United States Government Accountability Office
Report to Congressional Committees

May 2021

NASA

Assessments of Major Projects

Accessible Version

A Century of Non-Partisan Fact-Based Work

GAO-21-306

GAO@100

Highlights

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

Why GAO Did This Study

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

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

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

What GAO Recommends

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

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May 2021

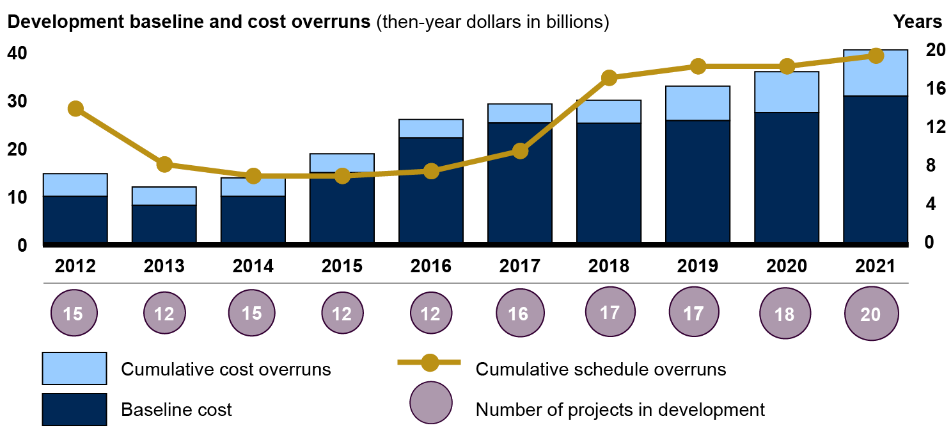
NASA

Assessments of Major Projects

What GAO Found

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

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



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

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

Year	Baseline cost	Cumulative cost overruns	Cumulative schedule overruns	Number of projects in development
2012	10147.9	4722.7	14.2	15
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

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

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

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

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

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Abbreviations

AEPS	Advanced Electric Propulsion System
AO	announcement of opportunity
ATLO	assembly, test, and launch operations
CCP	Commercial Crew Program
CDR	critical design review

CGI	Coronagraph Instrument
CLPS	Commercial Lunar Payload Services
CNES	Centre National d'Etudes Spatiales
COVID-19	Coronavirus Disease 2019
DAA	Deployable Antenna Assembly
DART	Double Asteroid Redirection Test
DRACO	Didymos Reconnaissance and Asteroid Camera for OpNav
DrACO	Drill for Acquisition of Complex Organics
DraMS	Dragonfly Mass Spectrometer
DSL	Deep Space Logistics
EGS	Exploration Ground Systems
EIS	Europa Imaging System
EPFD	Electrified Powertrain Flight Demonstration
ESA	European Space Agency
ESM	European Service Module
ESPRIT-RM	European System Providing Refueling, Infrastructure, and Telecommunications Refueler Module
EUS	Exploration Upper Stage
GERS	Gateway External Robotic System
GRNS	Gamma Ray and Neutron Spectrometer
GSLV	Geosynchronous Satellite Launch Vehicle
HALO	Habitation and Logistics Outpost
HLS	Human Landing System
i-Hab	International Habitat
I&T	integration and test
ICON	Ionospheric Connection Explorer
ICPS	Interim Cryogenic Propulsion Stage
IMAP	Interstellar Mapping and Acceleration Probe
IOC	initial operations capability
ISRO	Indian Space Research Organisation
ISS	International Space Station
JAXA	Japan Aerospace Exploration Agency
JCL	joint cost and schedule confidence level
JWST	James Webb Space Telescope
KaRIn	Ka-band Radar Interferometer
KASI	Korea Astronomy and Space Science Institute
KDP	key decision point
L9	Landsat 9
LBFD	Low Boom Flight Demonstrator
LCRD	Laser Communications Relay Demonstration
LICIACube	Light Italian CubeSat for Imaging of Asteroids
LIDAR	Light Detection and Ranging

MASPEX	MAss Spectrometer for Planetary EXploration
MDR	mission definition review
MISE	Mapping Imaging Spectrometer for Europa
ML2	Mobile Launcher 2
MPM	Multipurpose Module
NASA	National Aeronautics and Space Administration
NEO	Near Earth Object
NEOCam	NEO Camera
NEXT-C	NASA Evolutionary Xenon Thruster-Commercial
NISAR	NASA ISRO – Synthetic Aperture Radar
NPR	NASA Procedural Requirement
OCI	Ocean Color Instrument
Orion	Orion Multi-Purpose Crew Vehicle
OSAM-1	On-Orbit Servicing, Assembly and Manufacturing 1
PACE	Plankton, Aerosol, Cloud, ocean Ecosystem
PDP	Plasma Diagnostics Package
PDR	preliminary design review
PICA-D	Domestic Phenolic-Impregnated Carbon Ablator
PPE	Power and Propulsion Element
PUNCH	Polarimeter to Unify the Corona and Heliosphere
Roman	Nancy Grace Roman Space Telescope
SCaN	Space Communication and Navigation
SDO	Solar Dynamics Observatory
SDR	system definition review
SEP	Solar Electric Propulsion
SGSS	Space Network Ground Segment Sustainment
SIR	system integration review
SLS	Space Launch System
SPHEREx	Spectro-Photometer for the History of the Universe, Epoch of Re-ionization and Ices Explorer
SPIDER	SPace Infrastructure DExterous Robot
SWOT	Surface Water and Ocean Topography
TAG	Two Axis Gimbal
TDRS	Tracking and Data Relay Satellites
TRL	Technology Readiness Level
VIPER	Volatiles Investigating Polar Exploration Rover
WFI	Wide-Field Instrument
WFIRST	Wide-Field Infrared Survey Telescope
xEVA	Exploration Extravehicular Activity

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
A Century of Non-Partisan Fact-Based Work
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May 20, 2021

Congressional Committees

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

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

The explanatory statement of the House Committee on Appropriations accompanying the Omnibus Appropriations Act, 2009 included a provision for us to prepare project status reports on selected large-scale NASA programs, projects, and activities.[2] This is our 13th annual report responding to that mandate. This report assesses (1) the cost and schedule performance of NASA's portfolio of major projects, including the effects of the Coronavirus Disease 2019 (COVID-19) pandemic on the portfolio's performance; and (2) the development and maturity of technologies and progress in achieving design stability. This report also includes individual assessments of 33 of the 34 major NASA projects. When NASA determines that a project has an estimated life cycle cost of over $250 million, we include that project in our annual review through launch or completion. Accordingly, we did not complete an individual

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

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

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

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

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

[3]The Commercial Crew Program is in the implementation phase but has a tailored project life cycle and project management requirements. As a result, it was excluded from our cost and schedule performance, technology maturity, and design stability analyses. In addition, 13 projects were in an early stage of development, called formulation, where there are still unknowns about requirements, technology, and design. For those projects, we reported preliminary cost ranges and schedule estimates.

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

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

To assess the stability of project designs, we compared each project's design drawings status at the critical design review (CDR) against GAO's best practice of releasing at least 90 percent of drawings by this review.[5] We also analyzed subsequent changes in the number of design drawings. We reviewed historical data on design stability for major projects from our prior reports and compared these data to the performance of NASA's current portfolio of major projects.

To complete our project assessments, we reviewed monthly status reports, analyzed questionnaire data, and interviewed project officials to identify major sources of risk and the strategies that projects are using to mitigate them. Appendix I contains detailed information on our scope and methodology.

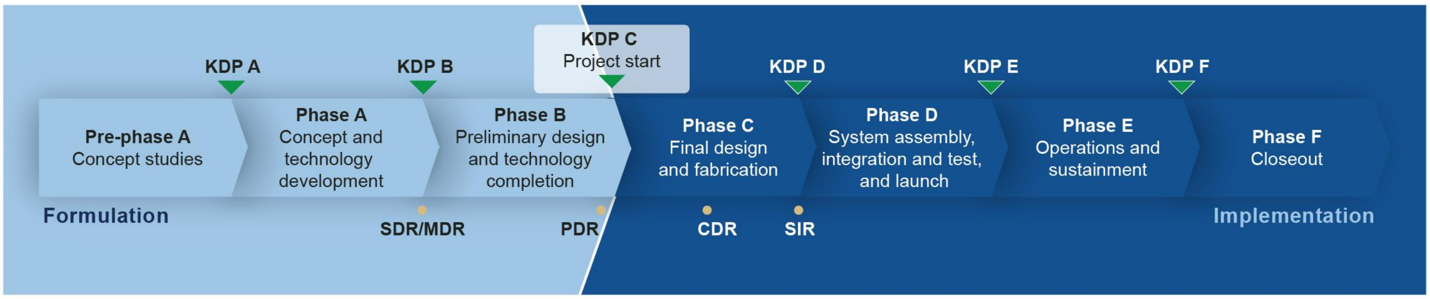
We conducted this performance audit from April 2020 to May 2021 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based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

Background

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

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

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



Management decision reviews

KDP = key decision point

Technical reviews

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

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

Project formulation consists of phases A and B, during which a project develops and defines requirements, cost and schedule estimates, and the system's design for implementation. Prior to entering phase B, a project develops a range of expected cost and schedule estimates, which are used to inform its budget planning. During phase B, the project also develops programmatic measures and technical leading indicators, which track various project metrics such as requirement changes, staffing demands, and mass and power utilization. Near the end of formulation, leading up to the PDR, the project team completes technology development and its preliminary design. Formulation culminates in a review at key decision point C, where cost and schedule baselines are established, documented, and confirmed.

After a project is confirmed, it begins implementation, consisting of phases C, D, E, and F. In this report, we refer to projects in phases C and D as being in development. A CDR is held during the latter half of phase C in order to determine if the design performs as expected and is stable enough to support proceeding with the final design and fabrication. After the CDR and just prior to beginning phase D, the project completes a system integration review to evaluate the readiness of the project and associated supporting infrastructure to begin system assembly, integration, and test. In phase D, the project performs system assembly, integration, test, and launch activities. Phases E and F consist of operations and sustainment and project closeout.

NASA Cost and Schedule Commitments

NASA's major projects have two sets of cost and schedule commitments—the management agreement and the agency baseline commitment. The management agreement can be viewed as a contract between the agency and the project manager. The project manager has the authority to manage the project within the parameters outlined in the agreement. The agency baseline commitment includes the cost and schedule baselines against which the agency's performance on a project is measured. To inform the management agreement and the agency baseline commitment, each project with a life cycle cost estimated to be greater than $250 million must also develop a joint cost and schedule confidence level (JCL) unless NASA waives the requirement. A JCL is an integrated analysis of a project's cost, schedule, risk, and uncertainty, the result of which indicates a project's likelihood of meeting a given set of cost and schedule targets.[6]

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

Table 1: Characteristics of Program Replans and Rebaselines

	Description	Potential Congressional Reporting
Replan	A replan is a process by which a program updates or modifies its plans. It generally is driven by changes in program or project cost parameters, such as if development cost growth is 15 percent or more of the estimate in the baseline report or a major milestone is delayed by 6 months or more from the baseline's date. A replan does not require a new project baseline to be established.	When the NASA Administrator determines that development cost growth is likely to exceed the development cost estimate by 15 percent or more, or a program milestone is likely to be delayed from the baseline's date by 6 months or more, NASA must submit a report to the Committee on Science, Space, and Technology of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate.[a]

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

	Description	Potential Congressional Reporting
Rebaseline	Rebaselining is the process that results in a change to the project's Agency Baseline Commitment. A rebaseline is initiated if the estimated development cost exceeds the baseline development cost estimate by 30 percent or more, or if the NASA Associate Administrator determines other events make a rebaseline appropriate.	When the NASA Administrator determines that development cost growth is likely to exceed the development cost estimate by 15 percent or more, or a program milestone is likely to be delayed from the baseline's date by 6 months or more, NASA must submit a report to the Committee on Science, Space, and Technology of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate.[a] Should a program exceed its development cost baseline by more than 30 percent, the program must be reauthorized by Congress and rebaselined in order for the contractor to continue work beyond a specified time frame.[b]

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

[a]51 U.S.C. § 30104(e)(1).

[b]51 U.S.C. § 30104(f).

Schedule and Cost Reserves for NASA Projects

The management agreement and agency baseline commitment include cost and schedule reserves held at the project and NASA headquarters levels, respectively.[7] Cost reserves are for costs that are expected to be incurred—for instance, to address project risks—but are not yet allocated to a specific part of the project. Schedule reserves are extra time in project schedules that can be allocated to specific activities, elements, and major subsystems to mitigate delays or address unforeseen risks. Project-held cost and schedule reserves are within the project manager's control. If the project requires additional time or money beyond the management agreement, NASA headquarters may allocate headquarters-held reserves, which represent the difference between the agency baseline commitment and the management agreement.

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

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

center.[8] For example, at the Goddard Space Flight Center, mission flight projects are required to hold cost reserves equal to at least 25 percent of the estimated cost remaining at the project confirmation review and 10 percent at the time of delivery to the launch site. Projects track their reserves between phases to help ensure they hold reserves consistent with these requirements.

NASA Projects Reviewed in GAO's Annual Assessment

Figure 2 includes a list of all projects included in this report. Over one-third of the projects are part of Artemis missions, which encompass NASA's efforts to return to the moon and beyond. For a list of all the projects and their current cost and schedule estimates, see appendix II. Appendix III includes a list of all the projects that we reviewed from 2009 to 2020.

[8]National Aeronautics and Space Administration, *Funded Schedule Margin and Budget Margin for Flight Projects,* Goddard Procedural Requirements 7120.7B (Sept. 17, 2018); *Marshall Space Flight Center Engineering and Program/Project Management Requirements,* Marshall Procedural Requirements 7120.1 (Oct. 20, 2016); Langley Research Center, *Space Flight Project Practices Handbook*, LPR 7120.5 B-2 (Mar. 17, 2014); and Jet Propulsion Laboratory, *Flight Project Practices*, *Rev. 8* (Oct. 6, 2010). The Kennedy Space Center and Johnson Space Center do not have center-specific guidance for reserves. The Johns Hopkins University Applied Physics Laboratory has guidelines for schedule reserves but not for cost reserves. The Johns Hopkins University Applied Physics Laboratory SD-QP-012, Rev. b, *Space Exploration Sector (SES) Quality Procedure: Earned Value Management System (EVMS) Project Management Control System (PMCS)* (Apr. 4, 2017).

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

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

● Artemis-related project

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

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

Category	Project
13 Formulation Projects	Dragonfly

Category	Project
13 Formulation Projects	Electrified Powertrain Flight Demonstration (EPFD)
13 Formulation Projects	Gateway - Deep Space Logistics (DSL)
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21 Implementation Projects	Spectro-Photometer for the History of the Universe, Epoch of Re-ionization and Ices Explorer (SPHEREx)
21 Implementation Projects	Surface Water and Ocean Topography (SWOT)
21 Implementation Projects	Mars 2020

Recent GAO Work on Selected NASA Projects

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

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

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

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

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

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

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

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

COVID-19

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

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

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

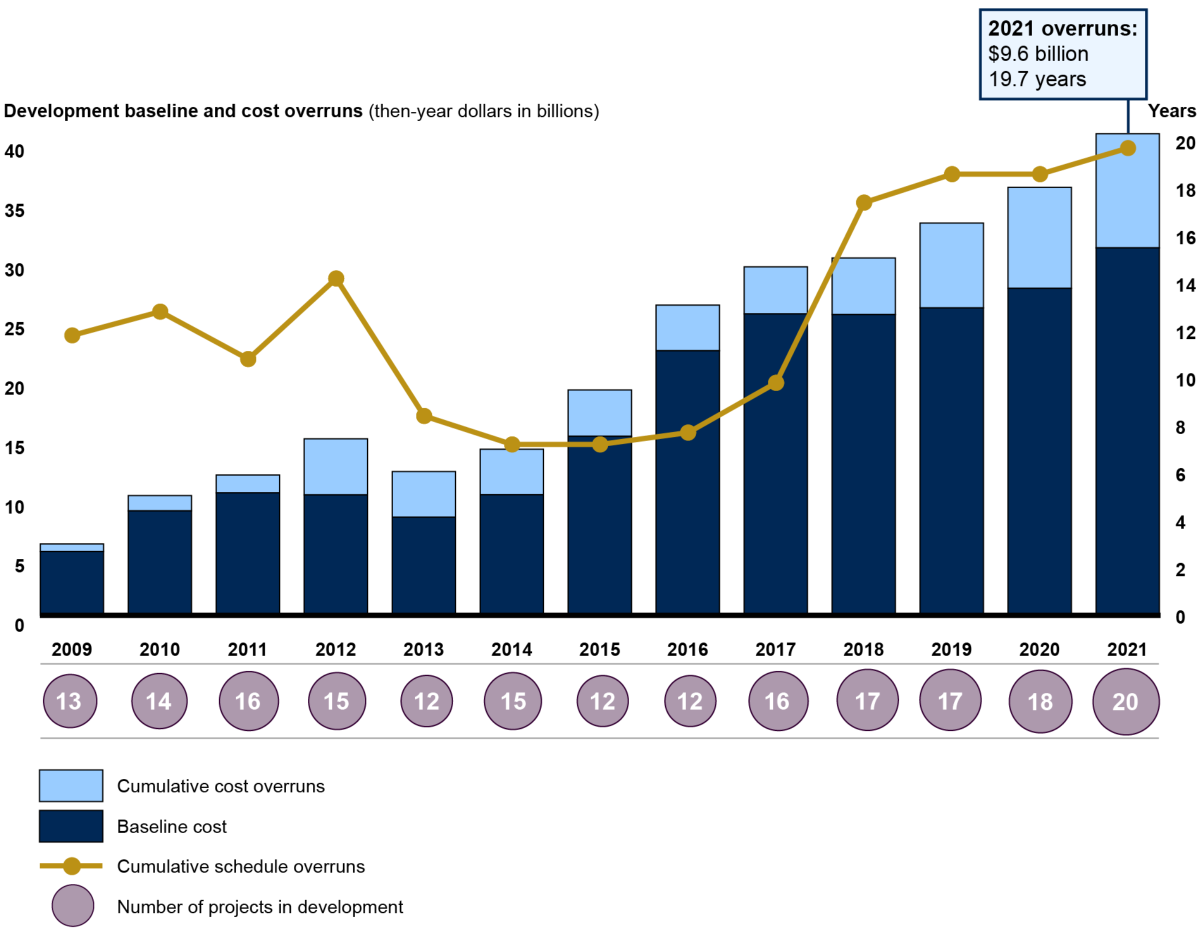
NASA's Portfolio of Major Projects in Development Continues to Face Cost Increases and Schedule Delays with Portfolio Growing

NASA is managing its largest number of major projects in development since 2009 while cost and schedule overruns continue to increase (see fig. 3). This is the fifth year in a row that cost and schedule deteriorated.

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

Specifically, total cumulative cost overruns increased from the $3.9 billion we reported in 2016 to the $9.6 billion we are reporting this year, and total cumulative schedule delays increased from 7.7 years to 19.7 years. In addition, over this same period, the number of projects in development increased from 12 to 20.

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



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

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

Year	Baseline cost	Cumulative cost overruns	Cumulative schedule overruns	Number of projects in development
2009	5372.5	643.2	11.8	13
2010	8793.4	1301.1	12.8	14
2011	10316.8	1509.2	10.8	16

Year	Baseline cost	Cumulative cost overruns	Cumulative schedule overruns	Number of projects in development
2012	10147.9	4722.7	14.2	15
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

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

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

Table 2 shows the cumulative cost and schedule changes for NASA's major projects in development as measured from their original baseline approved at their project confirmation review. It highlights the projects

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

anticipating no change in cost or a lower cost than originally baselined, as well as those estimating cost increases and schedule delays.

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

na	na	na	Changes from original baseline to current assessment	Changes from original baseline to current assessment	Changes from original baseline to current assessment
Cumulative performance status	**Project(s)**	**Baseline development cost estimate (millions of dollars)**	**Schedule delay (months)**	**Cost overrun (millions of dollars)**	**Percent cost growth**
No variance expected from cost or schedule baselines	DART; OSAM-1; PACE; Roman; SEP[a]; SPHEREx; and SWOT[a]	5,784.0 (total)	0	0.0	0.0
Lower than expected cost	Landsat 9	634.2	0	(46.5)	-7.3
Lower than expected cost	Psyche	681.9	0	(38.8)	-5.7
Lower than expected cost	Europa Clipper[a]	2,412.8	0	(66.0)	-2.7
Lower than expected cost	Lucy	622.2	0	(8.0)	-1.3
Higher than expected cost	NISAR[a]	661.0	0	58.6	8.9
Higher than expected cost	Orion	6,768.4	4	887.6	13.1
Higher than expected cost	LBFD	467.7	5	64.5	13.8
Higher than expected cost	Mars 2020	1,676.9	0	356.2	21.2
Higher than expected cost	EGS	1,843.5	36	652.8	35.4
Higher than expected cost	LCRD[a]	91.8	19	36.8	40.1
Higher than expected cost	SLS	6,390.0	36	2,718.3	42.5
Higher than expected cost	SGSS	368.1	48	589.2	160.1
Higher than expected cost	JWST	2,581.1	88	4,421.0	171.3
Totals		**30,983.6**	**236**	**9,625.7**	**31.1**

Legend: DART: Double Asteroid Redirection Test; OSAM-1: On-Orbit Servicing, Assembly and Manufacturing 1; PACE: Plankton, Aerosol, Cloud, ocean Ecosystem; Roman: Nancy Grace Roman Space Telescope; SEP: Solar Electric Propulsion; SPHEREx: Spectro-Photometer for the History of the Universe, Epoch of Re-ionization and Ices Explorer; SWOT: Surface Water and Ocean Topography; NISAR: NASA Indian Space Research Organisation

- Synthetic Aperture Radar; Orion: Orion Multi-Purpose Crew Vehicle; LBFD: Low Boom Flight Demonstrator; EGS: Exploration Ground Systems; LCRD: Laser Communications Relay Demonstration; SLS: Space Launch System; SGSS: Space Network Ground Segment Sustainment; JWST: James Webb Space Telescope.

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

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

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

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

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

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

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

[15]GAO-20-405.

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

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

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

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

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

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

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

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

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

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

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

- The LBFD project reported that its development costs grew by $64.5 million, and the project was delayed by 5 months primarily because of the contractor's delayed design drawings releases and its quality issues with supplier deliveries. According to NASA documentation, the

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

revised estimates also reflect the effect of contractor facility shutdowns due to COVID-19.

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

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

- The JWST project is now planning to launch in October 2021, which is an additional 7 months in delays since our last annual assessment primarily because of test schedule risks that were occurring before the pandemic.[17] The pandemic began while the project was analyzing its schedule, and, according to NASA documentation, approximately 2.5 months in COVID-19 delays were incorporated into the 7-month delay. The project estimates it has sufficient cost reserves to accommodate the delay. In addition, the project also moved some estimated funding originally set aside for development to operations.
- Orion program officials estimate that the project's launch readiness date will be delayed by 4 months because of delays to the Artemis I mission and production issues for the Artemis II spacecraft. Orion is baselined to the Artemis II mission, but any delay to Artemis I will affect the timing of the Artemis II mission due to Orion spacecraft work

[17] GAO-20-405.

that is planned to occur between these two missions. The 4-month delay also incorporated some pandemic-related delays to the European Service Module for Artemis II. The project currently estimates $30.6 million less in development costs than last year's estimate, which officials told us was due to some accounting adjustments, but the project's total estimated costs still exceed its baseline by over $887 million.

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

- The Europa Clipper project's latest development estimate is $66 million below its development cost baseline because the project moved some estimated development funding into its operations phase. Officials said this change was made to accommodate a longer flight time to get to Europa that is associated with a commercial launch vehicle.
- The Landsat 9 project's mature flight hardware, progress toward deliveries, and low-risk posture led NASA to reduce the project's available headquarters-held cost reserves by $46.5 million in May 2020. As a result, NASA is now estimating that the project will complete development at a lower cost than its original baseline. According to project documentation, COVID-19 effects were not reflected in the decision to reduce the project's available cost reserves.
- The Mars 2020 Perseverance Rover launched on schedule in July 2020 with its latest cost estimates falling slightly below what we reported last year. According to officials, this change moved estimated funding for selected development activities, such as testing of the system used to collect samples from the surface of Mars, to the operations and sustainment phase. While the project had to incorporate schedule work-arounds and had increased costs to maintain schedule because of the pandemic, the project was able to accommodate COVID-19 effects on development costs within its reserves.
- The Psyche project reported $38.8 million less in development costs due to the launch vehicle procurement cost being less than the original estimate when NASA approved the project's cost and schedule baseline.

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

COVID-19 Will Continue to Affect Cost and Schedule Performance

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

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

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

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

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

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

The information below provides additional detail.

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

- The Double Asteroid Redirection Test (DART) project was tracking cost risks prior to COVID-19 that the pandemic exacerbated. In February 2021, the project delayed its internal launch date by at least 4 months due in part to technical challenges associated with its navigation imager, which needs to be reinforced to ensure it withstands the stress of launch, and supply chain issues with the solar arrays. According to NASA, while COVID-19 was not the sole factor for the delay, it has been a significant and critically contributing factor because of reduced staff availability and the supply chain effects. The project is at risk of exceeding its cost baseline as a result of these delays.
- The NISAR project began reviewing its cost and schedule prior to COVID-19, and the pandemic has exacerbated cost and schedule concerns. The project began reviewing its cost and schedule because ISRO delayed the delivery of its radar due to delayed hardware deliveries. Since then, the pandemic and technical issues with a NASA-provided radar caused further delays. The project will seek approval from NASA for new cost and schedule estimates when the project enters the system assembly, integration and test, and launch phase in spring 2021. According to officials, the plan that the project submitted for approval exceeds the project's cost and schedule baselines and incorporates COVID-19 effects such as delays from facility closures.
- The Orion program will complete an updated joint cost and schedule confidence level analysis at its fall 2021 key decision point D review—which initiates the system assembly, integration and test, and launch phases—because its development costs have increased by more than 5 percent. Project officials told us that they expect to have to rebaseline the project to incorporate additional scope. At that time, they also plan to assess and incorporate effects from COVID-19.
- PACE was not tracking cost and schedule concerns prior to the pandemic, having just set baselines in fiscal year 2019, but COVID-19 costs and delays now threaten the project's baseline. PACE used the entirety of its cost reserves since the pandemic began to mitigate

COVID-19-related schedule delays such as a 5-month delay to a Netherlands Space Office-contributed instrument and project officials' inability to access NASA facilities to work on hardware. As of January 2021, the project estimated that any additional cost reserves needed to accommodate further delays would cause the project to exceed its cost baseline.

- The Surface Water Ocean Topography (SWOT) project tracked cost and schedule problems prior to COVID-19 that the pandemic exacerbated. SWOT used most of its cost and schedule reserves to mitigate instrument delivery delays prior to the pandemic and, as a result, did not have sufficient reserves to cover additional delays related to COVID-19. For example, the pandemic resulted in facility shutdowns and other inefficiencies, such as an inability to conduct on-site testing with the project's international partner. As of January 2021, SWOT was in the process of reviewing its baselines.

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

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

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

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

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

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

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

NASA has not received any additional appropriations related specifically to COVID-19.

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

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

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

Correctly identifying and selecting critical technologies can prevent waste of valuable resources—funds and schedule—later in an acquisition project.[20] Further, there can be an underrepresentation of technical risk if all critical technologies are not identified for a project.[21] The 19 projects in the current portfolio that were in development as of January 2021—

[19]GAO-20-48G.

[20]Technologies are considered critical if they are new or novel, or used in a new or novel way, and needed for a system to meet its operational performance requirements within defined cost and schedule parameters (i.e., cost and schedule targets set at key decision point B or C). Technologies identified as critical may change as programmatic or mission-related changes occur, system requirements are revised, or if technologies do not mature as planned. These critical technologies should be defined at a testable level, including any software needed to demonstrate their functionality, using a work breakdown structure or similar approach. In addition, a heritage technology can become critical if it is being used in a new or novel way where the form, fit, or function is changed; the environment to which it will be exposed in its new application is different than those for which it was originally qualified; or process changes have been made in its manufacture.

[21]GAO-20-48G.

meaning the project held both a PDR and a confirmation review—reported an average of 3.9 critical technologies.[22] This is an increase from last year, when projects reported an average of 2.1 critical technologies. The current portfolio of projects identifying critical technologies reflects the addition of two projects, Roman and SPHEREx, which collectively identified 10 critical technologies, and the removal of the Ionospheric Connection Explorer (ICON), which launched in 2019.

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

This year, we updated our critical technology definition to align with GAO's January 2020 Technology Readiness Assessment Guide, which states that heritage technologies being used in a new or novel manner should be considered critical technologies.[23] As part of this update, we stopped collecting information on heritage technologies unless projects identified them as critical. As a result of our changed methodology, several projects identified technologies as critical this year that they previously classified as heritage (and not critical). For example, the Europa Clipper and On Orbit Assembly and Manufacturing 1 (OSAM-1) projects identified a total of 16 technologies across both projects as critical this year that in prior years they classified as heritage.[24]

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

[23]GAO-20-48G.

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

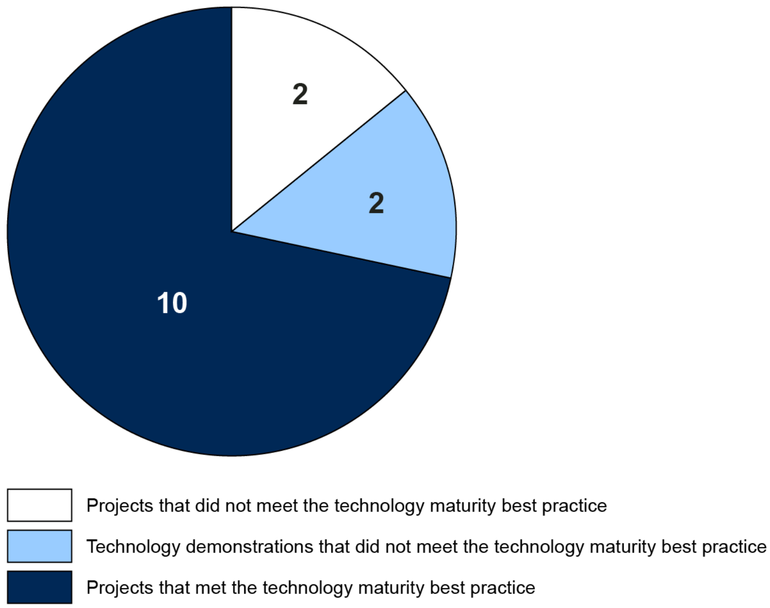
Further, according to GAO's Technology Readiness Assessment Guide, a program identifying and maturing its critical technologies by PDR to a Technology Readiness Level (TRL) 6—which includes demonstrating a representative prototype of the technology in a relevant environment that simulates the harsh conditions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

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

[25]GAO-20-48G.

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

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



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

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

Category	Category total
Projects that did not meet the technology maturity best practice	2
Technology demonstrations that did not meet the technology maturity best practice	2
Projects that met the technology maturity best practice	10

Note: This includes projects that completed preliminary design review and identified critical technologies. We included two technology demonstration missions in our analysis—the Laser Communication Relay Demonstration and On-Orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1) projects—because officials had told us that, while these technology demonstration missions are not required to mature technologies before launch, both of these projects intended to do so. We did not include OSAM-1's technologies related to the SPace Infrastructure DExtrous Robot (SPIDER) because they were added after the project's preliminary design review.

The two projects that did not meet the technology maturity best practice are Mars 2020 and the Nancy Grace Roman Space Telescope (Roman), which we previously reported held PDR with immature technologies.[27] Two other projects, LCRD and OSAM-1, are defined as technology demonstrations and did not meet the best practice. As we have previously reported, NASA's view is that these projects should not be included in the analysis because the purpose of technology demonstration missions is to demonstrate the maturity of new technologies during operations.[28] However, we included technologies from these projects because both projects planned to mature the technologies prior to launch, making the project susceptible to the same risks projects might experience if they fall short of the best practice. Two projects that held PDR and also identified critical technologies were added to our analysis this year—SPHEREx and VIPER. Both projects met the best practice and matured all of their reported critical technologies to TRL 6.

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

In June 2020, NASA published a Technology Readiness Assessment Best Practices Guide that aligns with GAO's definition of critical technologies.[29] This guide was published as part of the agency's

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

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

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

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

Number of Projects Meeting Design Stability Best Practice Remains Low

The number of projects with stable designs at critical design review (CDR) remains low. A CDR is the time in a project's life cycle when the integrity of the project design and its ability to meet mission requirements are assessed. Our work in the area of product development has shown that releasing at least 90 percent of engineering drawings by CDR lowers the risk of projects experiencing design changes and manufacturing problems that can lead to cost and schedule growth.[31] Engineering drawings are considered to be a good measure of the demonstrated stability of a product's design because the drawings represent the language used by engineers to communicate to the manufacturers the details of a new product design—what it looks like, how its components interface, how it functions, how to build it, and what critical materials and processes are required for fabrication and testing. Once the design of a product is finalized, the drawing is "releasable" to manufacturers.

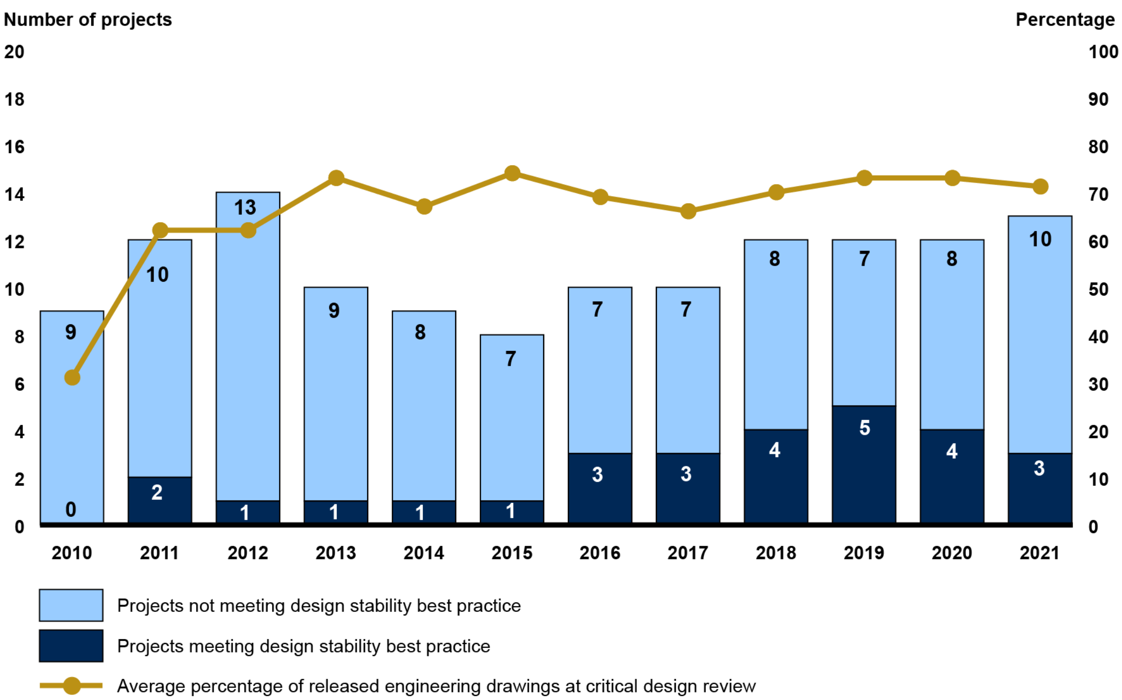
Of the 13 projects we reviewed that held CDR as of January 2021, three projects met the best practice of releasing 90 percent of design drawings by CDR, which is similar to recent years. The average percentage of

[30] GAO-21-119SP.

[31] GAO-02-701.

drawings releasable at CDR is 71.2 percent, a 2-percent decrease from last year (see fig. 5).

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



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

Accessible Data for Figure 5: NASA's Major Projects Performance 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
2010	0	9	31
2011	2	10	62
2012	1	13	62
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

Year	Projects meeting design stability best practice	Projects not meeting design stability best practice	Average percentage of released engineering drawings at critical design review
2020	4	8	73
2021	3	10	71.2

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

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

- Psyche did not use engineering drawings as a metric of design stability and was excluded from this analysis. Psyche officials explained that Psyche is a heritage design, and that the project assesses its design through detailed technical peer reviews of each system by subject matter experts.
- PACE held its CDR in February 2020 and did not meet the best practice, having released 61 percent of design drawings at that time. Project officials said they were able to focus on engineering drawings during COVID-19 while they were required to work remotely and could not physically access labs and other facilities needed to complete work on hardware. Within 11 months of CDR, the project released 99 percent of its drawings.
- Europa Clipper held its CDR in December 2020 and did not meet the best practice, having released 81.5 percent of design drawings at that time. According to officials, the bulk of the remaining drawings are assembly drawings and support equipment drawings that are used for integration and have maturity schedules later than the project's CDR. Some remaining drawings are associated with the previous uncertainty of the project's launch vehicle. Officials said they expect the rate of release to pick up as subsystems and instruments transition to their flight build over the next several months.

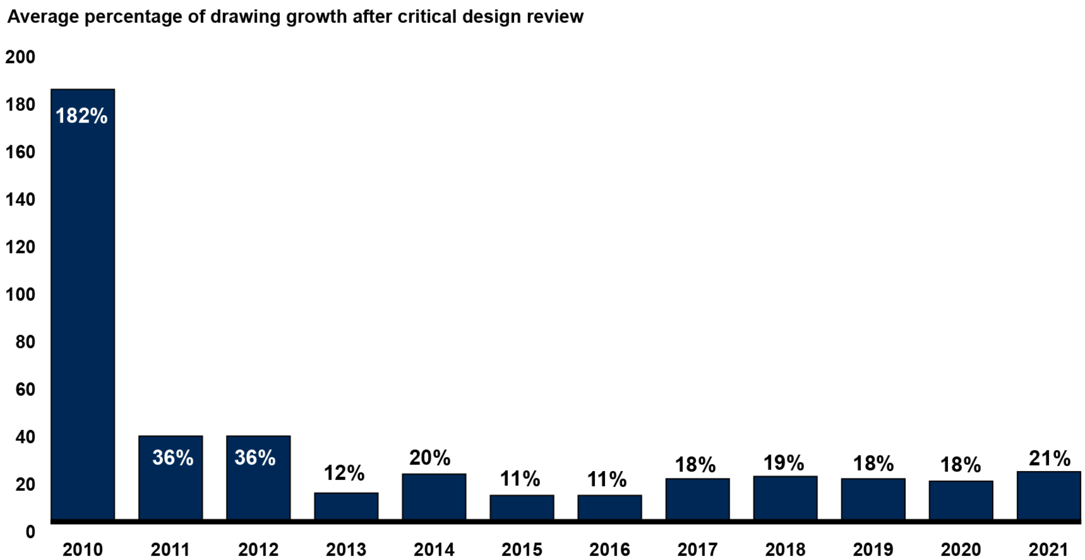
Since we last reported, we have seen poor outcomes for a project that did not meet the design stability best practice. We reported last year that the LBFD project held CDR in September 2019 with 37 percent of drawings released.[32] Since our report, the project increased its estimated cost by $74.7 million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

Design drawing growth after CDR has also generally remained steady since 2017, fluctuating between 18 and 21 percent (see fig. 6).[33] Experiencing a large amount of design drawing growth after CDR may be an indicator of instability in a project's design late in the development cycle. Design changes at this point can be costly to the project in terms of time and funding because hardware may need to be reengineered or reworked as a result. This year, 10 of 13 projects experienced drawing growth, which is one more than last year. This change is because of the launch of ICON, which had no drawing growth, and the addition of Europa Clipper and PACE to the analysis. Europa Clipper has not had drawing growth in the month since the project's CDR, but PACE experienced 37 percent drawing growth in the 11 months after CDR. The project's CDR occurred just before the start of the pandemic, and, as discussed above, project officials attributed the drawing growth to an increased focus on design maturity during the COVID-19 remote work environment while project officials were unable to work on hardware.

[32] GAO-20-405.

[33] Design drawing growth is measured as the number of design drawings projects expected at their respective critical design reviews compared to the updated number of design drawings projects expected as reported in data received by GAO each year.

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



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

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

Year	Average percentage of drawing growth after critical design review
2010	182
2011	36
2012	36
2013	12
2014	20
2015	11
2016	11
2017	18
2018	19
2019	18
2020	17
2021	21

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

As we previously reported, NASA officials raised concerns about our use of the engineering drawing best practice to assess design stability because they raised questions about its applicability for modern NASA projects.[34] We reported last year that there are a variety of potential tools—design drawings, mass and power margins, growth in requirements, and schedule performance—to measure design stability and no clear consensus on the topic within NASA.[35] NASA's Corrective Action Plan included an initiative to identify indicators that will advance NASA's ability to detect emerging issues that may affect a project's implementation. In December 2019, NASA reported that the research did not identify a "silver bullet" predictive metric or set of metrics. The study collected over 100 potential indicators, including drawing count metrics, and concluded that metrics work cohesively. One of the recommendations from the study was that NASA create a catalog of metrics to provide options from which projects can choose. In January 2021, NASA published this document titled "NASA Common Leading Indicators Detailed Reference Guide."

We recently started a body of work to update our best practices for product development. We anticipate that an important component of this work will be to identify current leading practices that facilitate design stability. We will continue to collaborate with NASA as we conduct this work, including leveraging information in the leading indicators guide, as appropriate. In the meantime, the design drawing metric remains a useful indicator. We continue to use engineering design drawings released by CDR because this metric can be applied commonly across most of NASA's portfolio of major projects and because it was among several metrics identified by a panel of experts—including former NASA officials—convened by the National Academy of Sciences for GAO in 2013.

Project Assessments

In the following section, we present the individual assessments of the 33 projects and one capability upgrade within a project that we reviewed in a

[34] GAO-19-262SP.

[35] GAO-20-405.

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

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

Figure 7: Illustration of a Sample Project Assessment

A B H C D E F G I

Double Asteroid Redirection Test

The DART project plans to travel to the near-Earth asteroid Didymos, a binary system, and impact the smaller of the two bodies. NASA will assess the deflection result of the impact for possible future use on other potentially hazardous near-Earth objects. The project stems from the NASA Authorization Act of 2008 and responds to near-Earth object guidance by the Office of Science and Technology Policy. The purpose of the project is to better understand our impact mitigation posture, and to respond to a recommendation by the National Research Council Committee to conduct a test of a kinetic impactor. The DART mission is part of the Asteroid Impact and Deflection Assessment, a collaboration with the European Space Agency and the Italian Space Agency.

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

FORMULATION: 02/16 Formulation start; 09/16 System requirements/ mission definition review; 04/18 Preliminary design review; 08/18 Project confirmation
IMPLEMENTATION: 06/19 Critical design review; 03/20 Integration and test readiness review; **01/21 GAO review**; 11/21 Target launch readiness date; 02/22 Committed launch readiness date

PROJECT INFORMATION

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

International Partners: **Italian Space Agency**

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

Launch Vehicle: **Falcon 9**

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

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

Budget Portfolio: **Science, Planetary Science**

PROJECT SUMMARY

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

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

DOUBLE ASTEROID REDIRECTION TEST

Cost and Schedule Status

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

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

Integration and Testing

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

International Partner

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

PROJECT OFFICE COMMENTS

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

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

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

B General description of the mission's objectives.

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

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

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

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

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

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

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

Source: GAO analysis. | GAO-21-306

Accessible Data for Figure 7: Illustration of a Sample Project Assessment

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

Assessments of Artemis Major Projects in the Formulation Phase

Infographic of Major NASA Projects and Programs Supporting Artemis Missions

Gateway – Exploration Extravehicular Activity (xEVA)

Gateway – Habitation and Logistics Outpost (HALO)

Gateway – Power and Propulsion Element (PPE)

Space Launch System Block 1B (SLS Block 1B)

Volatiles Investigating Polar Exploration Rover (VIPER)

Assessments of Artemis Major Projects in the Implementation Phase

Orion Multi-Purpose Crew Vehicle (Orion) and Docking System

Assessments of Other NASA Major Projects in the Formulation Phase

Electrified Powertrain Flight Demonstration (EPFD)

Interstellar Mapping and Acceleration Probe (IMAP)

Polarimeter to Unify the Corona and Heliosphere (PUNCH)

Letter

Assessments of Other NASA Major Projects in the Implementation Phase

Laser Communications Relay Demonstration (LCRD)

Nancy Grace Roman Space Telescope (Roman)

NASA ISRO – Synthetic Aperture Radar (NISAR)

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

Plankton, Aerosol, Cloud, ocean Ecosystem (PACE)

Space Network Ground Segment Sustainment (SGSS)

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

Agency Comments

We provided a draft of this report to NASA for comment. In written comments, NASA generally agreed with the findings of the report. The comments are reprinted in appendix V. NASA also provided technical comments, which have been addressed in the report, as appropriate.

We are sending copies of the report to the NASA Administrator and interested congressional committees. In addition, the report will be available at no charge on GAO's website at http://www.gao.gov.

If you or your staff have any questions about this report, please contact me at (202) 512-4841 or RussellW@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made major contributions to this report are listed in appendix VI.

W. William Russell
Director, Contracting and National Security Acquisitions

List of Committees

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

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

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

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

Appendix I: Objectives, Scope, and Methodology

This is our 13th annual report assessing selected large-scale National Aeronautics and Space Administration (NASA) programs, projects, and activities. When NASA determines that a project has an estimated life-cycle cost of over $250 million, we include that project in our annual review up through launch or completion. We did not include projects that held key decision point (KDP) A or its equivalent after December 1, 2020, in this report. The objectives of our review were to assess (1) the cost and schedule performance of NASA's portfolio of major projects, including the effect of the Coronavirus Disease 2019 (COVID-19) pandemic on the portfolio's performance; and (2) the development and maturity of technologies and progress in achieving design stability. We also described the status and assessed the risks and challenges faced by 33 of the 34 NASA major projects. We did not complete an individual assessment for one project, Mars 2020, which launched during our review in July 2020, but included data from this project in other analyses, as appropriate. We also included an assessment of the Orion Docking System, which is a capability upgrade within the Orion program for which NASA does not plan to establish a separate baseline.

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

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

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

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

To assess technology maturity, we used questionnaire data that provided the technology readiness levels (TRL) of each of the project's critical technologies at various stages of project development, including at the preliminary design review (PDR). Originally developed by NASA, TRLs are measured on a scale of one to nine, beginning with paper studies of a technology's feasibility and culminating with a technology fully integrated into a completed product. See appendix IV for the definitions of TRLs. Due to changes in our methodology surrounding how projects reported critical technologies, we did not compare this year's results against those in prior years.

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

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

For the 14 projects that identified critical technologies and held their PDR, we compared the TRLs of those projects' reported critical technologies against our technology maturity best practice to determine the extent to which these projects were meeting the best practice. Our best practices work has shown that reaching a TRL 6—which indicates that the

[1] GAO-20-48G.

representative prototype of the technology has been demonstrated in a relevant environment that simulates the harsh conditions of space—by the PDR is the level of maturity needed to minimize risks for space systems entering product development.[2] We did not assess technology maturity for those projects that had not yet reached the PDR at the time of this assessment or for projects that reported no critical technologies.

Our analysis of technology maturity included two technology demonstration projects: the Laser Communication Relay Demonstration (LCRD) and On-orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1) projects. The Mission Directorate in charge of technology demonstration projects policy does not require technology demonstrations to mature all of their technologies to TRL 6 by PDR.[3] NASA officials explained that this is because the purpose of some technology demonstration projects is to mature new technologies to TRL 6 or higher by the end of the demonstration, making it infeasible for these projects to achieve this level of maturity by PDR. However, we included LCRD and OSAM-1 in our analysis because they planned to mature their technologies prior to launching or reaching completion. Therefore, the same risks of subsequent technical problems that can result in cost growth and schedule delays identified in our best practices work apply to these projects. We did not include technologies in this analysis that were added after the project's PDR; in the case of OSAM-1, that includes all technologies related to the SPace Infrastructure DExterous Robot (SPIDER). We excluded two other technology demonstrations from this analysis—Solar Electric Propulsion and Low Boom Flight Demonstrator—because NASA does not plan to mature these technologies before operations or qualification testing.

To assess design stability, we reviewed 13 projects that had held a critical design review (CDR) and reported data on design drawings. We reviewed questionnaire data on the number of engineering drawings completed or projected for release by the project's CDR and as of our current

[2] GAO-20-48G.

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

assessment.[4] We took steps to assess the reliability of the project office-supplied data on the number of released and expected engineering drawings. For example, we collected the project offices' rationales for cases where it appeared that only a small percentage of the expected drawings were completed by the time of the design review or where the project office reported significant growth in the number of drawings released after the critical design review. In accordance with GAO's best practice, projects were assessed as having achieved design stability if at least 90 percent of projected drawings were released by the CDR.[5] We compared this year's results against those in prior years to assess whether NASA was improving in this area. We did not assess the design stability for those projects that had not yet reached the CDR at the time of this assessment.

Project Profile Information on Each Individual Project Assessment

This year, we developed individual project assessments for 33 projects with an estimated life-cycle cost greater than $250 million and one capability upgrade planned for Orion. We did not complete individual assessments for projects that launched during our review. For each project assessment, we included a description of each project's objectives; information concerning the NASA center and international partners involved in the project, if applicable; the project's cost and schedule performance, when available; key project dates; and a brief narrative describing the current status of the project. We also provided a detailed discussion of project challenges for selected projects, as applicable.

To assess the cost and schedule changes of each project, we either obtained data directly from NASA's Office of the Chief Financial Officer through our questionnaire or used preliminary estimates provided in project documentation. We had NASA confirm that preliminary estimates remained accurate as of January 2021 as part of the agency's review of

[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-02-701.

project assessments. For the Commercial Crew Program and the Space Network Ground Segment Sustainment project, we obtained current cost and schedule data directly from the program. When applicable, we compared the level of cost and schedule reserves held by the project to the level required by center policy.

To assess project time frames, we tracked acquisition cycle times as well as key milestone events in the life of the project. Acquisition cycle time is defined as the number of months between the project's start, or formulation start, and the projected or actual launch date. Formulation start generally refers to the initiation of a project; NASA refers to a project's start as KDP A or the beginning of the formulation phase. Projects selected as a result of a one-step announcement of opportunity (AO) enter formulation at KDP A. Projects selected as a result of a two-step AO process perform a concept development study and go through evaluation for down-selection, which serves as KDP B. The end of the acquisition cycle is the projected or actual launch date. The committed launch readiness date is determined through a launch readiness review that verifies that the launch system, spacecraft, and payloads are ready for launch. The implementation phase includes the operations of the mission and generally concludes with project disposal.

Project Challenges Discussion on Each Individual Project Assessment

To assess the status, risk, and challenges for each project, we submitted a questionnaire to each project office. In the questionnaire, we requested information on the maturity of critical technologies, the number of releasable design drawings at project milestones, and international partnerships.[6] GAO also held interviews with representatives from all of the projects across multiple NASA centers to discuss the information on the questionnaire. We then reviewed project documentation—including monthly status reports, project plans, schedules, risk assessments, and major project review documentation—to corroborate any testimonial evidence we received in the interviews. These reviews led to identification of further challenges faced by NASA projects. The second page of our project assessments highlights key challenges that have affected that project or could affect project performance. For this year's report, we identified challenges across the projects we reviewed in the categories of

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

cost and schedule, COVID-19, design, integration and test, launch, software, spacecraft, and technology. These challenges do not represent an exhaustive or exclusive list and are based on our definitions and assessments, not those of NASA.

Data Limitations

NASA provided preliminary estimated life-cycle cost ranges and associated schedules—which are generally established at KDP B—for three projects that had not yet entered implementation, one of which is under review. For the other 10 projects in formulation, NASA has not yet established preliminary cost estimates. NASA explained that preliminary estimates are generated for internal planning and fiscal year budgeting purposes at KDP B, which occurs midstream in the formulation phase, and, hence, are not considered a formal commitment by the agency on cost and schedule for the mission deliverables. NASA formally establishes cost and schedule baselines, committing itself to cost and schedule targets for a project with a specific and aligned set of planned mission objectives at KDP C, which follows a PDR. KDP C reflects the life-cycle point where NASA approves a project to leave the formulation phase and enter into the implementation phase. Due to changes that occur to a project's scope and technologies between KDP B and KDP C, the estimates of project cost and schedule can be significantly altered between the two KDPs.

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

Appendix II: Estimated Costs and Launch Dates for Major NASA Projects Assessed in GAO's 2021 Report

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

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

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

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

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

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

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

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

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

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

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

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

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

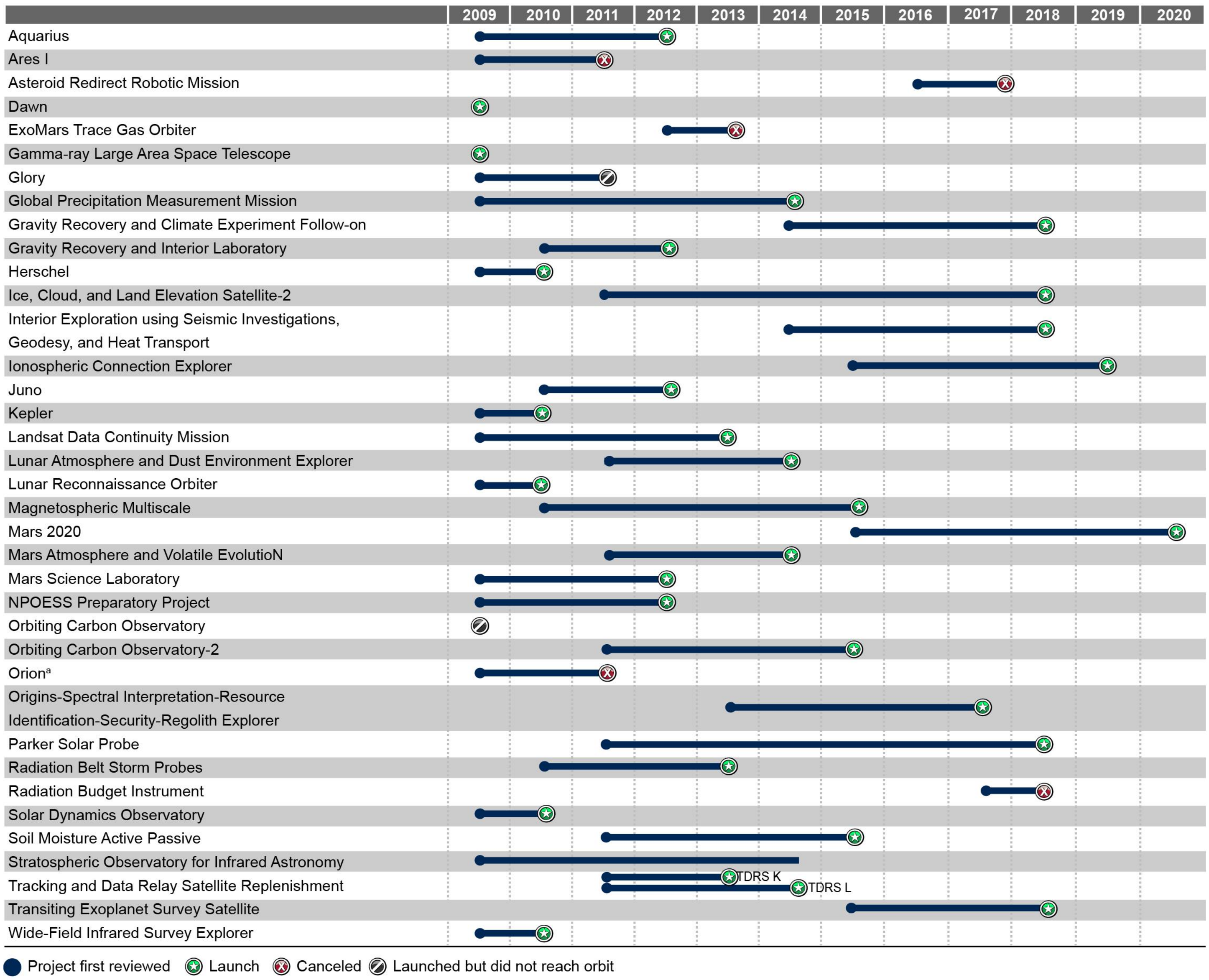
[c]The LBFD project does not have a launch readiness date but has an equivalent first flight event that marks the end of development.

[d]In 2016, NASA reclassified SGSS as a hybrid sustainment effort, rather than a major project. A hybrid sustainment effort still includes development work. As a result, we continue to include SGSS in our assessment. SGSS is a ground system that does not have a launch readiness date, but this date represents the end of the period of performance for the contract as part of the planned transition to the Space Communication and Navigation program.

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

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

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



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

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

Appendix IV: Technology Readiness Levels

Table 7: NASA Hardware Technology Readiness Levels (TRL)

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

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

Table 8: NASA Software Technology Readiness Levels (TRL)

TRL	Definition	Software description
1	Basic principles observed and reported.	Scientific knowledge is generated, underpinning basic properties of software architecture and mathematical formulation.
2	Technology concept and/or application formulated.	Practical application is identified but speculative, and no experimental proof or detailed analysis is available to support the conjecture. Basic properties of algorithms, representations, and concepts defined. Basic principles are coded, and experiments are performed with synthetic data.
3	Analytical and experimental proof-of-concept of critical function and/or characteristics.	Development of limited functionality to validate critical properties and predictions using non-integrated software components occurs.
4	Component and/or breadboard validation in a laboratory environment.	Key, functionality critical software components are integrated and functionally validated to establish interoperability and begin architecture development. Relevant environments are defined and performance in the environment predicted.
5	Component and/or brassboard validated in a relevant environment.	End-to-end software elements implemented and interfaced with existing systems/simulations conforming to target environment. End-to-end software system tested in relevant environment, meeting predicted performance. Operational environment performance predicted.
6	System/sub-system model or prototype demonstration in a relevant environment.	Prototype implementations of the software demonstrated on full-scale, realistic problems. Partially integrated with existing hardware/software systems. Limited documentation available. Engineering feasibility fully demonstrated.
7	System prototype demonstration in an operational environment.	Prototype software exists having all key functionality available for demonstration and test. Well integrated with operational hardware/software systems demonstrating operational feasibility. Most software bugs removed. Limited documentation available.
8	Actual system completed and “flight qualified” through test and demonstration.	All software has been thoroughly debugged and fully integrated with all operational hardware and software systems. All user documentation, training documentation, and maintenance documentation completed. All functionality successfully demonstrated in simulated operational scenarios. Verification and Validation completed.
9	Actual system flight proven through successful mission operations.	All software has been thoroughly debugged and fully integrated with all operational hardware and software systems. All documentation has been completed. Sustaining software support is in place. System has been successfully operated in the operational environment.

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

Appendix V: Comments from the National Aeronautics and Space Administration

National Aeronautics and
Space Administration

Office of the Administrator
Washington, DC 20546-0001

April 30, 2021

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

Dear Mr. Russell:

The National Aeronautics and Space Administration (NASA) appreciates the opportunity to comment on the Government Accountability Office (GAO) draft report entitled: "NASA: Assessments of Major Projects" (GAO-21-306).

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

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

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

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

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

NASA recognizes the inherent challenges in managing large, complex space flight and aeronautical programs that are uniquely designed to expand the boundaries of science and technology and achieve unprecedented capabilities and accomplishments. Therefore, NASA has accordingly worked over many years to improve policies and procedures that control cost and schedule while ensuring mission success. NASA has made substantial progress in the implementation of its High-Risk Corrective Action Plan (CAP), having completed six initiatives since its establishment in December 2018. In 2020, NASA renewed its CAP in response to GAO's continued designation of NASA's acquisition management practices on its High-Risk List. This renewed CAP contains four new initiatives, in addition to two already in progress from the 2018 plan. These initiatives are designed to strengthen the Agency's cutting-edge program and project management efforts and to improve transparency for NASA's stakeholders. NASA is pleased to see GAO's recognition of our progress in this High-Risk area in the most recent High-Risk Report published in March 2021. NASA further appreciates the GAO's recognition of these initiatives in the Quick Look assessment and will continue to provide the GAO with updates on our progress against the CAP, as successful implementation will contribute to improved programmatic performance across the Agency in the years ahead.

NASA appreciates the GAO evaluation of the Artemis programs during their formulation and development to send the first woman and next man to the surface of the Moon. These programs have made significant progress toward the ambitious goal set before them. Considering the FY 2021 Appropriations funding for Exploration Research & Development was less than half of the requested funding, the Gateway and HLS Programs are rapidly aligning their plans to the available FY 2021 budget and the implication of this appropriation on future year budgets. We encourage GAO to consider the anticipated impact of this reduced funding as it evaluates and provides recommendations to the audited programs. Preliminary estimates on milestone dates, reviews, and launch are directly linked to multi-year funding profiles. Changes to multi-year funding profiles can cause schedule changes that are unrelated to performance or technical issues. NASA thanks the GAO for this consideration during this dynamic period for Artemis.

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

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

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

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

NASA greatly appreciates the ongoing dialogue with the GAO on this critical engagement and is committed to working jointly to address any questions or concerns related to this effort. Please contact Mike O'Neil at (650) 604-2166 or Kevin Gilligan at (202) 358-4544 if you have any questions or require additional information.

Sincerely,

Stephen G. Jurczyk
Administrator (Acting)

Accessible Text for Appendix V: Comments from the National Aeronautics and Space Administration

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Sincerely,

Stephen G. Jurczyk
Administrator (Acting)

Appendix VI: GAO Contacts and Staff Acknowledgments

GAO Contact

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Staff Acknowledgments

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

Related GAO Products

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

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

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