology maturity included two technology demonstration projects: LCRD and On-orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1) projects. These projects are managed by Goddard Space Flight Center, whose policy does not require these technology demonstration projects to mature all of their technologies to TRL 6 by PDR.[2] NASA officials explained that this is because the purpose of some technology demonstration projects is to mature new technologies to TRL 6 or higher by the end of the demonstration, making it infeasible for these projects to achieve this level of maturity by PDR. However, we included LCRD and OSAM-1 in our analysis because they planned to mature their technologies prior to launching or reaching completion. Therefore, the same risks of subsequent technical problems that can result in cost growth and schedule delays identified in our best practices work apply to these projects. We did not include technologies in this analysis that were added after the project's PDR; in the case of OSAM-1, that includes all technologies related to the SPace Infrastructure DExterous Robot. We excluded two other technology demonstrations from this analysis—Solar Electric Propulsion and Low Boom Flight Demonstrator—because NASA does not plan to mature these technologies before operations or qualification testing. We excluded the Human Landing System (HLS) project because bid protests pending from April 2021 to November 2021 limited the project's ability to provide data regarding its critical technologies and associated technology readiness levels until February 2022. Upon receiving this data, our audit time frames did not allow sufficient time to follow-up with the project office to verify some of the information provided. We will follow-up with the project office on this information as part of our next annual report.

We used questionnaire data as-of January or February 2022 to assess the average number of critical technologies across projects that are past their confirmation review. We excluded technologies that were descoped after a project's confirmation review. We compared the average number of critical technologies per project with the average reported in our 2021 report to determine how the average number of critical technologies has

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

changed. We do not compare how the number of critical technologies per project has changed to years prior to 2021 because in 2021 we updated our critical technology definition to align with GAO's January 2020 Technology Readiness Assessment Guide.[3]

To assess design stability, we reviewed 14 projects that had held a critical design review (CDR) and reported data on design drawings. We reviewed questionnaire data on the number of design drawings completed or projected for release at the project's CDR and as of January 2022.[4] We took steps to assess the reliability of the project office-supplied data on the number of released and expected design drawings. For example, we followed up with project offices in cases where it appeared only a small percentage of expected drawings were completed by the time of the CDR or where the project office reported significant growth in the number of drawings released after the CDR. In accordance with GAO's best practice, projects were assessed as having achieved design stability if at least 90 percent of projected drawings were released by the CDR.[5] We compared this year's results against those in prior years to assess whether NASA was improving in this area. We also analyzed subsequent changes in the number of expected design drawings by comparing the number of expected drawings at the time of the project's CDR compared against its current expected drawing count. We did not assess the design stability for projects that had not yet reached the CDR at the time of this assessment or for projects that do not utilize design drawings.

To identify the metrics that projects use to measure design stability, we held meetings with NASA project officials and reviewed the NASA Common Leading Indicators Detailed Reference Guide, and reviewed selected projects documentation from critical design review. To describe how the NASA Common Leading Indicators Detailed Reference Guide was disseminated, we reviewed NASA documentation and held interviews with NASA officials at the Office of the Chief Engineer and project officials at the Science and Human Exploration Operations

[3]GAO-20-48G.

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

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

Mission Directorates. We also interviewed project officials and reviewed NASA policies to understand what guidance projects have when determining what design stability metrics to use.

Project Profile Information on Each Individual Project Assessment

This year, we developed individual project assessments for 33 projects with an estimated life-cycle cost for each greater than $250 million. We did not complete individual assessments for projects that launched or completed development in 2021, with the exception of the JWST and Lucy projects. Though JWST launched in 2021, we included a project assessment for it because House Report No. 112-284 included a specific provision for GAO to assess the JWST project annually and to report on its progress. We include a project assessment for the Lucy project to follow-up on some significant events that occurred after launch. For each assessment, we included a description of the project's objectives; information concerning the NASA center and international partners involved in the project, if applicable; the project's cost and schedule performance, when available; key project dates; and a brief narrative describing the current status of the project. We also provided a detailed discussion of project challenges for selected projects, as applicable.

To assess the cost and schedule changes of each project, we either obtained data directly from NASA's Office of the Chief Financial Officer through our questionnaire or used preliminary estimates provided in project documentation. For the Commercial Crew Program and the Space Network Ground Segment Sustainment project, we obtained current cost and schedule data directly from the program. We also had NASA confirm that preliminary estimates for the 15 projects in formulation remained accurate as of January 2022. NASA provided preliminary estimates of life-cycle cost ranges and associated schedules—which are generally established at KDP A or B—for 8 projects that had not yet entered implementation. Four other projects have preliminary schedule estimates, but associated preliminary cost estimates are yet to be determined. For the remaining 3 projects in formulation, NASA has not yet established preliminary cost or schedule estimates. According to NASA's key project management policy, projects establish preliminary cost and schedule range estimates at KDP A. 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 tracked acquisition cycle times as well as key milestone events in the life of the project. Acquisition cycle time is defined as the number of months between the project's start, or formulation start, and the projected or actual launch or completion date. Formulation start generally refers to the initiation of a project; NASA refers to a project's start as KDP A or the beginning of the formulation phase. 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. The committed launch readiness date is determined through a launch readiness review that verifies that the launch system, spacecraft, and payloads are ready for launch. The implementation phase includes the operations of the mission and concludes with project disposal.

Project Challenges Discussion on Each Individual Project Assessment

To assess the status, risk, and challenges for each project, we submitted a questionnaire to each project office. In the questionnaire, we requested information on the maturity of critical technologies, the number of releasable design drawings or other design stability data at project milestones, and international partnerships.[6] We also interviewed representatives from all except for two of the projects across multiple NASA centers to discuss the information on the questionnaire and the projects' status.[7] We then reviewed project documentation—including

[6]We did not collect this information for the Commercial Crew Program or the Exploration Ground Systems program because they are excluded from the related portfolio analyses. We also did not collect a questionnaire from the Space Network Ground Segment Sustainment project because the prime contract ended in June 2021 and we were able to use existing data from prior assessments.

[7]The HLS project was involved in resolving a bid protest from April 2021 to November 2021. As a result, we did not interview officials from HLS, and the project was unable to provide relevant data until February 2022. Upon receiving this data, our audit time frames did not allow sufficient time to meet with the project office to follow up on some of the information provided. We also did not interview Gateway – Deep Space Logistics (DSL) project officials, but instead spoke to Gateway program representatives about DSL's status.

monthly status reports, schedules, risk assessments, and major project review documentation—to corroborate any testimonial evidence we received in the interviews. These reviews led to identification of further challenges faced by NASA projects. The second page of our project assessments highlights key challenges that 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, COVID-19, design, integration and test, international partner, launch, spacecraft, and technology. These challenges do not represent an exhaustive or exclusive list and are based on our definitions and assessments, not those of NASA.

We conducted this performance audit from May 2021 to June 2022 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Appendix III: List of Major NASA Projects Included in GAO's Annual Assessments from 2009 to 2021

We reviewed 75 major NASA projects or programs since our initial review in 2009. See table 7 for a list of 44 projects that were included in our assessments from 2009 to 2021. These 44 projects, with the exception of the James Webb Space Telescope and Lucy, were not included in the 2022 individual project assessments because development culminated in an event such as a launch, an achievement of minimum success criteria, or cancelation.

Table 7: Major NASA Projects Reviewed in GAO's Annual Assessments from 2009 to 2021

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
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

Major project name	Year first reported	Date of development end	Result of development
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
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 Network Ground Segment Sustainment	2013	2021	Achieved minimum success
Stratospheric Observatory for Infrared Astronomy	2009	2014	Full operational capability
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-22-105212

[a]In 2014, NASA adopted Orion as the common name for Orion Multi-Purpose Crew Vehicle; the project did not change. This Orion project stems from the original Orion project that was canceled in June 2011 when the Constellation program was canceled after facing significant technical and funding issues. During the closeout process for the Constellation program, NASA identified elements

of the Ares I and Orion projects that would be transitioned for use on the new Space Launch System and Orion Multi-Purpose Crew Vehicle programs.

Appendix IV: Estimated Costs and Launch Dates for Major NASA Projects Assessed in GAO's 2022 Report

In this report, we assessed 37 major NASA projects. Table 8 shows the preliminary launch readiness data and cost estimates for projects in the formulation phase, which takes the project from concept to preliminary design.

Table 8: Preliminary Cost and Schedule Estimates of Major NASA Projects in Formulation Ordered by Preliminary Launch Date

Project name	Preliminary launch readiness date	Preliminary cost estimate (dollars in millions)
EPFD[a]	December 2023 – August 2024	311.8–469.4
Gateway Initial Capability[b]	July 2025 – February 2026	3,006.8–3,718.6
Gateway Initial Capability[b]: Gateway – HALO[c]	July 2025 – February 2026	1,173.0–1,530.3
Gateway Initial Capability[b]: Gateway – PPE[c]	July 2025 – February 2026	623.2–750.0
ML2	Fiscal year 2026	TBD
SLS Block IB[a]	Fiscal year 2026	TBD
MSR	2026 – 2028	3,413.5–4,899.5
NEO Surveyor	February 2026 – June 2026	896.1–991.1
CSP[a]	September 2026	290.3–354.9
Dragonfly	June 2027	2,100–2,500
GDC	September 2027 – May 2028	851.0–980.2
VERITAS	Fiscal year 2028	TBD
DAVINCI	Fiscal year 2030	TBD
xEVA[a]	TBD	TBD
Gateway - DSL	TBD	TBD
HLS	TBD	TBD

Legend: EPFD: Electrified Powertrain Flight Demonstration; HALO: Habitation and Logistics Outpost; PPE: Power and Propulsion Element; ML2: Mobile Launcher 2; SLS: Space Launch System; MSR: Mars Sample Return; NEO: Near Earth Object; CSP: Communications Services Project; GDC: Geospace Dynamics Constellation; VERITAS: Venus Emissivity, Radio science, InSAR, Topography, and Spectroscopy; DAVINCI: Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging; xEVA: Exploration Extravehicular Activity; DSL: Deep Space Logistics; HLS: Human Landing System.

Source: GAO analysis of NASA data. | GAO-22-105212

[a]The EPFD, SLS Block IB, CSP, and xEVA projects expect to mark the end of development with events equivalent to a launch readiness date. The EPFD project will complete development after first flights of each aircraft. The SLS Block IB project identified an associated capability readiness date. The CSP project has an estimated date for commercial capability readiness. The xEVA project will designate a delivery date for the space suits.

[b]The Gateway Initial Capability program's preliminary cost range includes costs to launch the PPE and HALO elements of Gateway together. It also includes program, mission, and execution costs estimated to range between $878.8 million and $1,106.5 million. See the Gateway program summary for additional details.

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

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

Table 9: Life-Cycle Cost and Schedule Estimates of Major NASA Projects in Implementation Ordered by Current Launch Readiness Date

Project name	Original baseline launch readiness date	Current launch readiness date	Original baseline life-cycle cost estimate (in millions)[a]	Current life-cycle cost estimate (in millions)
CCP-SpaceX[b]	April 2017	November 2020	2,599.0	2,735.7
SGSS[c,d]	June 2017	June 2021	493.9	1,123.0
Landsat 9	November 2021	September 2021	885.0	746.5
Lucy	November 2021	October 2021	981.1	989.1
DART	February 2022	November 2021	313.9	330.6
JWST[d]	June 2014	December 2021	4,963.6	9,867.7
LCRD[d]	November 2019	December 2021	262.7	319.5
EGS[d,e]	November 2018	Spring 2022	2,812.9	3,567.3
SLS[d,e]	November 2018	Spring 2022	9,064.0	11,782.3
Psyche	August 2022	August 2022	996.4	965.6
LBFD[f]	January 2022	December 2022	582.4	697.0
SWOT	April 2022	June 2023	754.9	822.4
NISAR[e]	September 2022	September 2023	866.9	971.2
VIPER[f]	November 2023	November 2023	433.5	433.5
Orion[d]	April 2023	May 2024	11,283.5	13,811.0
PACE	January 2024	May 2024	889.7	964.0
Europa Clipper	September 2025	October 2024	4,250.0	5,000.0
SPHEREx	April 2025	April 2025	451.4	451.4
OSAM-1[e]	September 2025	September 2025	1,780.0	1,926.1
IMAP	December 2025	December 2025	781.8	781.8
Roman	October 2026	May 2027	3,934.0	4,316.0
SEP[d,f]	December 2024	October 2028	335.6	382.4

Project name	Original baseline launch readiness date	Current launch readiness date	Original baseline life-cycle cost estimate (in millions)[a]	Current life-cycle cost estimate (in millions)
CCP-Boeing[b]	August 2017	Under review	4,229.6	4,501.2

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

Source: GAO analysis of NASA data. | GAO-22-105212

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

[c]SGSS is a ground system that does not have a launch readiness date, but this date represents the planned transition to another project within the Space Communication and Navigation program.

[d]NASA has approved rebaselines for the JWST, LCRD, EGS, SLS, SGSS, Orion, and SEP projects since they set original baselines at their confirmation reviews. See table 10 for additional information.

[e]The EGS, NISAR, OSAM-1, and SLS projects expect to experience additional cost growth or schedule delays, but the exact magnitude is unknown. The projects were reevaluating their cost or schedules at the time of our review. We use the latest cost and schedule estimates provided by NASA for EGS, NISAR, and SLS. For OSAM-1, we calculated a 15 percent cost growth to capture some of the cost growth expected from a pending replan.

[f]The LBFD, VIPER, and SEP projects expect to mark the end of development with events equivalent to a launch readiness date. The LBFD project has an equivalent first flight event. The VIPER project identifies an initial operational capability date. The SEP projects marks the end of development when its second qualification unit has completed testing and the life qualification report is accepted by NASA.

NASA approved rebaselines for seven major projects since they set their original cost and schedule baselines at their commitment reviews. Table 10 shows the latest approved rebaselined cost and schedule estimates as well as the current cost and schedule estimates for these projects.

Table 10: Approved Rebaseline and Current Life-Cycle Cost and Schedule Estimates for Major NASA Projects

Project name	Date of latest approved rebaseline	Latest approved rebaseline launch readiness date	Current launch readiness date	Latest approved rebaseline life-cycle cost estimate (in millions)	Current life-cycle cost estimate (in millions)
EGS[a]	June 2020	November 2021	Spring 2022	3,413.1	3,567.3
JWST	June 2018	March 2021	December 2021	9,662.7	9,867.7
LCRD	November 2019	January 2021	December 2021	310.5	319.5
Orion	August 2021	May 2024	May 2024	13,811.0	13,811.0
SEP[b]	March 2022	October 2028	October 2028	382.4	382.4
SGSS[b]	July 2015	September 2019	June 2021	842.2	1,123.0

Project name	Date of latest approved rebaseline	Latest approved rebaseline launch readiness date	Current launch readiness date	Latest approved rebaseline life-cycle cost estimate (in millions)	Current life-cycle cost estimate (in millions)
SLS[a]	June 2020	November 2021	Spring 2022	11,782.3	11,782.3

Legend: EGS: Exploration Ground Systems; JWST: James Webb Space Telescope; LCRD: Laser Communications Relay Demonstration; Orion: Orion Multi-Purpose Crew Vehicle; SEP: Solar Electric Propulsion; SGSS: Space Network Ground Segment Sustainment; SLS: Space Launch System.

Source: GAO analysis of NASA data. | GAO-22-105212

[a]The EGS and SLS projects expect to experience additional cost growth or schedule delays, but the exact magnitude is unknown. The projects were reevaluating their cost or schedules at the time of our review. We use the latest cost and schedule estimates provided by NASA for EGS and SLS.

[b]The SEP and SGSS projects expect to mark the end of development with events equivalent to a launch readiness date. The SEP project marks the end of development when its second qualification unit has completed testing and the life qualification report is accepted by NASA. SGSS is a ground system that does not have a launch readiness date, but this date represents the planned transition to another project within the Space Communication and Navigation program.

Appendix V: Annual Cost and Schedule Changes for Major NASA Projects in Development

Table 11: Annual Development Cost Overruns and Schedule Delays for Major NASA Projects in Development since GAO's 2021 Assessment

na	na	Changes between last GAO assessment and current assessment	
Annual performance status	**Project(s)**	**Schedule delay (months)**	**Cost growth (millions of dollars)**
First year estimate reported[a]	IMAP; VIPER	N/A	N/A
No change from prior year	SGSS; SPHEREx	0	0.0
Underrunning prior estimate	Landsat 9	(2)	(92.0)
Underrunning prior estimate	Lucy	(1)	(49.2)
Mixed cost or schedule performance from prior year	DART	(3)	11.8
Mixed cost or schedule performance from prior year	Europa Clipper	(11)	162.2
Overrunning prior estimate	SLS[b]	6	0
Overrunning prior estimate	Psyche	0	8.0
Overrunning prior estimate	LCRD	6	16.5
Overrunning prior estimate	LBFD	6	40.0
Overrunning prior estimate	SEP	46	47.3
Overrunning prior estimate	NISAR[b]	12	54.7
Overrunning prior estimate	SWOT	14	67.5
Overrunning prior estimate	PACE	4	74.3
Overrunning prior estimate	EGS[b]	6	96.2
Overrunning prior estimate	JWST	2	115.0
Overrunning prior estimate	OSAM-1[b]	0	146.1
Overrunning prior estimate	Roman	7	371.9
Overrunning prior estimate	Orion	9	1,645.2
Totals		**101**	**2,715.5**

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

Source: GAO analysis of NASA data. | GAO-22-105212

Note: Positive values indicate cost growth or launch delays. Values in parentheses indicate cost decreases or earlier than planned launch dates. Data are primarily as-of January 2022 with a few exceptions noted in appendix II.

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

[b]The EGS, NISAR, OSAM-1, and SLS projects expect to experience additional cost growth or schedule delays, but the exact magnitude is unknown. The projects were reevaluating their cost or schedules at the time of our review. To calculate a cost change against prior reported estimates, we use the latest cost and schedule estimates provided by NASA for EGS, NISAR, and SLS. For OSAM-1's latest estimate, we calculated a 15 percent cost growth from its original baseline to capture some of the cost growth expected from a pending replan.

Appendix VI: Technology Readiness Levels

Table 12: 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-22-105212

Table 13: 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 system are tested in a relevant environment, meeting predicted performance. Operational environment performance is predicted.
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-22-105212

Appendix VII: Comments from NASA

National Aeronautics and Space Administration

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

June 6, 2022

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-22-105212).

The work conducted at NASA is vital to the strategic interests of the United States and continues to inspire our people at home and throughout the world. We create "first-ever" missions and approaches that showcase American ingenuity, pioneer new science and technology, improve long-term affordability of aeronautics and space exploration, reinforce U.S. preeminence in space, improve life on Earth, and address critical national challenges. The U.S. GAO congressionally mandated annual assessment is an opportunity for NASA to receive an independent perspective on its performance in the acquisition of major programs and projects. We appreciate the open and constructive dialogue between NASA and the GAO engagement team, and we look forward to continuing to work with the GAO to identify and address any challenges that may enable cost and schedule improvements in our current and future projects.

This year's report represents the 14th 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. NASA has worked closely with GAO to find and implement improvements in our programs. As the NASA portfolio grows to reflect expanded national objectives, the number of major projects in this annual engagement is expected to continue to grow. The 2021-2022 engagement cycle included 37 major projects, an increase of 50 percent in just a few years, representing the largest number of projects reviewed in the history of the annual assessment. We expect the number of projects to increase once again in next year's cycle. We continue to monitor and refine strategies to implement reviews on a sustainable basis, given the anticipated continued expansion of the scope of activities entrusted to NASA. We also welcome suggestions from GAO to identify any options for streamlining the assessment process.

In this year's report, the GAO states that the NASA portfolio of major projects is facing the largest ever set of overruns and delays. The GAO reaches this conclusion by summing the cumulative cost and schedule growth against original baselines for the projects currently in the

2

portfolio. GAO, however, acknowledges that most of the cumulative cost and schedule growth is driven by only a small subset of projects–JWST, SLS, and Orion–notably NASA's three largest programs. It is worth noting that GAO's use of cumulative data against original baselines creates a situation where the trend cannot effectively improve until those three programs exit the Quick Look scope along with their associated cumulative data. The cumulative approach also obscures the excellent progress NASA has achieved in controlling cost and schedule for most of the portfolio, particularly for small- and mid-sized major projects. Moreover, the GAO's approach of limiting cost performance measurement against original baselines in some cases leads to a mischaracterization that all cost variation is a result of poor performance. For example, the Orion program's 2021 rebaseline incorporated a significant increase in total cost to account for a directed scope change, but GAO's report does not clearly reflect the important distinction that the cost variation is not entirely tied to cost performance. 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.

The challenges brought on by the COVID-19 pandemic continue to be felt by nearly all programs involved in this year's assessment. COVID-19 is an unprecedented event, and NASA's understanding of the impact of COVID-19 continues to evolve. NASA will continue to monitor and address the cost and schedule impacts of COVID-19 on its major projects. A final accounting of the full impact of COVID-19 on Agency activities will not be available until well after the Agency and its contractors and partners are operating in a post-pandemic environment. As case rates across the country decline, NASA is exiting the COVID-19 Response Framework and beginning to return to worksites on a more consistent basis within the context of the Future of Work framework. We look forward to a future where the GAO team is able to interact directly in person with program and project personnel and to experience visits to NASA facilities and see the hardware to gain a tangible experience of the progress NASA continues to make.

NASA recognizes the inherent challenges of managing large, complex space flight and aeronautical 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) role 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 High Risk CAP. NASA is pleased to see GAO's recognition of our progress in this high-risk area in the most recent High Risk Report published in March 2021 and again in a GAO High Risk update released in March 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 against the CAP. NASA is currently working to update the CAP in July 2022 to capture additional associated initiatives that continue to address the area of acquisition management.

NASA appreciates GAO's review of the Artemis Campaign's programs and major projects. Refinement of the Artemis Campaign continues to progress as the Agency advances toward landing the first woman and person of color on the surface of the Moon. The uncrewed Artemis I mission, which will carry multiple scientific payloads into deep space, is set to launch later this year; the launch date will be set after the successful completion of Wet Dress

Rehearsal, the last major test left in a campaign of various checks of the integrated vehicle and launch facility. Completion of the Artemis I mission will yield valuable launch and flight data, as well as numerous lessons learned. Work on Artemis II and III mission hardware has also continued to meet major milestones. The Artemis II and III Core Stages are actively being produced and tested at the Michoud Assembly Facility. The SLS Block 1B vehicle design for Artemis IV is under development and progressing towards its Critical Design Review (CDR) this summer. At Kennedy Space Center, the arrival of the Artemis II European Service Module (ESM) in the fall of 2021 has allowed NASA teams to focus on the integration and testing of the Environmental Control and Life Support System within both the ESM and crew module adapter, while work has continued on the installation of core avionics, power, and wiring in the crew module. The refurbishment and integration of Artemis I non-core avionics into Artemis II hardware will begin upon successful completion of the Artemis I mission. The contract for Human Landing System's (HLS) first crewed landing is in place with SpaceX. HLS and SpaceX were able to resume work last summer following conclusion of the bid protest and related stay of performance. SpaceX has successfully completed the first several contract milestones and deliverables. Gateway has completed aligning the requirements for Power and Propulsion Element (PPE) and Habitation and Logistics Outpost (HALO) for the integrated launch of the Gateway initial capability. Both PPE and HALO with their prime contractors Maxar and Northrup Grumman respectively, have completed their preliminary design review (PDR) activities and are moving into hardware development. Gateway design and development has progressed, completing 33 subsystem PDRs as of the end of April, and on path to completing their overall initial capability PDR-informed Sync Review. NASA has also formulated the Extravehicular Activity (EVA) and Human Surface Mobility (HSM) Program under the Artemis Campaign Development Division. This program is providing integration for the various systems that support crew exploration both near Earth and on the Moon including the surface suits and tools that will be used on the Artemis III lunar landing mission. All of these efforts within the Artemis Campaign are paving the way to a sustainable presence on the lunar surface.

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 look forward to working with GAO to develop guidelines that account for technology demonstrations where the demonstration itself is designed to test integrated technologies/systems in a space environment to give other NASA missions the confidence to use them and to facilitate commercialization of the technology. We understand GAO is open to further discussion on methodology and look forward to meeting with GAO on the subject.

NASA thanks the GAO for continuing to work with project subject-matter experts to consider and incorporate technical corrections as part of this audit. We appreciate the consideration of these comments, which is important for an accurate and balanced 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 must be aware of the fiscal environment and ensure we optimize use of all our resources–our workforce effort, funding, and time. Please contact Kevin Gilligan at (202) 503-8665 or by e-mail at kevin.m.gilligan@nasa.gov if you have any questions or require additional information.

Sincerely,

Accessible Text for Appendix VII: Comments from NASA

June 6, 2022

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Director
Contracting and National Security Acquisitions
United States Government Accountability Office
Washington, DC 20548

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Sincerely,

Bill Nelson

Appendix VIII: GAO Contacts and Staff Acknowledgments

GAO Contact

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

Staff Acknowledgments

In addition to the contact named above, Kristin Van Wychen (Assistant Director); Juli Steinhouse (Analyst-in-Charge); Brian Bothwell; Ryan Braun; Daniel Chandler; Erin Cohen; Jewel Conrad; Tina Cota-Robles; Lorraine Ettaro; Kurt Gurka; Erin Kennedy; Joy Kim; Meredith Allen Kimmett; Natalie Logan; Christina Lowe Loumeau; John Ortiz; Jose A. Ramos; Carrie Rogers; Edward J. SanFilippo; Daniel Singleton; Ryan Stott; Roxanna T. Sun; Hai Tran; Tom Twambly; John Warren; Alyssa Weir; and Tonya Woodbury 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), Lockheed Martin Aeronautics (Low Boom Flight Demonstrator).

Front cover: NASA (Exploration Extravehicular Activity), Anton/dimazel/dottedyeti/stock.adobe.com (moon, Earth, and space background).

Appendix I: GAO analysis of NASA data (all cost performance and schedule performance figures) and GAO analysis of NASA documentation (all time line figures).

Appendix X: Accessible Data

Data Tables

Accessible Data for Cumulative Cost and Schedule Overruns for NASA's Major Projects in Development

Year	Cumulative cost overruns (then-year dollars in billions)	Cumulative schedule overruns	Number of projects in development
2013	3840.9	8.4	12
2014	3838.1	7.2	15
2015	3911.7	7.2	12
2016	3857.3	7.7	12
2017	3967.7	9.8	16
2018	4770	17.4	17
2019	7156.1	18.6	17
2020	8520.1	18.6	18
2021	9625.7	19.7	20
2022	11954.4	28.1	21

Accessible Data for Figure 2: Cumulative Development Cost and Schedule Overruns for NASA's Portfolio of Major Projects Since 2013

Year	Baseline cost (then-year dollars in billions)	Cumulative cost overruns (then-year dollars in billions)	Cumulative schedule overruns	Number of projects in development
2013	8268.8	3840.9	8.4	12
2014	10159.7	3838.1	7.2	15
2015	15084.8	3911.7	7.2	12
2016	22300.6	3857.3	7.7	12
2017	25412	3967.7	9.8	16
2018	25359.4	4770	17.4	17
2019	25918.4	7156.1	18.6	17
2020	27570.7	8520.1	18.6	18
2021	30983.6	9625.7	19.7	20
2022	30232.4	11954.4	28.1	21

Accessible Data for Figure 3: Annual Development Cost Overruns for Major NASA Projects since GAO's 2021 Assessment

Development cost overruns of $2.8 billion since GAO's 2021 assessment (in then-year millions of dollars)

NASA project	Annual development cost overrun (in then-year millions of dollars)
Orion	1,645.2
Roman	371.9
Europa Clipper	162.2
OSAM-1	146.1
JWST	115.0
EGS	96.2
PACE	74.3
SWOT	67.5
NISAR	54.7
SEP	47.3
LBFD	40.0
LCRD	16.5
DART	11.8
Psyche	8.0

Accessible Data for Figure 4: Annual Development Schedule Delays for Major NASA Projects in Development since GAO's 2021 Assessment

NASA project	Delay (in months)
SEP	46
SWOT	14
NISAR	12
Orion	9
Roman	7
LCRD	6
LBFD	6
EGS	6
SLS	6
PACE	4
JWST	2

Accessible Data for Figure 5: Number of Major NASA Projects Meeting GAO's Best Practice of Achieving a Technology Readiness Level 6 by Preliminary Design Review

Category	2021	2022
Technology demonstration projects that did not meet the technology maturity best practice	2	2
Projects that did not meet the technology maturity best practice	2	2
Projects that met the technology maturity best practice	10	11

Accessible Data for Figure 6: Performance of Major NASA Projects against Best Practice for Design Stability

Year	Projects meeting design stability best practice	Projects not meeting design stability best practice	Average percentage of released engineering drawings at critical design review
2013	1	9	73
2014	1	8	67
2015	1	7	74
2016	3	7	69
2017	3	7	66
2018	4	8	70
2019	5	7	73
2020	4	8	73
2021	3	10	71.2
2022	3	11	70

Accessible Data for Figure 7: Average Percentage of Engineering Drawing Growth after Critical Design Review among Major NASA Projects from 2013 to 2022

Year	Average percentage of drawing growth after critical design review
2013	12
2014	20
2015	11
2016	11
2017	18
2018	19
2019	18
2020	18
2021	21
2022	23

Accessible Data for Figure 8: Illustration of a Sample Project Assessment

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

B. General description of the mission’s objectives.

C. Time line identifying key dates for the project including when the project began formulation, held major design reviews, began implementation, and launched or fielded an operating capability.

D. Project Information: Information on the responsible NASA center, international partners, launch plans, mission duration, the source of the mission’s requirements, and the budget portfolio.

E. Project Summary: Brief narrative describing the current status of the project.

F. Schedule: For projects in formulation, the preliminary launch readiness target date or range of dates. For projects in implementation, the approved schedule baseline and latest estimate.

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

H. The second page of the assessment is an analysis of the project challenges and the extent to which each project faces cost, schedule, or performance risks because of these challenges.

I. Project Office Comments: General comments provided by the cognizant project office.

Data Tables (Costs)

CCP

CCP	Boeing (dollars in millions)	SpaceX (dollars in millions)
Date of estimate	Jan. 2022	Aug. 2021
Original contract value (as of fiscal year 2014)	$4,229.6	$2,599.0
Current maximum contract value (as of January 2022) b	$4,501.2	$2,735.7
Percent Total Cost Change	6.4%	5.3%

Note a: As reported by NASA as of January 2022 and includes contract costs for development, operations, and special studies.

Note b: SpaceX completed development and began post-certification missions to the ISS in November 2020.

CSP

CSP	Data (dollars in millions)
Date of latest estimate	Jan. 2022
Latest estimate	$290.3 - $354.9

Note 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.

DAVINCI

DAVINCI	Data (then-year dollars in millions)
Date of latest estimate	To Be Determined
Latest estimate	To Be Determined

Dragonfly

Dragonfly	Data (then-year dollars in millions)
Date of latest estimate	Jan. 2022
Latest estimate	$2,100 - $2,500 (under review)

Note 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.

Gateway - DSL

Gateway Deep Space Logistics (DSL) (*then-year dollars in millions*)	**Data**
Date of latest estimate	To Be Determined
Latest estimate	To Be Determined

EGS

Exploration Ground Systems (EGS)	Baseline (then-year dollars in millions)	Latest Estimate (then-year dollars in millions)
Date of estimate	FY 2014	Jan. 2022
Formulation	$969.4	$974.7
Development	$1,843.5	$2,592.5
Operations	$0.0	$0.0
Total	$2,812.9	$3,567.3

- Percent Total Cost Change: 26.8%
- Cost under review?: Under review

EPFD

EPFD	Data (then-year dollars in millions)
Latest estimate as of	Jan. 2022
Latest estimate	$311.8 - $469.4

Note 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.

Europa Clipper

Europa Clipper	Baseline (then-year dollars in millions)	Latest Estimate (then-year dollars in millions)
Date of estimate	FY 2019	Mar. 2022
Formulation	$1,219.0	$1,219.0
Development	$2,412.8	$2,509.0
Operations	$618.2	$1,272.0
Total	$4,250.0	$5,000.0

Percent Total Cost Change: 17.6%
Cost under review?

Gateway

Gateway	Data (then-year dollars in millions)
Date of latest estimate	Jan. 2022
Latest estimate	$3,006.8 – $3,718.6

Note 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 estimate for planning purposes.

GDC

Geospace Dynamics Constellation (GDC)	Data (then-year dollars in millions)
Date of latest estimate	Jan. 2022
Latest estimate	$851.0 - $980.2

Note 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.

Gateway - HALO

Gateway - HALO	Data (then-year dollars in millions)
Date of latest estimate	Jan. 2022
HALO preliminary cost range	$1,173.0 - $1,530.3
PPE preliminary cost range	$632.2 - $750.0
Gateway program mission execution preliminary cost range and co-manifested vehicle	$1,210.6 - $1,438.8
Gateway Initial Capability preliminary cost range	$3,006.8 - $3,718.6

Note 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.

HLS

Human Landing System (HLS)	Data (then-year dollars in millions)
Date of latest estimate	To Be Determined
Latest estimate	To Be Determined

Note a: NASA did not require the HLS program to establish a preliminary cost estimate for the program.

IMAP (then-year dollars in millions)

Interstellar Mapping and Acceleration Probe (IMAP)	Baseline (then-year dollars in millions)	Latest Estimate (then-year dollars in millions)
Date of estimate	FY 2021	Jan. 2022
Formulation	$117.6	$117.6
Development	$589.5	$589.5
Operations	$74.8	$74.8
Total	$781.8	$781.8

- Percent Total Cost Change: 0.0%
- Cost under review?

JWST

James Webb Space Telescope (JWST)	Baseline (then-year dollars in millions)	Latest Estimate (then-year dollars in millions)
Date of estimate	FY 2009	Jan. 2022
Formulation	$1,800.1	$1,800.1
Development	$2,581.1	$7,117.1
Operations	$582.4	$950.6
Total	$4,963.6	$9,867.7

Percent Total Cost Change 98.8%
Cost under review?

LBFD

Low Boom Flight Demonstrator (LBFD)	Baseline (then-year dollars in millions)	Latest Estimate (then-year dollars in millions)
Date of estimate	FY 2019	Jan. 2022
Formulation	$100.5	$100.5
Development	$467.7	$572.2
Operations	$14.2	$24.4
Total	$582.4	$697.0

- Percent Total Cost Change: 19.7%
- Cost under review?

Lucy

Lucy	Baseline (then-year dollars in millions)	Latest Estimate (then-year dollars in millions)
Date of estimate	FY 2019	Jan. 2022
Formulation	$94.7	$94.7
Development	$622.2	$565.0
Operations	$264.2	$329.3
Total	$981.1	$989.1

- Percent Total Cost Change: 0.8%
- Cost under review?

ML2

ML2	Data (then-year dollars in millions)
Date of latest estimate	To Be Determined
Latest estimate	To Be Determined

MSR

Mars Sample Return (MSR)	Data (then-year dollars in millions)
Date of latest estimate	Jan. 2022
Latest estimate	$3,413.5 - $4,899.5

Note 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.

NEOSurveyor

Near Earth Object Surveyor (NEO Surveyor)	Data (then-year dollars in millions)
Date of latest estimate	Jan. 2022
Latest estimate	$896.1 - $991.1

Note 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.

NISAR

NASA Indian Space Research Organisation - Synthetic Aperture Radar (NISAR)	Baseline (then-year dollars in millions)	Latest Estimate (then-year dollars in millions)
Date of estimate	FY 2016	Jan. 2022
Formulation	$117.0	$117.0
Development	$661.0	$774.3
Operations	$88.9	$79.9
Total	$866.9	$971.2

- Percent Total Cost Change: 12.0%
- Cost under review?: Under Review

Orion

Orion Multi-Purpose Crew Vehicle (Orion)	Baseline (then-year dollars in millions)	Latest Estimate (then-year dollars in millions)
Date of estimate	FY 2015	Jan. 2022
Formulation	$4,515.1	$4,509.6
Development	$6,768.4	$9,301.2
Operations	$0.0	$0.0
Total	$11,283.5	$13,811.0

- Percent Total Cost Change: 22.4%
- Cost under review?

OSAM-1

On-Orbit Servicing, Assembly and Manufacturing 1 (OSAM-1)	Baseline (then-year dollars in millions)	Latest Estimate (then-year dollars in millions)
Date of estimate	FY 2020	Jan. 2022
Formulation	$740.6	$740.6
Development	$974.4	$1,120.5
Operations	$65.0	$65.0
Total	$1,780.0	$1,926.1

- Percent Total Cost Change: 8.2%
- Cost under review?: Under Review

PACE

Plankton, Aerosol, Cloud, ocean Ecosystem (PACE)	Baseline (then-year dollars in millions)	Latest Estimate (then-year dollars in millions)
Date of estimate	FY 2019	Jan. 2022
Formulation	$260.3	$260.3
Development	$558.0	$632.3
Operations	$71.4	$71.4
Total	$889.7	$964.0

Percent Total Cost Change: 8.4%
Cost under review?

Gateway - PPE

Gateway - PPE	Data (then-year dollars in millions)
Date of latest estimate	Jan. 2022
HALO Latest preliminary estimate	$1,173.0 - $1,530.3
PPE latest preliminary estimate	$632.2 - $750.0
Gateway program mission execution preliminary cost range and co-manifested vehicle	$1,210.6 - $1,438.8
Gateway Initial Capability latest preliminary estimate	$3,006.8 - $3,718.6

Note 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.

Psyche

Psyche	Baseline (then-year dollars in millions)	Latest Estimate (then-year dollars in millions)
Date of estimate	FY 2019	Jan. 2022
Formulation	$143.7	$143.7
Development	$681.9	$651.1
Operations	$170.8	$170.8
Total	$996.4	$965.6

- Percent Total Cost Change -3.1%
- Cost under review?

Roman

Nancy Grace Roman Space Telescope (Roman)	Baseline (then-year dollars in millions)	Latest Estimate (then-year dollars in millions)
Date of estimate	FY 2020	Jan. 2022
Formulation	$635.9	$633.8
Development	$2,898.1	$3,270.0
Operations	$400.0	$412.2
Total	$3,934.0	$4,316.0

- Percent Total Cost Change 9.7%
- Cost under review?

SEP

Solar Electric Propulsion (SEP)	Baseline (dollars in millions)	Latest Estimate (dollars in millions)
Date of estimate	FY 2020	Jan. 2022
Formulation	$179.7	$179.2
Development	$155.9	$203.2
Operations	$0.0	$0.0
Total	$335.6	$382.4

- Percent Total Cost Change: 13.9%
- Cost under review?: Under Review

SLS

Space Launch System (SLS)	Baseline (dollars in millions)	Latest Estimate (dollars in millions)
Date of estimate	FY 2014	Jan. 2022
Formulation	$2,674.0	$2,674.0
Development	$6,390.0	$9,108.3
Operations	$0.0	$0.0
Total	$9,064.0	$11,782.3

- Percent Total Cost Change: 30.0%
- Cost under review?

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

SLS Block IB

Space Launch System Block IB (SLS Block IB)	Data (then-year dollars in millions)
Date of latest estimate	To Be Determined
Latest estimate	To Be Determined

SPHEREx

Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ices Explorer (SPHEREx)	Baseline (then-year dollars in millions)	Latest Estimate (then-year dollars in millions)
Date of estimate	FY 2021	Jan. 2022
Formulation	$64.2	$64.2
Development	$367.8	$367.8
Operations	$19.5	$19.5
Total	$451.4	$451.4

- Percent Total Cost Change: 0.0%
- Cost under review?

SWOT

Surface Water and Ocean Topography (SWOT)	Baseline (then-year dollars in millions)	Latest Estimate (then-year dollars in millions)
Date of estimate	FY 2016	Jan. 2022
Formulation	$136.8	$136.8
Development	$571.5	$639.0
Operations	$46.7	$46.7
Total	$754.9	$822.4

- Percent Total Cost Change: 8.9%
- Cost under review?

VERITAS

Venus Emissivity, Radio science, InSAR, Topography, And Spectroscopy (VERITAS)	Data (then-year dollars in millions)
Date of latest estimate	To Be Determined
Latest estimate	To Be Determined

VIPER

Volatiles Investigating Polar Exploration Rover (VIPER)	Baseline (then-year dollars in millions)	Latest Estimate (then-year dollars in millions)
Date of estimate	FY 2021	Jan. 2022
Formulation	$80.1	$80.1
Development	$336.2	$336.2
Operations	$17.2	$17.2
Total	$433.5	$433.5

Percent Total Cost Change: 0.0%
Cost under review?

xEVA

Exploration Extravehicular Activity (xEVA)	Data (then-year dollars in millions)
Date of latest estimate	To Be Determined
Latest estimate	To Be Determined

Data Tables (Schedules)

CCP

CCP	Boeing	SpaceX [c]
Start Date	09/14	09/14
Original certification review date	08/17	04/17
Current proposed certification review date (as of January 2022)	Under Review	11/20
Launch Date Months Change	At least 53 months	43 months

CSP

CSP	Data
Latest Estimate As-of Date	Jan. 2022
Project Start Date	12/20
Latest Estimate date of commercial capability readiness	09/26

DAVINCI

DAVINCI	Data
Latest Estimate As-of Date	Jan. 2022
Project Start Date	05/21
Latest Estimate Launch Date	Fiscal Year 2030

Dragonfly

Dragonfly	Data
Latest Estimate As-of Date	Jan. 2022
Project Start Date	06/19
Latest Estimate Launch Date	06/27

Gateway - DSL

Gateway Deep Space Logistics (DSL)	Data
Latest Estimate As-of Date	Jan. 2022
Project Start Date	04/19
Latest Estimate	To Be Determined

EGS

Exploration Ground Systems (EGS)	Baseline	Latest Estimate
Date of estimate	FY 2014	Mar. 2022
Launch Date	11/18	Spring 2022

- Project Start: 02/12
- Launch Date Months Change: 42
- Schedule under review?: Under Review

EPFD

EPFD	Data
Latest Estimate As-of Date	Jan. 2022
Project Start Date	06/20
Latest Estimate date of First Flights	12/23 - 8/24

Europa Clipper

Europa Clipper	Baseline	Latest Estimate
Date of estimate	FY 2019	Mar. 2022
Launch Date	09/25	10/24

- Project Start: 06/15
- Launch Date Months Change: -11
- Schedule under review?

Gateway

Gateway	Data
Latest Estimate As-of Date	Jan. 2022
Project Start Date	04/19
Latest Estimate Launch Date	07/25 - 02/26

GDC

Geospace Dynamics Constellation (GDC)	Data
Latest Estimate As-of Date	Jan. 2022
Project Start Date	09/20
Latest Estimate Launch Date	09/27 – 05/28

Gateway - HALO

Gateway - HALO	Data
Latest Estimate As-of Date	Jan. 2022
Project Start Date	04/19
Latest Estimate Launch Date	07/25 - 02/26

HLS

Human Landing System (HLS)	Data
Latest Estimate As-of Date	Jan. 2022
Project Start Date	05/19
Latest Estimate	To Be Determined

IMAP

Interstellar Mapping and Acceleration Probe (IMAP)	Baseline	Latest Estimate
Date of estimate	FY 2021	Jan. 2022
Launch Date	12/25	12/25

- Project Start: 05/18
- Launch Date Months Change: 0
- Schedule under review?

JWST

James Webb Space Telescope (JWST)	Baseline	Latest Estimate
Date of estimate	FY 2009	Jan. 2022
Launch Date	06/14	12/21

- Project Start: 03/99
- Launch Date Months Change: 90
- Schedule under review?

LBFD

Low Boom Flight Demonstrator (LBFD)	Baseline	Latest Estimate
Date of estimate	FY 2019	Jan. 2022
First Flight Date	01/22	12/22

- Project Start: 09/16
- First Flight Date Months Change 11
- Schedule under review?

Lucy

Lucy	Baseline	Latest Estimate
Date of estimate	FY 2019	Jan. 2022
Launch Date	11/21	10/21

- Project Start: 12/16
- Launch Date Months Change: -1
- Schedule under review?

ML2

Mobile Launcher 2 (ML2)	Data
Latest Estimate As-of Date	Jan. 2022
Project Start Date	Continued from EGS program
Latest Estimate Launch Date	Fiscal Year 2026

MSR

Mars Sample Return (MSR)	Data
Latest Estimate As-of Date	Jan. 2022
Project Start Date	09/20
Latest Estimate Launch Date	2026 - 2028

NEOSurveyor

Near Earth Object Surveyor (NEO Surveyor)	Data
Latest Estimate As-of Date	Jan. 2022
Project Start Date	06/20
Latest Estimate Launch Date	02/26 - 06/26

NISAR

NASA Indian Space Research Organisation - Synthetic Aperture Radar (NISAR)	Baseline	Latest Estimate
Date of estimate	FY 2016	Jan. 2022
Launch Date	09/22	09/23

- Project Start: 03/14
- Launch Date Months Change: 12
- Schedule under review?: Under Review

Orion

Orion Multi-Purpose Crew Vehicle (Orion)	Baseline	Latest Estimate
Date of estimate	FY 2015	Jan. 2022
Artemis II Launch Date	04/23	05/24

- Project Start: 02/12
- Artemis II Launch Date Months Change: 13
- Schedule under review?

OSAM-1

On-Orbit Servicing, Assembly and Manufacturing 1 (OSAM-1)	Baseline	Latest Estimate
Date of estimate	FY 2020	Jan. 2022
Launch Date	09/25	09/25

- Project Start 05/16
- Launch Date Months Change: 0
- Schedule under review?: Under Review

PACE

Plankton, Aerosol, Cloud, ocean Ecosystem (PACE)	Baseline	Latest Estimate
Date of estimate	FY 2019	Jan. 2022
Launch Date	01/24	05/24

- Project Start 06/16
- Launch Date Months Change: 4
- Schedule under review?

Gateway – PPE

Gateway - PPE	Data
Latest Estimate As-of Date	Jan. 2022
Project Start Date	09/17
Latest Estimate Launch Date	07/25 - 02/26

Psyche

Psyche	Baseline	Latest Estimate
Date of estimate	FY 2019	Jan. 2022
Launch Date	08/22	08/22

- Project Start: 12/16
- Launch Date Months Change: 0
- Schedule under review?

Roman

Nancy Grace Roman Space Telescope (Roman)	Baseline	Latest Estimate
Date of estimate	FY 2020	Jan. 2022
Launch Date	10/26	05/27

- Project Start 02/16
- Launch Date Months Change: 7
- Schedule under review?

SEP

Solar Electric Propulsion (SEP)	Baseline	Latest Estimate
Date of estimate	FY 2020	Jan. 2022
Completion Date	12/24	10/28

- Project Start: 03/15
- Completion Date Months Change: 46
- Schedule under review?

SLS

Space Launch System (SLS)	Baseline	Latest Estimate
Date of estimate	FY 2014	Mar. 2022
Launch Date	11/18	Spring 2022

- Project Start: 11/11
- Launch Date Months Ch:ange: 42
- Schedule under review?: Under Review

SLS Block IB

Space Launch System Block IB (SLS Block IB)	Data
Latest Estimate As-of Date	Jan. 2022
Project Start Date	Continued from SLS program
Latest Estimate Launch Date	Fiscal Year 2026

SPHEREx

Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ices Explorer (SPHEREx)	Baseline	Latest Estimate
Date of estimate	FY 2021	Jan. 2022
Launch Date	04/25	04/25

- Project Start: 02/19
- Launch Date Months Change: 0
- Schedule under review?

SWOT

Surface Water and Ocean Topography (SWOT)	Baseline	Latest Estimate
Date of estimate	FY 2016	Jan. 2022
Launch Date	04/22	06/23

- Project Start: 11/12
- Launch Date Months Change: 14
- Schedule under review?

VERITAS

Venus Emissivity, Radio science, InSAR, Topography, And Spectroscopy (VERITAS)	Data
Latest Estimate As-of Date	Jan. 2022
Project Start Date	05/21
Latest Estimate Launch Date	Fiscal Year 2028

VIPER

Volatiles Investigating Polar Exploration Rover (VIPER)	Baseline	Latest Estimate
Date of estimate	FY 2021	Jan. 2022
Launch Date	11/23	11/23

- Project Start: 10/19
- Launch Date Months Change: 0
- Schedule under review?

xEVA

Exploration Extravehicular Activity (xEVA)	Data
Latest Estimate As-of Date	Jan. 2022
Project Start Date	07/19
Latest Estimate	To Be Determined

Data Tables (Timelines)

CCP

Category	Category information
Transportation Capabilities phase contract awards	09/14
SpaceX uncrewed test flight	03/19
Boeing uncrewed test flight-1	12/19
SpaceX crewed test flight	05/20
SpaceX final certification and first post certification flight	11/20
GAO review	1/22
Boeing uncrewed test flight-2	No earlier than 05/22
Boeing crewed test flight	Under review
Boeing final certification	Under review
Post-certification operational missions	2020 - 2028

Dragonfly

Category	Category information
Formulation start	06/19
Internal system requirements review	08/20
GAO review	01/22
Preliminary design review	10/22
Project confirmation	1/2023
Critical design review	11/23
System integration review	01/26
Preliminary launch readiness date	06/27

EPFD

Category	Category information
Formulation start	06/20
System requirements review	09/20
Contract awards	09/21
GAO review	01/22
GE systems readiness review	02/22
GE preliminary design review	04-05/22
magniX systems readiness review	TBD
EPFD delta systems readiness review	TBD
magniX preliminary design review	TBD
Project confirmation	TBD
GE critical design review	Fiscal year 2023
magniX critical design review	TBD
Preliminary range for First Flight Concept 1 and 2	12/23 - 08/24

Europa Clipper

Category	Category information
Formulation start	06/15
System requirements/mission definition review	01/17
Preliminary design review	08/18
Delta preliminary design review	06/19
Project confirmation	08/19
Critical design review	12/20
System integration review	11/21
GAO review	01/22
Target launch readiness date	10/24
Committed launch readiness date	09/25

Gateway – HALO

Category	Category information
Formulation start	04/19
System definition review	02/20
Preliminary design review	05/21
GAO review	01/22
Project confirmation	07/22
Critical design review	08/22
System integration review	12/22
Preliminary launch readiness date	07/25 - 02/26

Gateway - PPE

Category	Category information
Formulation start	09/17
System requirements review	09/19
Preliminary design review	11/21
GAO review	01/22
Critical design review	05/22
Project confirmation	07/22
System integration review	05/23
Preliminary launch readiness date	07/25 - 02/26

IMAP

Category	Category information
Formulation start	05/18
System requirements/mission definition review	12/19
Preliminary design review	05/21
Project confirmation	07/21
GAO review	01/22
Critical design review	Under review
System integration review	Under review
Target launch readiness date	02/25
Committed launch readiness date	12/25

LBFD

Category	Category information
Start of concept formulation studies	03/13
Mission definiton review	03/14
LBFD formulation start	09/16
Preliminary design review	08/18
Project confirmation	11/18
Critical design review	09/19
GAO review	01/22
First flight date	12/22
System acceptance review	11/23
Aircraft transfer review	08/24

ML2

Category	Category information
Formulation start	Continued from EGS program
System requirements review	03/20
Preliminary design review steps 1 and 2	03/21 and 12/21
GAO review	1/22
Project confirmation	Under Review
Critical design review	Under review
Multi-Element Verification and Validation	Under review
Preliminary launch readiness date	Fiscal year 2026

NEOSurveyor

Category	Category information
Formulation start	06/20
System requirements/mission definition review	09/20
GAO review	01/22
Preliminary design review	09/22
Project confirmation	11/22
Critical design review	11/23
System integration review	01/25
Preliminary launch readiness date	02-06/26

NISAR

Category	Category information
Formulation start	03/14
System requirements/mission definition review	12/14
Preliminary design review	06/16
Project confirmation	08/16
Critical design review	10/18
System integration review	10/20
GAO review	01/22
Target launch readiness date	Under review
Committed launch readiness date	Under review

Orion

Category	Category informaton
Formulation start under Constellation program	07/06
Orion canceled under Constellation program	02/10
Formulation start	02/12
Preliminary design review	08/14
Exploration flight test	12/14
Project confirmation	09/15
Critical design review	10/15
GAO review	01/22
First uncrewed flight launch readiness date	Under review
First crewed flight target launch readiness date	03/24
First crewed flight committed launch readiness date	05/24

OSAM-1

Category	Category information
Formulation start	05/16
System requirements/mission definition review	10/16
Preliminary design review	11/17
Project confirmation	06/20
GAO review	01/22
Critical design review	02/22
System integration review	03/23
Target launch readiness date	Under review
Committed launch readiness date	Under review

PACE

Category	Category information
Formulation start	06/16
System requirements/mission definition review	01/17
Preliminary design review	06/19
Project confirmation	08/19
Critical design review	02/20
GAO review	01/22
System integration review	08/22
Target launch readiness date	01/24
Committed launch readiness date	05/24

Psyche

Category	Category information
Project selection	12/16
Project mission system review	04/18
Preliminary design review	03/19
Project confirmation	05/19
Critical design review	05/20
System integration review	12/20
GAO review	01/22
Committed launch readiness date	08/22

Roman

Category	Category information
Formulation start	02/16
System requirements/mission definition review	03/18
Preliminary design review	10/19
Project confirmation	02/20
Critical design review	09/21
GAO review	01/22
System integration review	01/25
Target launch readiness date	10/26
Committed launch readiness date	05/27

SEP

Category	Category information
Formulation start	03/15
AEPS System requirements review	05/16
AEPS Preliminary design review	08/17
PDP System requirements review	05/19
Project confirmation	02/20
PDP Preliminary design review	03/20
GAO review	01/22
AEPS Critical design review	03/22
PDP Critical design review	06/22
PDP due to PPE	05/23
AEPS qualification due to PPE	10/28

Timeline notes to include:

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

SLS 1B

Category	Category information
Formulation start	Continued from SLS Program
Preliminary design review	11/16
GAO review	01/22
Project confirmation	TBD
Critical design review	08/22
System integration review	TBD
Preliminary launch readiness date	Fiscal year 2026

SPHEREx

Category	Category information
Project selection	02/19
Project mission systems review	10/19
Preliminary design review	10/20
Project confirmation	01/21
Critical design review	01/22
GAO review	01/22
System integration review	03/23
Target launch readiness date	09/24
Committed launch readiness date	04/25

SWOT

Category	Category information
Formulation start	11/12
System requirements/mission definition review	05/14
Preliminary design review	04/16
Project confirmation	05/16
Critical design review	02/18
System integration review	03/21
GAO review	01/22
Target launch readiness date	12/22
Committed launch readiness date	06/23

VIPER

Category	Category information
Formulation start	10/19
Requirements sync review	04/20
Preliminary design review	08/20
Project confirmation	03/21
Critical design review	10/21
GAO review	01/22
System integration review	06/22
Delivery to Astrobotic	07/23
Initial operational capability	11/23

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