United States Government Accountability Office

Report to Congressional Committees

May 2019

NASA

Assessments of Major Projects

Accessible Version

GAO-19-262SP

GAO Highlights

Highlights of GAO-19-262SP, a report to congressional committees

May 2019

NASA

Assessments of Major Projects

Why GAO Did This Study

This report provides GAO's annual snapshot of how well NASA is planning and executing its major acquisition projects. GAO previously found that, as of February 2018, the cost and schedule performance of major projects was deteriorating, with 9 of 17 projects in development reporting cost or schedule growth. GAO also found that NASA was likely to continue to see cost and schedule growth, as new, large projects were entering the portfolio while others were taking longer to launch than planned.

The explanatory statement of the House Committee on Appropriations accompanying the Omnibus Appropriations Act, 2009 included a provision for GAO to prepare status reports on selected large-scale NASA programs, projects, and activities. This is GAO's 11th annual assessment. This report assesses (1) the cost and schedule performance of NASA's major projects and (2) the maturity of critical technologies, among other issues. This report also includes assessments of 21 of NASA's 24 major projects, each with a life-cycle cost of over $250 million using 2018 data. This report does not assess what effect, if any, the government shutdown that ended in January 2019 had on performance. To conduct its review, GAO analyzed cost, schedule, technology maturity, and other data; reviewed project status reports; and interviewed NASA officials.

What GAO Recommends

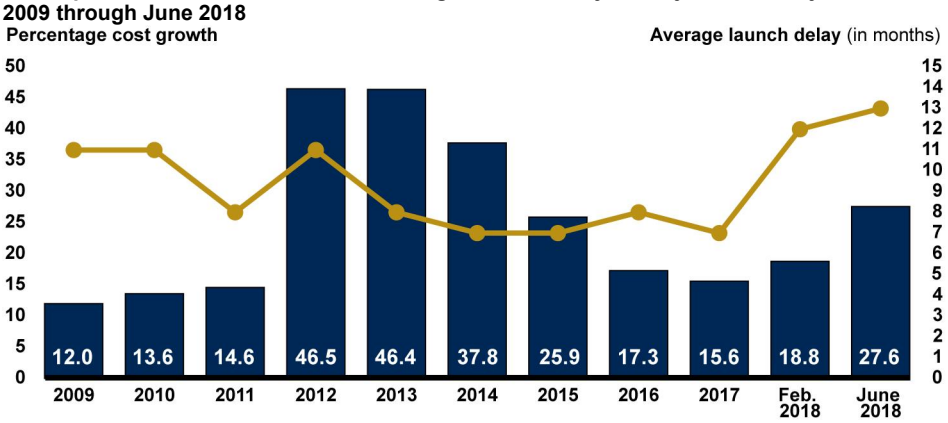
In prior reports, GAO has made related recommendations that NASA generally agreed with; 14 of these are not yet fully addressed. NASA generally agreed with the findings in this report.

View GAO-19-262SP. For more information, contact Cristina T. Chaplain at (202) 512-4841 or chaplainc@gao.gov.

What GAO Found

The cost and schedule performance of the National Aeronautics and Space Administration's (NASA) portfolio of major projects continues to deteriorate. For this review, cost growth was 27.6 percent over the baselines and the average launch delay was approximately 13 months, the largest schedule delay since GAO began annual reporting on NASA's major projects in 2009. See figure.

Development Cost Performance and Average Launch Delay for Major NASA Projects from 2009 through June 2018



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-19-262SP

Note: Data is as of June 2018 with some exceptions. For example, data was updated for projects that held decision reviews subsequent to that date but before the end of the calendar year 2018.

This deterioration in cost and schedule performance is largely due to integration and test challenges on the James Webb Space Telescope (see GAO-19-189 for more information). The Space Launch System program also experienced significant cost growth due to continued production challenges. Further, additional delays are likely for the Space Launch System and its associated ground systems. Senior NASA officials stated that it is unlikely these programs will meet the launch date of June 2020, which already reflects 19 months of delays. These officials told GAO that there are 6 to 12 months of risk associated with that launch date.

GAO found some subjectivity in the processes NASA uses to identify and assess critical technologies—those that are required for the project to successfully meet customer requirements—which could understate the development risk that its major projects face. The average number of critical technologies NASA reported increased slightly in 2019, but remains low compared to historical data. However, GAO found inconsistencies in how projects identify critical technologies. For example, the Lucy project determined that operating its solar array in a previously unexplored environment did not warrant identifying it as a critical technology, while the Ionospheric Connection Explorer (ICON) project did identify a technology as critical because of its use in a new environment. NASA is planning to clarify its guidance on technology readiness, among other measures. GAO will continue to monitor NASA's efforts in this area.

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Abbreviations

AIM	Asteroid Impact Monitor
ASI	Italian Space Agency
CCP	Commercial Crew Program
CNES	Centre National d'Etudes Spatiales
DART	Double Asteroid Redirection Test
DSOC	Deep Space Optical Communications
EGS	Exploration Ground Systems
EM-1	Exploration Mission 1
EM-2	Exploration Mission 2
ESM	European Service Module
ESA	European Space Agency
EVMS	Earned Value Management System
GRACE-FO	Gravity Recovery and Climate Experiment Follow-On
GSLV	Geosynchronous Satellite Launch Vehicle
HARP-2	Hyper Angular Rainbow Polarimeter

HEOMD	Human Exploration and Operations Mission Directorate
ICESat-2	Ice, Cloud, and Land Elevation Satellite-2
ICON	Ionospheric Connection Explorer
IMAP	Interstellar Mapping and Acceleration Probe
InSight	Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport
ISRO	Indian Space Research Organisation
ISS	International Space Station
JCL	joint cost and schedule confidence level
JPSS-2	Joint Polar Satellite System-2
JWST	James Webb Space Telescope
KaRIn	Ka-Band Radar Interferometer
KDP	key decision point
LBFD	Low Boom Flight Demonstrator
LCRD	Laser Communications Relay Demonstration
LIDAR	Light Detection and Randing
NASA	National Aeronautics and Space Administration
NEXT-C	NASA's Evolutionary Xenon Thruster-Commercial
NISAR	NASA ISRO Synthetic Aperture Radar
NPR	NASA Procedural Requirements
OCI	Ocean Color Instrument
Orion	Orion Multi-Purpose Crew Vehicle
PACE	Plankton, Aerosol, Cloud ocean Ecosystem
PDR	preliminary design review
PIXL	Planetary Instrument for X-ray Lithochemistry
PSP	Parker Solar Probe
RBI	Radiation Budget Instrument
REASON	Radar for Europa Assessment and Sounding: Ocean to Near-surface
SADA	Solar Array Drive Assembly
SCaN	Space Communication and Navigation
SCS	Sampling and Caching Subsystem
SDO	Solar Dynamics Observatory
SLS	Space Launch System
SGSS	Space Network Ground Segment Sustainment
SHERLOC	Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals
SLS	Space Launch System
SPEXone	Spectro-Polarimeter for Planetary Exploration
SRON	Netherlands Institute for Space Research
STMD	Space Technology Mission Directorate
SWOT	Surface Water and Ocean Topography

SwRI	Southwest Research Institute
TESS	Transiting Exoplanet Survey Satellite
USRA	Universities Space Research Association
WFIRST	Wide-Field Infrared Survey Telescope

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U.S. GOVERNMENT ACCOUNTABILITY OFFICE
441 G St. N.W.
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May 30, 2019

Congressional Committees

The National Aeronautics and Space Administration (NASA) is planning to invest about $63 billion over the life-cycle of its current portfolio of 24 major projects, which we define as those projects or programs that have a life-cycle cost of over $250 million. These projects aim to continue exploring Earth and the solar system and extend human presence beyond low Earth orbit, among other things. This report provides an overview of NASA's planning and execution of these major acquisitions—an area that has been on GAO's High-Risk list since 1990 in view of NASA's persistent cost growth and schedule delays in the majority of its major projects.[1] This report includes assessments of NASA's key projects across mission areas, such as the Space Launch System (SLS) for human exploration, Mars 2020 for planetary science, and the Plankton, Aerosol, Cloud ocean Ecosystem (PACE) for Earth science.

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 11th annual report responding to that mandate. This report assesses (1) the cost and schedule performance of NASA's portfolio of major projects, (2) the maturity of critical technologies, and (3) the stability of project designs at key points in the development process. This report also includes individual assessments of 21 of the 24 major NASA projects in NASA's current portfolio. When NASA determines that a project has an estimated life-cycle cost of over $250 million, we include that project in our annual review up through launch or completion. We did not complete individual project assessments for three projects that launched during our review.

To complete our annual assessments, we typically compare cost and schedule performance of NASA's portfolio across each of our reporting

[1]GAO, *High-Risk Series: Substantial Efforts Needed to Achieve Greater Progress on High-Risk Areas*, GAO-19-157SP (Washington, D.C.: Mar. 6, 2019).

[2]See Explanatory Statement, 155 Cong. Rec. H1653, 1824-25 (daily ed., Feb. 23, 2009), on H.R. 1105, the Omnibus Appropriations Act, 2009, which became Pub. L. No. 111-8. In this report, we refer to these as major projects as NASA does not use the term "large scale."

periods. The reporting period is the year we issue our report, and we have typically used cost and schedule data that NASA provided to us early in that calendar year. For example, for our last assessment, we based the 2018 reporting period on data NASA provided to us in January and February 2018.[3] Due to the partial government shutdown, which occurred between December 2018 and January 2019 due to a lapse in appropriations for fiscal year 2019, data included in this report is current as of December 2018, unless otherwise noted. This report does not assess the effects, if any, of the partial government shutdown on the cost or schedule of the projects in the portfolio.

To assess the cost and schedule performance, technology maturity, and design stability of NASA's major projects, we obtained information on these areas from project officials using data questionnaires, analyzed projects' monthly status reports and other documentation, and interviewed NASA project and headquarters officials. There are 24 major projects in total, but the information available depends on where a project is in its life cycle.[4] For the 17 projects in the implementation phase, we compared current cost and schedule estimates as of June 2018 to their original cost and schedule baselines, identified the number of critical technologies being developed, and assessed their technology maturity against GAO-identified acquisition best practices. If a project had a major decision event, such as establishing a cost and schedule baseline, before the end of December 2018, we included that data in our analysis. In addition, NASA provided an updated cost estimate for the Space Launch System as of September 2018 that we included in our analysis.

We also examined a subset of the 24 major projects—six projects that had not yet held a preliminary design review as of the beginning of our review—to provide observations on the extent to which technology risk across NASA's major projects is reported. We selected one of these projects, Europa Clipper, for a more in depth review of how the project identified and evaluated its critical technologies compared against best practices in GAO's exposure draft Technology Readiness Assessment

[3]GAO-18-280SP.

[4]Six projects were in an early stage of development called formulation when there are still unknowns about requirements, technology, and design. For those projects, we reported preliminary cost ranges and schedule estimates. A seventh project, the Commercial Crew Program, has a tailored project life cycle and project management requirements. As a result, it was excluded from our cost and schedule performance, technology maturity, and design stability analyses.

Guide.[5] We selected this project from our subset of six projects for several reasons, including its high life-cycle cost estimate and because the project was approaching its preliminary design review, which is the point when projects are expected to have matured their critical technologies. While the case study provides us with a more in-depth understanding of NASA's process for selecting and evaluating critical technologies, we cannot generalize findings from this case study to all of the major projects in NASA's portfolio.

To assess the stability of project designs at key points in the development process, we also compared the number of releasable design drawings at the critical design review against GAO-identified acquisition best practices and analyzed subsequent design drawings changes. Twelve projects completed a critical design review before December 2018 and were included in this analysis. We reviewed historical data on cost and schedule performance, technology maturity, and design stability for major projects from our prior reports and compared it to the performance of NASA's current portfolio of major projects. Finally, to conduct our 21 individual project assessments, we analyzed monthly status reports 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 2018 to May 2019 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.

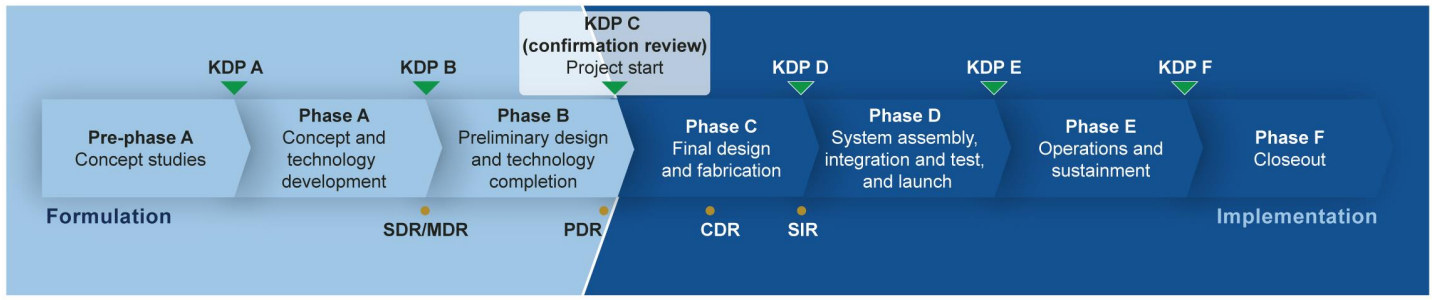
Background

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

[5]GAO, *GAO Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects – Exposure Draft*, GAO-16-410G (Washington, D.C.: Aug. 11, 2016).

implementation into phase A through phase F. Major projects must get approval from senior NASA officials at key decision points before they can enter each new phase. Figure 1 depicts NASA's life cycle for space flight projects.

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



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 presentation of National Aeronautics and Space Administration information. | GAO-19-262SP

Project formulation consists of phases A and B, during which the projects develop and define requirements, cost and schedule estimates, and the system's design for implementation. NASA Procedural Requirements 7120.5E, NASA Space Flight Program and Project Management Requirements, specifies that during formulation, the project must complete a formulation agreement to establish the technical and acquisition work that needs to be conducted during this phase and define the schedule and funding requirements for that work. The formulation agreement should identify new technologies and their planned development, the use of heritage technologies, risk mitigation plans, and testing plans to ensure that technologies will work as intended in a relevant environment. Prior to entering phase B, projects develop a range of the project's expected cost and schedule which is used to inform the budget planning for that project. During phase B, the project also develops programmatic measures and technical leading indicators, which track various project metrics such as requirement changes, staffing demands, and power utilization. Near the end of formulation, leading up

to the preliminary design review, the project team completes technology development and its preliminary design.

Formulation culminates in a review at key decision point C, known as project confirmation, where cost and schedule baselines are established and documented in the decision memorandum. The decision memorandum outlines the management agreement and the agency baseline commitment. The management agreement can be viewed as a contract between the agency and the project manager. The project manager has the authority to manage the project within the parameters outlined in the agreement. The agency baseline commitment includes the cost and schedule baselines against which the agency's performance on a project may be measured.

To inform the management agreement and the agency baseline commitment, each project with a life-cycle cost estimated to be greater than $250 million must also develop a joint cost and schedule confidence level (JCL). The JCL initiative, adopted in January 2009, produces a point-in-time estimate that includes, among other things, all cost and schedule elements in phases A through D, incorporates and quantifies known risks, assesses the effects of cost and schedule to date on the estimate, and addresses available annual resources. NASA policy requires that projects be baselined and budgeted at the 70 percent confidence level and funded at a level equivalent to at least the 50 percent confidence level.[6]

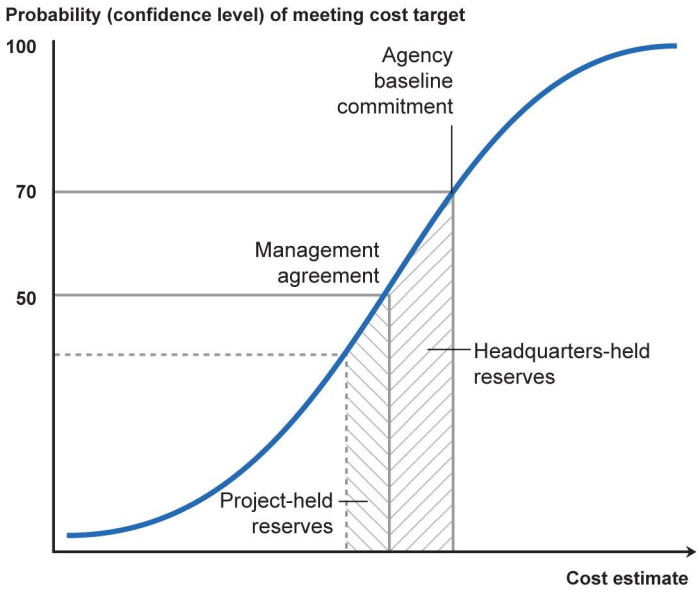
The management agreement and agency baseline commitment include cost and schedule reserves held at the project and NASA headquarters level, respectively.[7] Cost reserves are for costs that are expected to be incurred—for instance, to address project risks—but are not yet allocated to a specific part 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

[6]NASA Procedural Requirements (NPR) 7120.5E, *NASA Space Flight Program and Project Management Requirements* paras 2.4.4 and 2.4.4.2 (Aug. 14, 2012) (hereinafter cited as NPR 7120.5E (Aug. 14, 2012)). The decision authority for a project can approve it to move forward at less than the 70 percent confidence level. That decision must be justified and documented.

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

management agreement—for example, if a project needs additional funds for an issue outside of the project's control—NASA headquarters may allocate headquarters-held reserves. The total amount of cost and schedule reserves held at the project level varies based on where the project is in its life cycle. Figure 2 notionally depicts how NASA would distribute cost reserves for a project that was baselined in accordance with its JCL policy.

Figure 2: Notional Distribution of Cost Reserves for a Project Budgeted at the 70 Percent Confidence Level



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-19-262SP

Six NASA centers or laboratories are responsible for managing 23 NASA major projects. Of these, three centers or laboratories manage 17 of the 23 major projects and require or recommend that projects hold a certain level of cost and schedule reserves at key project milestones.[8] For example, at the Goddard Space Flight Center, projects are required to

[8]NASA, Goddard Procedural Requirements 7120.7B, *Funded Schedule Margin and Budget Margin for Flight Projects* (Sept. 17, 2018); Marshall Procedural Requirements 7120.1, *Marshall Space Flight Center Engineering and Program/Project Management Requirements* (Oct. 20, 2016); and Jet Propulsion Laboratory, *Flight Project Practices*, *Rev. 12* (Dec. 14 2017). The Kennedy Space Center and Johnson Space Center do not have center-specific guidance for reserves. The Johns Hopkins University Applied Physics Laboratory manages the Parker Solar Probe (PSP), Double Asteroid Redirect Test (DART), and Interstellar Mapping and Acceleration Probe (IMAP) projects and has guidelines for schedule reserves, but not for cost reserves.

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. The 24th major project included in our review, the Low Boom Flight Demonstrator (LBFD), does not have a lead center because it is using a virtual project office model. Project officials stated that they plan to use a mix of center policies in managing the LBFD acquisition.

After a project is confirmed, it begins implementation, consisting of phases C, D, E, and F. In this report, we refer to projects in phase C and D as being in development. A critical design review is held during the latter half of phase C to determine if the design is mature enough to support proceeding with the final design and fabrication. After the critical design review and just prior to beginning phase D, the project completes a system integration review to evaluate the readiness of the project and associated supporting infrastructure to begin system assembly, integration and test. In phase D, the project performs system assembly, integration, test, and launch activities. Phases E and F consist of operations and sustainment and project closeout, which includes final delivery of all remaining project deliverables and safe decommissioning/disposal of space flight systems and other project assets.

NASA Projects Reviewed in GAO's Annual Assessment

NASA's portfolio of major projects covers a range of project types including satellites equipped with advanced sensors for studying the Earth, a rover that plans to collect soil and rock samples on Mars, telescopes for exploring the universe, and spacecraft for transporting humans and cargo beyond low-Earth orbit. When NASA determines that a project will have an estimated life-cycle cost of more than $250 million, we include that project in our annual review.

This report reviews a total of 24 major projects and includes individual assessments of 21 of those major NASA projects (see table 1). We did not include an individual assessment for three projects that launched during the course of our review. One project is being assessed for the first time this year: Interstellar Mapping and Acceleration Probe (IMAP). For a list of the 24 projects and their current cost and schedule estimates, see appendix II. Appendix III provides a list of all the projects that we have reviewed from 2009 to 2019 in our series of annual reports.

Table 1: Major NASA Projects Reviewed in GAO's 2019 Assessment

Projects in formulation	Europa Clipper
	Interstellar Mapping and Acceleration Probe
	Plankton, Aerosol, Cloud, ocean Ecosystem (PACE)
	Psyche
	Restore-L
	Wide Field Infrared Survey Telescope (WFIRST)
Projects in implementation	Commercial Crew Program (CCP)
	Double Asteroid Redirection Test (DART)
	Exploration Ground Systems (EGS)
	Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2) [a]
	Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport (InSight) [a]
	Ionospheric Connection Explorer (ICON)
	James Webb Space Telescope (JWST)
	Landsat 9
	Laser Communications Relay Demonstration (LCRD)
	Low Boom Flight Demonstrator (LBFD)
	Lucy
	Mars 2020
	NASA ISRO Synthetic Aperture Radar (NISAR)
	Orion Multi-Purpose Crew Vehicle (Orion)
	Parker Solar Probe (PSP) (formerly Solar Probe Plus) [a]
	Space Launch System (SLS)
	Space Network Ground Segment Sustainment (SGSS)
	Surface Water and Ocean Topography (SWOT)

Source: GAO. | GAO-19-262SP

[a]The IceSat-2, InSight, and Parker Solar Probe projects launched in 2018.

Over the past 7 years, we have issued several reports assessing NASA's progress acquiring specific large projects and programs in more depth.[9] For example, we found in July 2016 that all three human spaceflight programs—the Orion Multi-Purpose Crew Vehicle (Orion), SLS, and Exploration Ground Systems (EGS)—were making progress in resolving technical issues and maturing designs, but that pressure on the limited cost and schedule reserves put the schedule for their first combined mission, the uncrewed Exploration Mission-1 (EM-1), at risk.[10] Subsequently, in April 2017, we found that given the combined effects of

[9]See Related GAO Products at the end of this report.

[10]GAO-16-620 and GAO-16-612.

ongoing technical challenges in conjunction with limited cost and schedule reserves, it was unlikely that these programs would achieve the November 2018 launch readiness date.[11] We recommended that NASA confirm whether this launch readiness date was achievable and, if warranted, propose a new, more realistic EM-1 date, and report to Congress on the results of its schedule analysis. NASA agreed with both recommendations and stated that it was no longer in its best interest to pursue the November 2018 launch readiness date. In June 2017, NASA notified Congress of its assessment of the EM-1 schedule. Subsequently, in December 2017, NASA approved a new EM-1 schedule of December 2019 with 6 months schedule reserve to extend the date to June 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 and has now been replanned twice.[12] Prior to being approved for development, cost estimates for JWST ranged from $1 billion to $3.5 billion, with expected launch dates ranging from 2007 to 2011. Before 2011, early technical and management challenges, contractor performance issues, low levels of cost reserves, and poorly phased funding levels caused JWST to delay work after confirmation, which contributed to significant cost and schedule overruns, including launch delays. Following an independent review, Congress placed an $8 billion cap on the formulation and development costs for the project in November 2011. NASA rebaselined JWST with a life-cycle cost estimate of $8.835 billion that included additional money for operations and a planned launch in October 2018. Between September 2017 and June 2018, the project's planned launch date was delayed three times, culminating in another independent review and a replan with a new

[11]GAO-17-414.

[12]A replan is a process generally 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. A rebaseline is a process initiated if the NASA Administrator determines the development cost growth is more than 30 percent of the estimate provided in the baseline of the report, or if other events make a rebaseline appropriate. When the NASA Administrator determines that development cost growth is likely to exceed the development cost estimate by 15 percent or more, or a program milestone is likely to be delayed from the baseline's date by 6 months or more, NASA must submit a report to the Committee on Science, Space, and Technology of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate. 51 U.S.C §30104(e)(2)(reporting requirement).

project cost estimate of $9.663 billion and a new launch date of March 2021.

In March 2019, we found that before the JWST project enters its final phase of integration and test, it must conduct a review to determine if it can launch within its cost and schedule commitments.[13] As part of this review, the project is not required to update its joint cost and schedule confidence level analysis, but government and industry cost and schedule experts have found it is a best practice to do so. We recommended that the NASA Administrator should direct the JWST project office to conduct a joint cost and schedule confidence level analysis prior to its system integration review. NASA concurred with the recommendation.

Affordability of NASA's Portfolio Will Be Strained as Cost and Schedule Performance Continues to Deteriorate and New Projects Begin

The cost and schedule performance of NASA's portfolio of major projects continues to deteriorate. Since we last reported in May 2018, cost growth has increased to 27.6 percent and the average launch delay is approximately 13 months, the largest schedule delay we have ever reported.[14] This deterioration in cost and schedule performance is largely due to the replan of the JWST project as a result of spacecraft integration and test challenges. Cost growth in the past year was further driven by the SLS program, stemming from continued production challenges with the SLS core stage—which functions as the SLS's fuel tank and structural backbone. In its fiscal year 2019 budget request, NASA did not request funding for two major projects yet were proceeding with planned work on them. If Congress continues to fund these projects along with other ongoing major projects, NASA will have to increase its annual funding request for major projects in future years or make other funding trade-offs as part of its annual budget request.

[13]GAO, *James Webb Space Telescope: Opportunity Nears to Provide Additional Assurance That Project Can Meet New Cost and Schedule Commitments,* GAO-19-189 (Washington, D.C.: Mar. 26, 2019).

[14]GAO-18-280SP.

NASA Cost and Schedule Performance Continues to Deteriorate with Further Growth Likely

The cost and schedule performance of NASA's portfolio of major projects continues to deteriorate. Since our last assessment, overall portfolio cost growth was 27.6 percent, up from 18.8 percent.[15] At that time, we also found that 18.8 percent may not represent the total cost growth for the portfolio. This was because the Orion program—one of the largest projects in the portfolio—did not have an updated cost estimate and project officials expected cost growth. In June 2018, the Orion program provided an updated cost estimate, which is included in the analysis in this report. The average launch delay increased to approximately 13 months, up from 12 months since we last reported and is the longest launch delay we have reported since our first assessment in 2009 (see figure 3).

[15]GAO-18-280SP.

Figure 3: Development Cost Performance and Average Launch Delay for Major NASA Projects from 2009 through June 2018

Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-19-262SP

[a]In February 2018, we were not able to determine the full extent of portfolio cost growth because NASA did not have an updated cost estimate for the Orion program at that time. The June 2018 data reflects the updated estimate.

[b]Data are as of June 2018 with the exception of projects that held decision reviews subsequent to that date but before the end of the calendar year 2018. Those projects include Double Asteroid Redirection Test, Lucy, Low Boom Flight Demonstrator, and Space Network Ground Segment Sustainment. The decision memorandum for Space Network Ground Segment Sustainment received final signatures in February 2019; however, the reviews were held prior to December 2018. In addition, for projects that launched in 2018, we used the final development cost data from the project's Key Decision Point E memorandum, which may have occurred after June 2018.

Cost and schedule performance deteriorated largely due to the most recent replan of the JWST project in response to spacecraft integration and test challenges, among other factors. As we found in March 2019, to develop a new schedule for JWST's replan, NASA took into account the remaining integration and test work and added time to address other potential threats to the schedule, including about 6 months to address an

integration and test anomaly that occurred on the spacecraft in 2018.[16] As a result of the replan, the project had a 10-month launch delay beyond the 19-month delay since our last assessment and an $813.8 million cost increase.[17] When JWST is excluded from the above analysis, the average schedule delay was approximately 9 months.

Cost growth since our last assessment was further driven by the SLS program, stemming from continued production challenges with the SLS core stage—which functions as the SLS's fuel tank and structural backbone.[18] According to program officials, Boeing underestimated both the complexity of engine section assembly and the time and manpower that would be needed to complete the effort, which has contributed to cost growth.

In addition to JWST and SLS, four other projects—SGSS, ICON, Mars 2020, and Orion—experienced cost growth since we last reported in May 2018.[19] ICON also experienced a schedule delay. The remaining 11 major projects stayed within cost and schedule estimates since we last reported. Of these projects, Parker Solar Probe, which launched in August 2018, completed technology development having spent approximately $40 million less than its cost baseline. Table 2 provides data on the cost and schedule performance of the 17 major projects in development that have cost and schedule baselines since our last assessment.[20]

[16]GAO-19-189.

[17]GAO-18-280SP.

[18]GAO-18-280SP.

[19]GAO-18-280SP.

[20]GAO-18-280SP.

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

		Confirmation Date	Changes between Last GAO Assessment and Current Assessment		Cumulative Performance from Original Baseline through June 2018	
Overall Performance	**Project**	**Year**	**Cost (millions)**	**Schedule (months)**	**Cost (millions)**	**Schedule (months)**
Lower than expected cost	PSP[a]	2014	-$35.1	0	-$40.5	0
Within baseline	SWOT	2016	$0.0	0	$0.0	0
	Landsat 9	2017	$0.0	0	$0.0	0
	Lucy	2018	$0.0	0	$0.0	0
	LBFD	2018	$0.0	0	$0.0	0
	DART	2018	$0.0	0	$0.0	0
Higher than expected cost	ICON	2014	$2.2	6	$2.2	14
	Mars 2020	2016	$37.7	0	$48.4	0
	NISAR	2016	$0.0	0	$22.0	0
	Orion (EM-2)	2015	$530.7	0	$379.0	0
Replan[b]	InSight [a]	2014	-$25.2	0	$106.5	26
	EGS (EM-1)	2014	$0.0	0	$421.4	19
	SLS (EM-1)	2014	$880.8	0	$1028.6	19
Rebaseline[b]	JWST	2008	$813.8	10	$4,421.5	81
	ICESat-2[a]	2012	-$28.5	-1	$177.8	16
	SGSS	2013	$167.6	0	$589.2	48
Under revision	LCRD[c]	2017	TBD	0	TBD	0
Total:			**$2344**	**15**	**$7156.1**	**223**

Legend: PSP: Parker Solar Probe; DART: Double Asteroid Redirection Test; SWOT: Surface Water and Ocean Topography; NISAR: NASA Indian Space Research Organisation – Synthetic Aperture Radar; ICON: Ionospheric Connection Explorer; InSight: Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport; LCRD: Laser Communications Relay Demonstration; SLS: Space Launch System; EM-1: Exploration Mission 1; ; ICESat-2: Ice, Cloud, and Land Elevation Satellite-2; EGS: Exploration Ground Systems; SGSS: Space Network Ground Segment Sustainment; EM-2: Exploration Mission 2; JWST: James Webb Space Telescope; Orion: Orion Multi-Purpose Crew Vehicle.

Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-19-262SP

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

NASA provided data to GAO in June 2018, with the exception of projects that held decision reviews subsequent to that date but before the end of the calendar year 2018. Those projects include DART, Lucy, LBFD, and SGSS. The decision memorandum for SGSS received final signatures in February 2019; however, the reviews were held prior to December 2018. In addition, NASA provided an updated cost estimate based on data as of September 2018 for the Space Launch System program. Finally, for projects that launched in 2018, we used the final development cost data from the project's Key Decision Point E memorandum, which may have occurred after June 2018.

[a]InSight, IceSat-2, and Parker Solar Probe projects launched in 2018.

[b]A replan is a process generally 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. NASA replanned the SLS

program when development costs did not increase by 15 percent or more. A replan does not require a new project baseline to be established. A rebaseline is a process initiated if the NASA Administrator determines that development costs increase by 30 percent or more or if other events make a rebaseline appropriate. When the NASA Administrator determines that development cost growth is likely to exceed the development cost estimate by 15 percent or more, or a program milestone is likely to be delayed from the baseline's date by 6 months or more, NASA must submit a report to the Committee on Science, Space, and Technology of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate. 51 U.S.C § 30104(e)(2)(reporting requirement).

[c]LCRD is expected to undergo a replan based on schedule delays from its mission partner.

Beyond JWST and SLS, reasons projects experienced cost increases or schedule delays include the following:

- Mars 2020 experienced cost growth in multiple areas, including new developments such as the Sampling and Caching Subsystem (SCS) that will collect and cache Martian soil and rock samples and the Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals (SHERLOC) that will search for organics and minerals that have been altered by watery environments. SHERLOC and SCS faced technical challenges that resulted in increased costs.
- ICON experienced schedule delays and associated cost growth due to issues with its Pegasus launch vehicle, not with the observatory portion of the project. The project missed its latest launch date due to anomalous telemetry from the launch vehicle. In November 2018, the project convened a Failure Review Board to investigate the anomaly. Project officials noted that the ICON observatory was completed on schedule and within cost. As of December 2018, the program had not rescheduled the launch date.
- The Orion program completed an updated cost estimate, which includes a 5.6 percent development cost increase. Program officials explained that the major drivers of this cost growth were the slip of the EM-1 launch date, which reflected delays in the delivery of the service module; Orion contractor underperformance; and NASA directed scope increases, including purchasing EM-2 avionics. Furthermore, as we found in 2018, NASA officials told us that new hardware and development challenges contributed to increased cost for the program.[21]
- The SGSS project completed a cost estimate through its final acceptance review. As we found last year, NASA had only approved the SGSS project's cost estimate through the initial operational

[21]GAO-18-280SP.

readiness review, currently planned for September 2019.[22] As a result, the $167.6 million increase in table 2 represents the additional costs for the SGSS project for the time between the initial operational readiness review to final acceptance review, which is currently scheduled for November 2020.

We found three challenges in measuring the cost and schedule performance of the portfolio this year. First, the cost growth and schedule delays are likely an underestimate for the portfolio for two reasons.

- The LCRD instrument is a hosted payload on an Air Force Space Test Program mission, and NASA is assessing the impact of continued delays with the spacecraft bus to LCRD's cost and schedule. According to officials, the contractor—with whom the Air Force holds the contractual relationship—has experienced technical challenges refurbishing the existing spacecraft bus to meet the requirements of one of the other, non-NASA payloads. The full extent of the delay and cost increases will not be known until the Air Force provides the LCRD project with the contractor's updated schedule and finalizes a new cost-sharing agreement with its mission partners. At that time, the LCRD project will be able to complete a new estimate of its schedule and associated costs.
- Although the Orion project provided a revised cost estimate in June 2018, this cost estimate assumes a launch date of September 2022, which is 7 months earlier than the program's baseline date of April 2023—the commitment date between NASA, Congress and OMB. Subsequently, program officials told us that its cost projections fund one of those seven months. However, the estimate is still not complete as it does not account for all costs that NASA would incur if the program executes to its committed baseline date of April 2023. We continue to follow up with NASA on this through other ongoing work.

Second, the human spaceflight programs continue to experience challenges executing to cost and schedule commitments but the extent of those challenges are not yet captured in our assessment. In November 2018—within 1 year of announcing a delay for the first mission—senior NASA officials acknowledged that the revised June 2020 launch date is unlikely. These officials told us that there are 6 to 12 months of risk associated with this date. This means that additional delays beyond the

[22]GAO-18-280SP.

19 months of delays captured in our analysis for SLS and ground systems are likely.

Finally, the SLS and EGS projects are performing development work for missions beyond EM-1 that is not captured in the portfolio analysis because NASA has not established baselines for those efforts. We cannot assess cost and schedule performance as part of our portfolio analysis until NASA establishes baselines for these efforts. To that end, we have made recommendations in the past on the need for NASA to baseline the programs' costs for capabilities beyond the first mission; however, a significant amount of time has passed without NASA taking steps to fully implement these recommendations. For example, in May 2014, we recommended that because NASA intends to use increased capabilities of the SLS, Orion, and ground support efforts well into the future, that it should establish baselines for those efforts.[23] NASA partially agreed with the recommendation but has not taken action. In our February 2019 high-risk report, we reported that the agency has not taken action on several recommendations related to understanding the long-term costs of its human exploration programs.[24] Further, we found there was a lack of transparency in major project cost and schedules, especially for the human spaceflight programs. As we noted in the high risk report, without transparency into these estimates, both NASA and Congress have limited data to inform decision making.[25]

NASA Will Continue to be Challenged to Budget for Planned Major Projects Given Competing Priorities

In its fiscal year 2019 budget request, NASA did not request funding for two major projects—WFIRST and PACE—but was proceeding with planned work on these projects while waiting for a final appropriation decision. The two projects together will require almost $3 billion over the next five years, according to NASA documents. Further, in May 2018, NASA reported selecting the Interstellar Mapping and Acceleration Probe project to begin formulation and implementation with a life-cycle cost cap

[23]GAO, *NASA: Actions Needed to Improve Transparency and Assess Long-Term Affordability of Human Exploration Programs*, GAO-14-385 (Washington, D.C.: May 8, 2014).

[24]GAO-19-157SP.

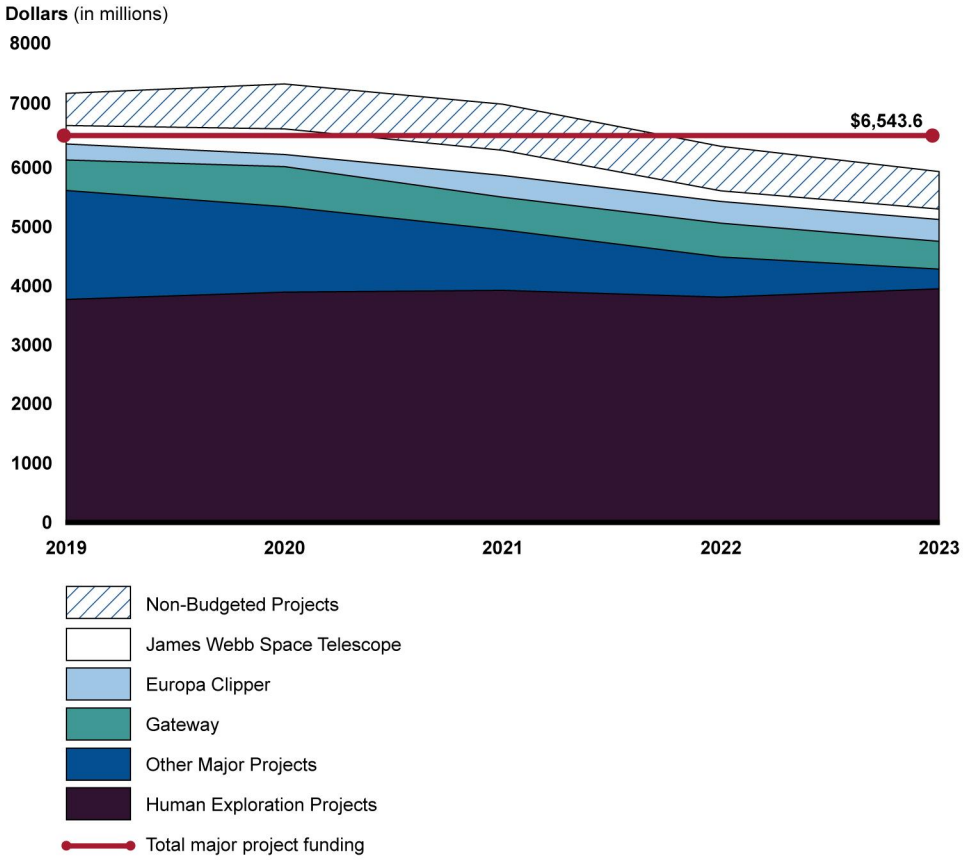
[25]GAO-19-157SP.

of $565 million, which was not yet categorized as a major project in NASA's fiscal year 2019 budget request.

Continuing these efforts along with other ongoing major projects—including funding for a new Gateway that NASA envisions as a staging point for missions to the Moon and deep space—will result in NASA having to either increase its annual funding request for major projects or continue to make funding trades between projects as part of the annual budget request. For example, in its fiscal year 2020 budget request, NASA again did not request funding for WFIRST and PACE. Agency officials stated that they have difficulty managing the portfolio of major projects—particularly in conducting longer range planning—with continuing funding uncertainties. Further, officials stated that they receive direction from Congress to fund certain projects that may not be in the agency's longer-range planning. We have previously found that the agency has faced difficulties in executing its plans due to budget uncertainty.[26] As seen in figure 4, assuming NASA's future budget requests align with its budget request for fiscal year 2019, NASA's potential commitments exceed its topline major-project budget until fiscal year 2022, when a minimal wedge of available funding—approximately $344 million— for new requests begins to open up.

[26]GAO, *NASA: Assessments of Major Projects*, GAO-14-338SP (Washington, D.C.: Apr. 15, 2014).

Figure 4: Five-Year Budget Profile for NASA Major Projects Assuming a Flat Budget (Fiscal Years 2019-2023)



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-19-262SP

As the figure illustrates, NASA is currently managing a portfolio of programs that costs more than what its planned annual budget request can support, and this trend will continue, assuming its budget requests stay on the same trajectory. Our previous work on Department of Defense acquisitions shows that when agencies commit to more programs than resources can support, unhealthy competition for funding is created among programs. This situation can lead to inefficient funding adjustments, such as moving money from one program to another or

deferring costs to the future.[27] We have also found similar conditions at the Coast Guard. In July 2018, we found that the Coast Guard's funding plans over the next 5 years for its portfolio of major acquisitions exceeds average budget requests in the last several years.[28] To address funding constraints, the Coast Guard has been in a reactive mode by making prioritization decisions through the annual budget process without identifying how trade-off decisions made in the current budget cycle will affect the future of the acquisition portfolio. As a result, the Coast Guard has continued to defer planned acquisitions to future years and left a number of operations capability gaps unaddressed that could affect future operations.

NASA might also find the available funding in the out years could quickly be consumed by additional demands in funding. This would exacerbate the amount of time that NASA will continue to operate in its current predicament, where its typical level of budget request does not support the number of projects in its portfolio. Examples of possible demands for that future funding include the following:

- **Cost growth to existing large projects:** In 2016 and 2017, we found that projects appear most likely to rebaseline between their critical design review and system integration review—the riskiest point in the development cycle.[29] The current portfolio of major projects includes six projects in that phase, meaning these projects are at risk of future cost growth or schedule delays. Further, some major projects will soon set cost and schedule baselines that may exceed preliminary estimates, requiring more funding than originally envisioned. For example, the Europa Clipper project planned to hold its confirmation review and set cost and schedule baselines in October 2018 following its preliminary design review; however, due to ongoing design challenges, the project now plans to hold the review in fall 2019. The project indicated in a cost exercise in preparation for its confirmation

[27]GAO, *DOD Acquisition Outcomes: A Case for Change*, GAO-06-257T (Washington, D.C.: Nov. 15, 2005); *Space Acquisitions: DOD Needs to Take More Action to Address Unrealistic Initial Cost Estimates of Space Systems,* GAO-07-96 (Washington, D.C.: Nov. 17, 2006); and *Defense Acquisitions: A Knowledge-Based Funding Approach Could Improve Major Weapon System Program Outcomes*, GAO-08-619 (Washington, D.C.: July 2, 2008).

[28]GAO, Coast Guard Acquisitions: Actions Needed to Address Longstanding Portfolio Management Challenges. GAO-18-454 (Washington, D.C.: July 24, 2018).

[29]GAO-16-309SP and GAO-17-303SP.

review that its costs would increase above preliminary estimates. Project officials explained that the expected cost increase is the result of conducting a more detailed cost estimate.

- **New lunar efforts:** The proposed fiscal year 2019 budget for the Gateway project already accounts for over $2.7 billion, or about 9 percent of NASA's major-project budget, over the next 5 years. The proposed budget for lunar efforts in addition to Gateway is more than $3 billion over the next 5 years, which officials indicated may include several new major projects with life-cycle costs over $250 million.
- **New projects joining the portfolio:** The $6.5 billion flat budget line illustrated in figure 4 does not include funding for new projects or projects that have not yet been proposed. For example, the latest decadal survey for astronomy and astrophysics, conducted by the National Research Council in 2010 to identify priorities for the agency over the next 10 years, proposes a gravity-wave observatory that would detect the mergers of black holes, among other objectives. With a proposed 50 percent cost-share between NASA and the European Space Agency, the project is estimated to cost NASA $1.5 billion over 9.5 years. NASA officials agreed that the future budget is unlikely to support the $1.5 billion estimated cost for the above project, or about $750 million for the agency's share of the project. As a result, NASA officials stated they are only planning to spend $400 million over the next decade for the project, which NASA stated can be accommodated within its major project portfolio. Further, NASA officials stated that demand on future funding could be mitigated because the agency includes projected funding in its budget for future missions. This projected funding is not reflected in the $6.5 billion flat budget line illustrated in the figure above. However, this planned funding may be budgeted to other agency priorities until new projects are confirmed and later appropriated funding through the budget process.

Subjectivity in Identifying and Assessing Critical Technologies Could Understate Risk

Subjectivity in the processes NASA uses to identify and assess critical technologies could understate the development risk that its major projects face. The average number of critical technologies NASA reported increased slightly when comparing data from January 2018 to December 2018 because two of the new projects in the portfolio reported one or more critical technologies. However, the number remains low compared

to data we collected in 2009 and 2010. While this decline may be an indication that recent projects are taking on less technology risk than their predecessors, we also found inconsistencies in the portfolio on how projects identify critical technologies, and these inconsistencies may affect comparisons. A study completed by NASA in 2016 also found subjectivity in how projects identify critical technologies. This study team also reported that projects may interpret technology readiness levels differently because guidance and definitions are spread throughout several documents. Most of NASA's major projects in development reported that they matured their technologies to the level recommended by best practices by their preliminary design review—continuing a trend since 2013. Our best practices work has shown that reaching this level of maturity can minimize risks for projects entering development, which lowers the risk of subsequent cost growth and schedule delays.

NASA Projects Continue to Report Lower Numbers of Critical Technologies than Prior Years, but NASA Plans to Address Inconsistent Identification

Complex acquisition efforts require the development of cutting-edge technologies and their integration into large and complex systems; NASA refers to such technologies as critical or new technologies. Such acquisition efforts may also use existing technologies, but in new applications or environments, which NASA refers to as heritage technologies. Our product development best practices do not make this distinction. We generally describe critical technologies as those that are required for the project to successfully meet customer requirements, which can include both existing and new technology. Further, according to GAO's Technology Readiness Assessment Guide, heritage technologies can become critical if being used in a different form, fit, or function.[30] Additionally, the Guide notes that determining a technology is not critical is problematic when technologies are being applied in a different operational environment, particularly when used in a novel way.

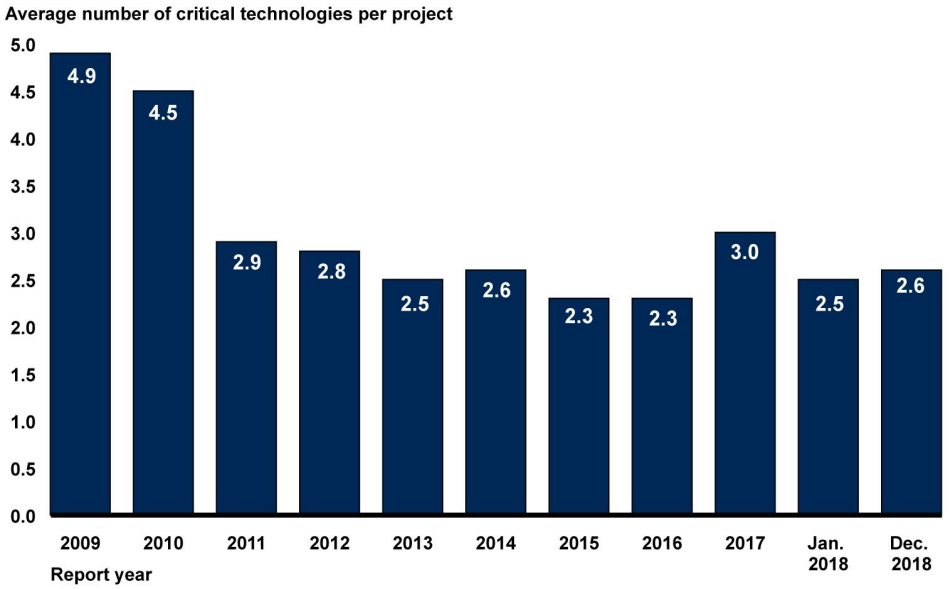
According to GAO's Technology Readiness Assessment Guide, critical technologies must be identified to achieve a comprehensive evaluation of technological risk. Failing to identify all critical technologies, including those with which there is prior experience but which the project plans to use in a new or novel manner, increases risk of overruns in cost and

[30]GAO-16-410G.

schedules and performance shortfalls. While underreporting technical risks can hinder decision makers' full understanding of a project's progress, correctly identifying critical technologies may better position the government to have realistic discussions about how to mitigate potential risks. For example, NASA projects are required to document new technologies as part of the project's Formulation Agreement, which establishes the technical and acquisition work to be conducted during the formulation phase and defines schedule and funding requirements for that work. Further, projects' independent standing review boards determine whether projects' new technologies are developed to an adequate state of readiness, or back-up options are identified, in order to successfully complete preliminary design reviews. If projects do not comprehensively identify critical technologies, NASA loses insight at key decision reviews about potential cost and schedule impacts if there are risks associated with the maturity of those technologies.

Over the past 8 years, projects have self-reported 3 or fewer critical technologies on average. This represents a marked decrease from the 4.9 and 4.5 average numbers of critical technologies reported in 2009 and 2010 respectively (see figure 5).

Figure 5: Average Number of Critical Technologies Reported by NASA's Major Projects in Development from 2009 through December 2018



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-19-262SP

Note: Includes all projects that held both a preliminary design review (PDR) and project confirmation by December 2018, except for the Restore-L project. The Restore-L project held PDR by this timeframe, but has continued to delay its confirmation review.

The 17 projects in the current portfolio that were in development as of December 2018 reported an average of 2.6 critical technologies, a slight increase compared to last year's average of 2.5 critical technologies. We removed three projects from our analysis because two of them—Gravity Recovery And Climate Experiment-Follow On (GRACE-FO) and Transiting Exoplanet Survey Satellite (TESS)—launched in 2018 and the third, Radiation Budget Instrument (RBI), was canceled that same year. Of these three, RBI had reported having 3 critical technologies while GRACE-FO and TESS both reported having zero. We added three projects—DART, LBFD, and Lucy—that were in development as of December 2018. Of the three, DART and LBFD reported three and one critical technologies respectively, while Lucy reported zero.

We have previously observed that the decline in the average number of critical technologies from 2009 and 2010 may be an indication that recent projects are taking on less technology risk than their predecessors by incorporating fewer new critical technologies into their design.[31] While this may still be the case, our analysis also found that inconsistencies in how projects across the portfolio identify critical technologies have the potential to affect a comparison of the average number of technologies from year to year.

For example, the Lucy project determined that increasing the size of its solar array and operating it in a previously unexplored environment did not warrant identifying the solar array as a critical technology. In contrast, the ICON project reported that its interferometer is a critical technology because it is being used in a different application, even though it is not a new technology. In addition, the Europa Clipper project identified no critical technologies, but many of the project's nine heritage technologies require modifications to meet mission requirements. Europa Clipper project officials explained that they classified some of those heritage technologies as "new," in part because they will operate in a new or novel environment, but do not use the terminology "critical." Though the technologies were identified as heritage, the Lucy and Europa Clipper projects will have development work to adapt the technologies for their purposes. While not all heritage technologies that require development

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

work should be identified as critical, these examples illustrate the subjectivity that exists in making these decisions.

In 2016, a NASA technology readiness assessment study team—made up of 19 senior and experienced managers in the fields of systems development and technology selection—found that the identification of critical technologies is subject to interpretation across centers and projects. The team found that this was due, in part, to a lack of clear technology definitions, including what qualifies as a critical technology. For example, it found a lack of consistency in determining what should be considered new or heritage technology as opposed to what is standard engineering development. The study team defines standard engineering development as slight modifications to technologies, as long as the modification is within the technology's original design intention or demonstrated capability. The study team further stated that correctly identifying technologies allows projects to better understand cost and schedule impacts of new technology risk and to plan with more confidence.

In December 2018, NASA established a corrective action plan in order to address recent cost and schedule growth experienced by several high-profile missions as well as NASA's inclusion on GAO's High Risk list. In response to a recommendation made by the study team, one of the initiatives that NASA plans to implement is to create a Technology Readiness Assessment Best Practices Document. This document is intended to capture the technology readiness assessment information that is scattered throughout the agency, provide links to governing documents, and document best practices across the agency. If further study team recommendations are implemented as part of this document, the document would include adding a step in the technology readiness assessment process to classify technology as either new, engineering, or heritage, and providing guidance on the use of critical technology. We will continue to monitor NASA's efforts in this area.

GAO Assessment of NASA's Process to Identify Critical Technologies for the Europa Clipper Project

To get a better sense of how NASA identifies critical technologies, we compared the Europa Clipper project's process to the best practices in GAO's Technology Readiness Assessment Guide.[a] We found that the Europa Clipper project's process for identifying critical technologies had both strengths and weaknesses. With respect to strengths, the project did consider the technologies' operational environments and whether the application of existing technologies was new or novel. For example, the project identified the Mapping Imaging Spectrometer for Europa cryocooler technology as "new" because its performance had not been demonstrated for the Europa mission radiation environment, among other things.

The Europa Clipper project, however, did not demonstrate that it used a rigorous, objective, reliable, and documented approach based on a work breakdown structure—which can be thought of as an illustration of the work that will satisfy a program's requirements—or other key program documents to initially identify critical technology candidates or why some technologies were selected and others were not. For example, though project officials told us that they identified new technologies in instrument proposals and early assessments, they did not provide documentation of these proposals and assessments, and we were therefore unable to confirm how this occurred. Further, using instrument proposals alone would not have been sufficient to ensure that all of the project's technologies were considered when determining the project's new technologies. For example, instrument proposals would not have included technology related to the spacecraft, if applicable. Project officials told us that spacecraft subsystems generally would not include critical technologies, but agreed that the process for determining that for Europa Clipper was not documented.

Additionally, though officials said they used a flow chart with clear criteria to determine if a technology was new, engineering development, or heritage, the project did not provide documentation to show if or how this process was carried out for the various technologies. They also told us that as more information became available in the course of the project's evaluation process, some technologies initially identified as new, such as the Europa Imaging System detector, were reclassified as engineering development. However, officials did not provide documentation or further explanation of how or why this change occurred. A best practice is to annotate a work breakdown structure, or a logical alternative such as a program risk register, and then list critical technologies with the reasons why other technologies were not selected. This allows anyone who participates in the technology readiness assessment to see an account of how the critical technologies were systematically determined rather than through an undocumented or arbitrary selection process.

[a]GAO, *GAO Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects – Exposure Draft*, GAO-16-410G (Washington, D.C.: Aug. 11, 2016).

NASA Projects Reported Generally Maintaining Technology Maturity, but NASA Has Identified Steps That Could Address Differing Assessments of Technology Readiness Levels

We found that most of NASA's major projects in development—10 of 16 projects—met the best practice of maturing all technologies to a technology readiness level 6 by their preliminary design review, which is

generally consistent with the past several years. We did not include the LBFD project, which is a flight demonstration, because the project does not intend to mature its technologies until it reaches the operations phase. Our best practices work has shown that reaching a technology readiness level 6—which includes demonstrating a representative prototype of the technology in a relevant environment that simulates the harsh conditions of space—by preliminary design review can minimize risks for the systems entering product development.[32]

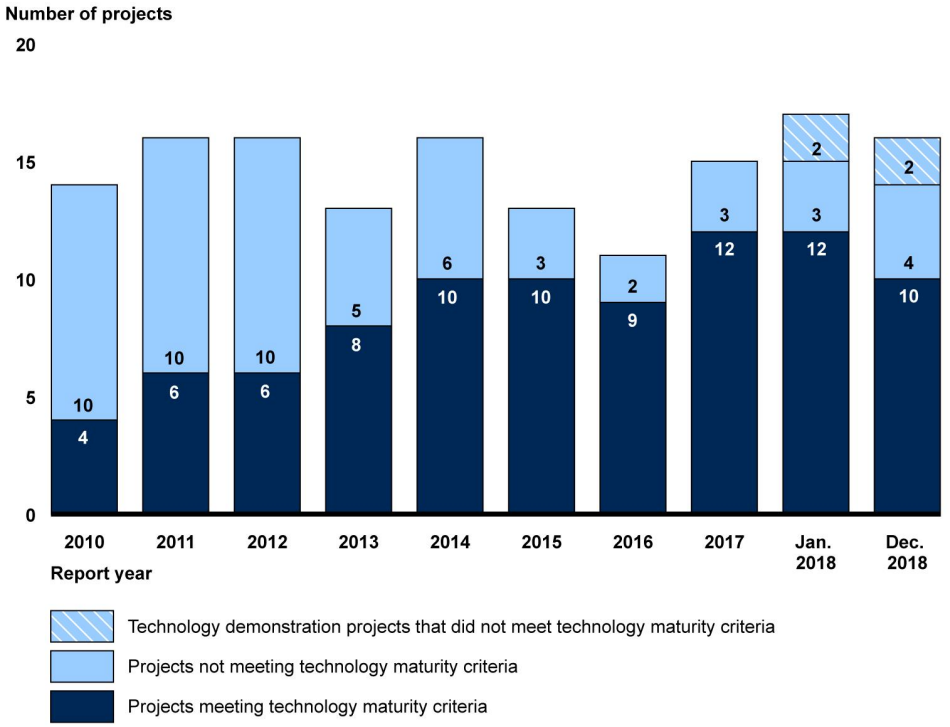
We have previously reported that allowing technology development to carry over into product development increases the risk that significant problems will be discovered late in development. Addressing such problems may require more time, money, and effort to fix because they may require more extensive retrofitting and redesign as well as retesting.[33] Figure 6 depicts NASA's major projects in development, including two technology demonstration projects that did not meet the best practice. The LCRD and Restore-L projects are technology demonstration projects managed by Goddard Space Flight Center, whose policy does not require technology demonstrations to mature all of their technologies to technology readiness level 6 by preliminary design review.[34] NASA officials explained that this is because the purpose of some technology demonstration projects is to mature new technologies to technology readiness level 6 or higher by the end of the demonstration, making it not feasible for these projects to achieve this level by the preliminary design review. However, we included LCRD and Restore-L in our analysis because both planned to mature their technologies prior to launching. Appendix IV provides a description of technology readiness levels, which are the metrics used to assess technology maturity.

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

[33]GAO, *Defense Acquisitions: Improvements Needed in Space Systems Acquisition Management Policy,* GAO-03-1073 (Washington, D.C.: Sept. 15, 2003).

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

Figure 6: Number of NASA's Major Projects Attaining Technology Maturity by Preliminary Design Review from 2010 through December 2018



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-19-262SP

Note: Includes projects that completed preliminary design review and identified critical or heritage technologies. By the end of 2018, 17 of 24 NASA major projects had held this review and identified critical or heritage technologies. However, this analysis does not include the LBFD project, as it is a flight demonstration project that does not intend to reach maturity until the operations phase.

Of the two projects we added to our technology maturity analysis this year—DART and Lucy—only Lucy matured its technologies to a technology readiness level 6. The DART project matured six of seven technologies; however, NASA's Evolutionary Xenon Thruster-Commercial (NEXT-C) technology, which is managed outside of the DART project, did not reach technology readiness level 6 by the time of the project preliminary design review in April 2018.[35] Of the six projects that did not meet the best practice, two—LCRD and Mars 2020—had technologies

[35]NEXT-C is a project managed at Glenn Research Center under the Discovery Program and will provide electric propulsion for DART. The DART mission will be the first time this technology will fly operationally and, if successful, serve as qualification for future deep space missions. However, the NEXT-C team was unable to fully mature the thruster's propulsion processing unit prior to DART's preliminary design review, which had been delayed 2 months to allow for more time to mature the NEXT-C technology.

identified by the project as heritage and critical, and two—JWST and Restore-L—had only heritage technologies that were not matured to a technology readiness level 6 by the preliminary design review.

In addition to a lack of clear technology definitions, the NASA study team we discussed above also found different interpretations of technology readiness levels used across different projects. The study team found this was due in part to minimal guidance spread across four documents that did not reference each other. The team also found that technology is often estimated to be at a higher level of maturity than it actually is, as the assessments are frequently self-performed by the project and are not always independently validated. As a result, officials may lack a true understanding of technology risks and their impacts on the project, which in turn can lead to cost and schedule growth.

We found one instance where a project may not have fully considered the implications of not having yet demonstrated components as an integrated system when assessing maturity levels. The LCRD project rated its lunar laser communications demonstration technology at a technology readiness level 9 based on the maturity of its individual components. However, technology readiness level 9 is defined as “actual system has been proven in successful mission operations,” and the LCRD technology had not yet been demonstrated as an integrated system. NASA policy includes the “weakest link” concept, in which the maturity of the system can be determined by the technology readiness level of its least mature component. According to the NASA study team report, though, the correct interpretation of the “weakest link” concept is that while the system can be rated no higher than the technology readiness level of its least mature component, the difficulty of integration must also be taken into account when determining the maturity of the system. As a result, the maturity of the total system may be lower than the maturity of the least mature component. While we acknowledge the use of “weakest link” in determining the technology readiness level of the system as a whole, our analysis indicates that the project initially did not take into account possible difficulties during integration of the components. However, project officials later acknowledged that a technology readiness level of 6 would have been more appropriate. Officials stated that one component of the technology could have been accurately assessed as a technology readiness level 9; however, two others had not yet been demonstrated operationally.

NASA is taking steps to address some of the concerns that both we and the study team highlighted in this area through its December 2018

corrective action plan initiative to create a Technology Readiness Assessment Best Practices Document. As the study team recommended in its report, this document will consolidate processes, guidance, and best practices that are currently scattered throughout the agency into a single reference source, as well as provide links to governing documents. Based on further recommendations from the study team, this best practices document could also include an updated technology readiness levels table in order to increase consistency and reduce ambiguity. We will continue to monitor NASA's efforts in this area.

GAO Assessment of NASA's Process to Evaluate Critical Technologies for the Europa Clipper Project

To get a better sense of how NASA evaluates critical technologies, we compared the Europa Clipper project's process to the best practices in GAO's Technology Readiness Assessment Guide.[a] We found that the Europa Clipper project's process for evaluating critical technologies was generally stronger than its process for identifying critical technologies. For example, the project determined consistent definitions of the technology readiness levels and the evidence needed to achieve the designated category before the assessment. In addition, the assessment team interviewed testing officials to determine whether the test results and testing environment were sufficient and acceptable.

However, the project did not provide documentation of all pertinent information related to the analysis, such as how the starting technology readiness levels for any of the project's new technologies were determined. Some technologies were assigned a specific technology readiness level near the beginning of the project, while others were evaluated as simply "less than 6." As a result, the credibility of the assigned technology readiness levels is decreased. According to project officials, completion of the necessary tests to achieve technology readiness level 6 is more relevant than the starting technology readiness level. GAO's *Technology Readiness Assessment Guide* states that having the necessary information is important so that the assessment team can make a credible determination of the technology readiness level from the supporting documentation.

[a]GAO, GAO Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects – Exposure Draft, GAO-16-410G (Washington, D.C.: Aug. 11, 2016).

NASA Has Maintained Improvements in Design Stability at Key Design Review, but Most Projects Continue to Experience Changes after That Review

Most projects have not demonstrated a stable design at the project's critical design review, but more are doing so now than several years ago. In addition, the average percentage of released drawings for the portfolio has remained generally consistent with the past 5 years. Our work on product development best practices shows that releasing at least 90

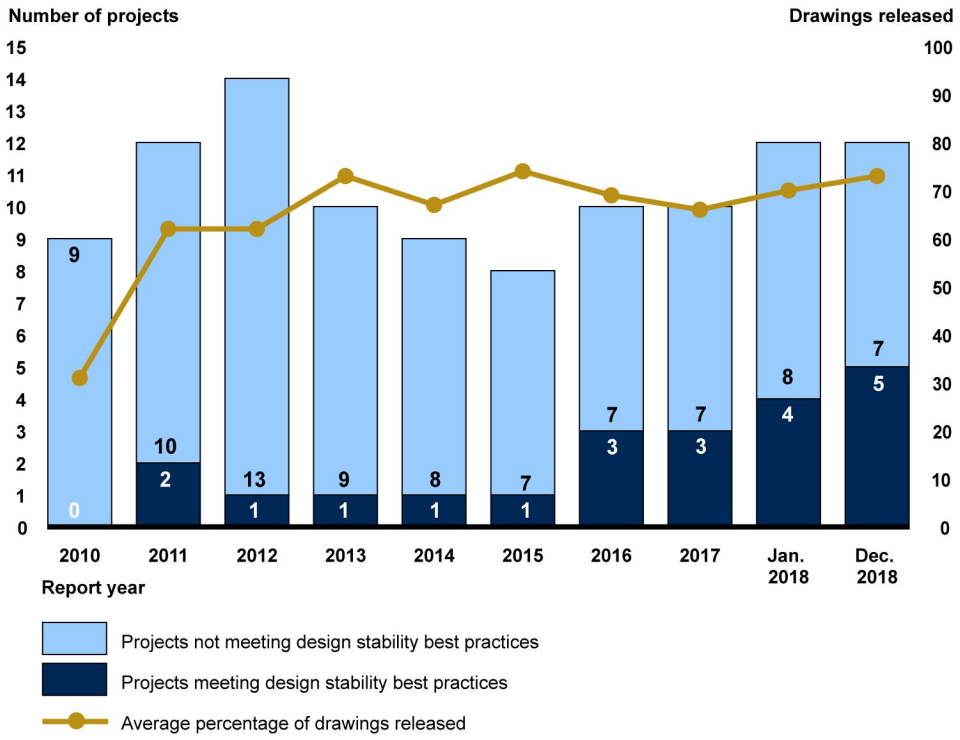
percent of engineering drawings by the time of the critical design review lowers the risk of projects experiencing design changes and manufacturing problems that can lead to cost and schedule growth. Further, many of NASA's major projects—including several of those that did not demonstrate a stable design at critical design review—continue to experience late design changes. Design changes after the critical design review can be costly to the project in terms of time and funding because hardware may need to be reengineered or reworked as a result.

NASA Has Maintained Improvements in the Number of Projects with Stable Design

NASA has maintained the number of projects with stable designs at critical design review, but most projects still do not meet the best practice. The critical design review is the time in the project's life cycle when NASA assesses the integrity of the project design and its ability to meet mission requirements. Our work on product development best practices shows that at least 90 percent of engineering drawings should be releasable by this review to lower the risk of manufacturing problems and subsequent cost and schedule growth. Engineering drawings are considered to be a good measure of the demonstrated stability of a product's design because the drawings represent the language used by engineers to communicate to the manufacturers the details of a new product design—what it looks like, how its components interface, how it functions, how to build it, and what critical materials and processes are required to fabricate and test it. Once the design of a product is finalized, the drawing is "releasable."

Of the 12 projects that have held a critical design review before December 2018, only five met the best practice of releasing 90 percent of their current projected engineering drawings by the time of the review (see figure 7). This is an improvement over the past 8 years. In addition, the average percentage of released drawings for the portfolio at critical design review is 73 percent, which has remained generally consistent with the past 5 years.

Figure 7: NASA Major Projects that Released at least 90 Percent of Engineering Drawings by Critical Design Review and Average Percentage of Released Drawings at the Review from 2010 to December 2018



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-19-262SP

Since we last reported, we added three projects and removed three projects from our analysis.[36] All three projects we added to the analysis—Landsat 9, NISAR, and SWOT—met the best practice for percentage of engineering drawings released at critical design review. Two projects—GRACE-FO and TESS—launched last year and were removed from our analysis of design drawings. A third project—RBI—was canceled. Of these three projects, two—GRACE-FO and RBI—had met the best practice and one, TESS, had not.

Similar to our previous report, five of the seven projects that did not meet the best practice released fewer than 60 percent of engineering drawings by critical design review.[37] For example, we found that Orion held its

[36]GAO-18-280SP.

[37]GAO-18-280SP.

critical design review in October 2015 with only 53 percent of its current expected design drawings released, significantly lower than the best practice of 90 percent. Orion did not release 90 percent of its expected drawings until 2017, about two years after its critical design review.

The average percentage of design drawings released by critical design review may increase in the future, as the two projects that currently have the lowest percentages of releasable drawings, PSP and InSight, with 31 and 51 percent of drawings released respectively, launched in 2018 and will be exiting the portfolio next year.

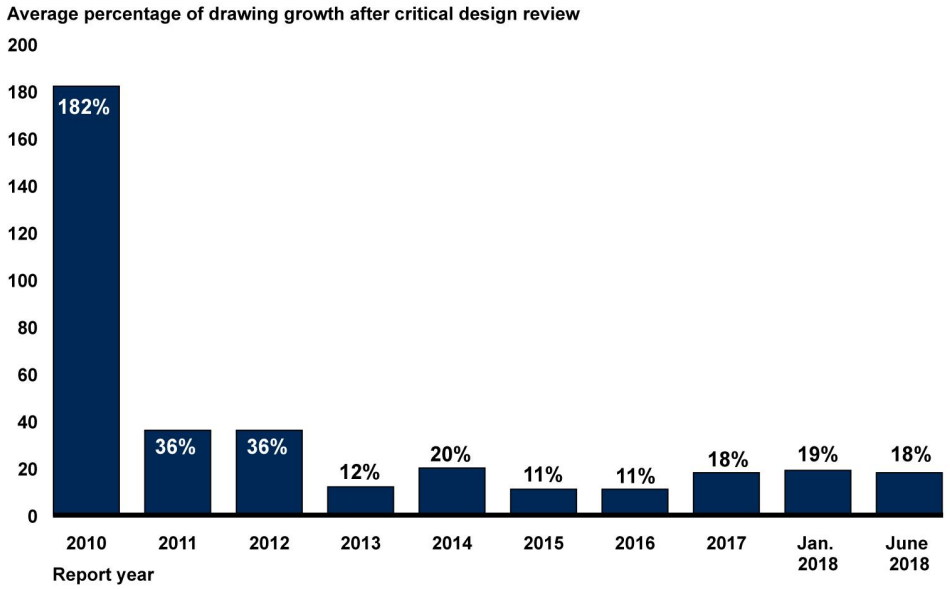
NASA Design Drawing Growth Is Relatively Steady, but Late Design Drawing Growth Still Occurs

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—referred to as design drawing growth—has remained relatively steady. However, some projects continue to experience late growth. If a project experiences a large amount of engineering drawing growth after this review, it may be an indicator of instability in the project 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 re-engineered or reworked as a result.

The average percentage of drawing growth for projects past critical design review decreased slightly, from 19 percent to 18 percent (see figure 8). Of the 11 projects included in this year's analysis, 9 experienced design drawing growth after their critical design review, ranging from 1 to 52 percent. This is an improvement from last year, when 11 out of 12 projects experienced design drawing growth. Further, 6 of 8 of the projects that did not meet the best practice of releasing 90 percent of their design drawings by critical design review then had late design drawing growth of 15 percent or higher.[38] The projects that had the most late drawing growth—JWST and InSight—were among the projects that had released the lowest percentage of drawings prior to the critical design review, at 56 and 51 percent respectively. This analysis also removed the GRACE-FO, RBI, and TESS projects for reasons discussed above.

[38]We did not collect drawing growth data on the NISAR project since it held critical design review after our data collection ended for this particular analysis.

Figure 8: Average Percentage of Engineering Drawing Growth after Critical Design Review for NASA Major Projects from 2010 to June 2018



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-19-262SP

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 and drawings for SDO's instruments were not included in this review. The project launched in 2010 and exited the portfolio.

The NISAR project is not included in the above analysis because it held its critical design review in October 2018.

Three of the projects in the portfolio—Mars 2020, Orion, and LCRD—have experienced design drawing growth ranging from 1 to 8 percent since last year's report. For example, Mars 2020 experienced drawing growth related to the Sample and Caching Subsystem and mechanical subsystems. This is an area that we will continue to monitor as part of our annual assessments.

Project Assessments

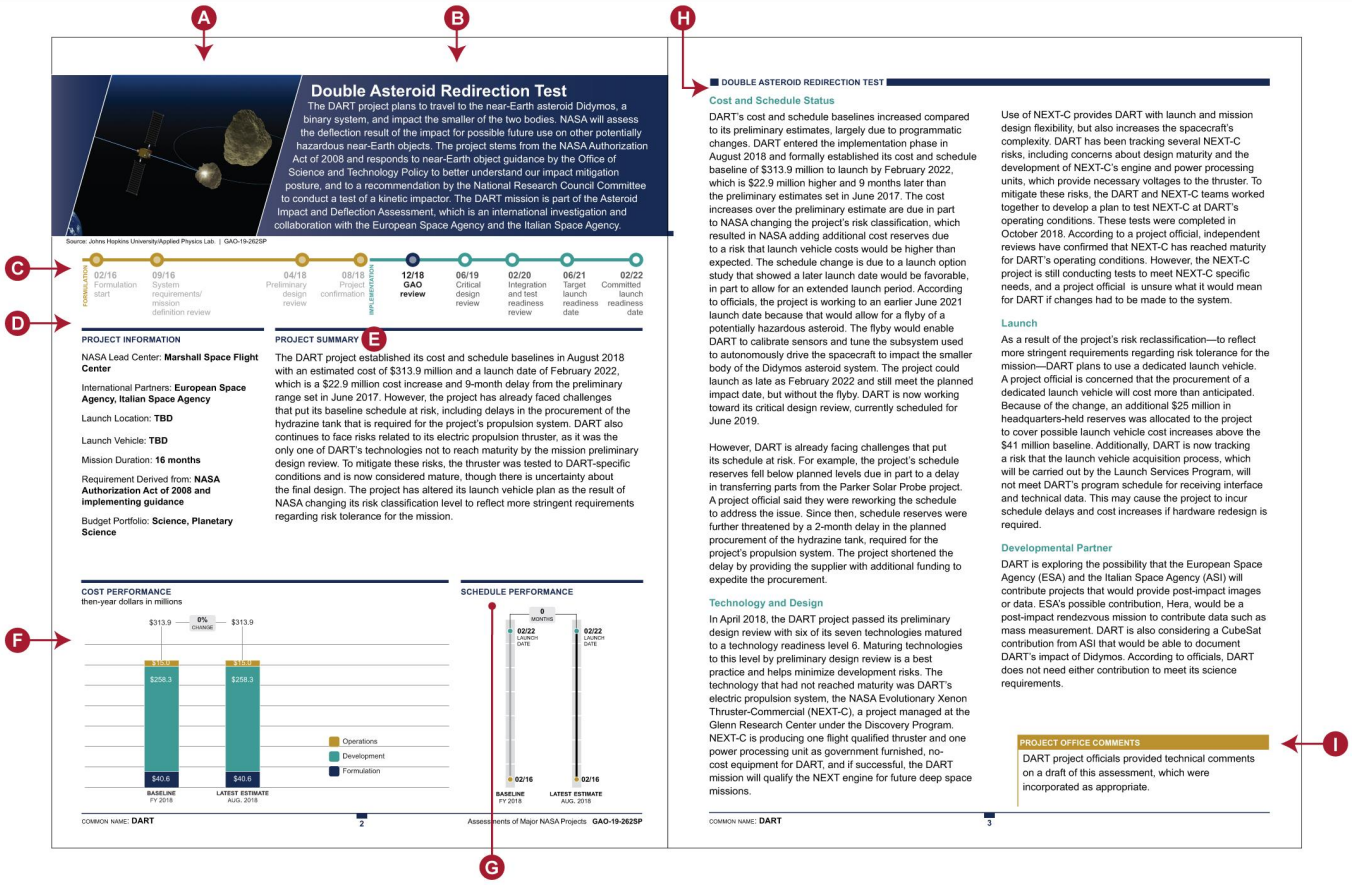
In the following section, we summarize the individual assessments of the 21 projects we reviewed in a two-page or one-page profile of each project. Each assessment includes a description of the project's objectives, information about the NASA centers and international partners involved in the project, the project's cost and schedule performance, a timeline identifying key project dates, and a brief narrative describing the

current status of the project.[39] Nineteen assessments describe the challenges we identified, as well as challenges that we have identified in the past. On the first page, the project profile presents the standard information listed above. On the second page of the assessment, we provide an analysis of the project challenges, and outline the extent to which each project faces cost, schedule, or performance risks because of these challenges, if applicable. Two of the assessments do not provide an in-depth review of program challenges because the projects had few, if any, challenges to report. The information presented in these assessments was obtained from NASA documentation, answers to our questionnaire by NASA officials, interviews with project staff, and includes our analysis of project cost and schedule information. NASA project offices were provided an opportunity to review drafts of the assessments prior to their inclusion in the final product, and the projects provided both technical corrections and more general comments. We integrated the technical corrections as appropriate and summarized the general comments at the end of each project assessment.

See figure 9 for an illustration of a sample assessment layout.

[39]The manifested launch date is the launch date which the project is working toward, and when a launch vehicle is available to launch the project. This date is only a goal launch date for the project, not a commitment that they will launch on this date. The committed launch readiness date is determined through a launch readiness review that verifies that the launch system and spacecraft/payloads are ready for launch.

Figure 9: Illustration of a Sample Project Assessment



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

Source: GAO analysis. | GAO-19-262SP

(For text of Individual project assessments, see separate PDF attachment. For content missing from report for 508 purposes, please contact GAO for data.)

Agency Comments and Our Evaluation

We provided a draft of this report to NASA for its review and comment. In its written response, reprinted in appendix VI, NASA stated it values GAO's independent perspective on NASA major acquisitions. NASA also noted that it looks forward to continuing to work with GAO to identify and address challenges that may enable cost and schedule improvements.

In commenting on GAO's use of design drawing best practices, NASA stated that it no longer uses the percentage of design drawings released by critical design review as a metric to measure design stability. NASA stated that the design drawing release metric is a legacy standard developed prior to the use of computerized drawings and is no longer an applicable standard for modern NASA projects.

NASA has expressed similar opinions in the past, but our reviews of NASA and DOD projects have found that, generally, programs that complete certain knowledge practices have better cost and schedule outcomes than programs that do not implement those practices. Knowledge that a product's design is stable early in the program facilitates informed decisions about whether to significantly increase investments and reduces the risk of costly design changes that can result from unknowns after initial manufacturing begins. Likewise, later knowledge that the design can be manufactured affordably and with consistent high quality prior to making a production decision ensures that targets for cost and schedule during production will be met.

Further, in light of different opinions about the importance of assessing design stability of a project at the critical design review, GAO convened a panel of experts in the space community in 2013. The experts—both government and industry—identified additional metrics that could buttress the assessment of programs throughout all phases of development, including the program's level of funding reserves and schedule margin. While we incorporated these additional metrics into our assessments of individual projects, they cannot be effectively associated with measurement at any one point in a project's life cycle, which is important to assessing NASA's overall progress in reducing acquisition risk.

While we continue to believe that having a stable design at a project's critical design review is an important measure and key to successful programmatic outcomes, we understand that technology advancements may have changed the way design drawings are documented and used across NASA. We look forward to continued dialogue with NASA on the best ways to assess design progress in light of these changes.

In commenting on GAO's practice of including projects in formulation, NASA indicated that it would like for GAO to return our focus to projects that have reached confirmation because it can be overly burdensome for projects in formulation to respond to GAO requests for information. GAO has always included projects in formulation since we began this assessment of NASA's major projects in 2009. It is important to include projects that are early in the acquisition lifecycle in order to provide Congress with a complete understanding of the cost, schedule, and technical performance of NASA's portfolio of major projects. Further, project confirmation reviews might be delayed creating a situation where significant risk is behind the project before the project was included in our assessment. For example, this year, NASA delayed the Restore-L project's confirmation review by over a year due to funding issues even though the project is proceeding with activities normally completed after project confirmation. If we focused only on projects that have held a confirmation review, we would not provide Congress with a full understanding of the risks and challenges projects are facing when NASA delays confirmation reviews.

NASA also provided technical comments, which we incorporated as appropriate.

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

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

Cristina T. Chaplain
Director, Contracting and National Security Acquisitions

List of Committees

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

The Honorable Ted Cruz
Chairman
The Honorable Kyrsten Sinema
Ranking Member
Subcommittee on Aviation and Space
Committee on Commerce, Science, and Transportation
United States Senate

The Honorable José Serrano
Chairman
The Honorable Robert Aderholt
Ranking Member
Subcommittee on Commerce, Justice, Science, and Related Agencies
Committee on Appropriations
House of Representatives

The Honorable Kendra Horn
Chairwoman
The Honorable Brian Babin
Ranking Member
Subcommittee on Space and Aeronautics
Committee on Science, Space, and Technology
House of Representatives

Appendix I: Objectives, Scope, and Methodology

The objectives of our review were to assess (1) the cost and schedule performance of the National Aeronautics and Space Administration's (NASA) portfolio of major projects, (2) the maturity of critical technologies and (3) the stability of project designs at key points in the development process. We also described the status and assessed the risks and challenges faced by NASA's 24 major projects, each with life-cycle costs more than $250 million. When NASA determines that a project has an estimated life-cycle cost of over $250 million, we include that project in our annual review up through launch or completion. We did not complete individual assessments for three projects that launched during our review, but included data from these projects in other analyses, as appropriate.

This is our 11th annual report assessing selected large-scale NASA program, projects, and activities. To complete our annual assessments, we typically compare cost and schedule performance of NASA's portfolio across each of our reporting periods. The reporting period is the year we issue our report, and we have typically used cost and schedule data that NASA provided to us early in that calendar year. For example, for our last assessment, we based the 2018 reporting period on data NASA provided to us in January and February 2018.[1] Due to the partial government shutdown, which occurred between December 2018 and January 2019 due to a lapse in appropriations for fiscal year 2019, data included in this report is current as of December 2018, unless otherwise noted. This report does not assess the effects, if any, of the partial government shutdown on the cost or schedule of the projects in the portfolio.

To respond to the objectives of this review, we developed several standard data questionnaires. We developed multiple questionnaires, which were completed by NASA's Office of the Chief Financial Officer, to gather data on each project's cost and schedule. We used another questionnaire, which was completed by each project office, to gather data on projects' technology and design maturity and development partners. The information available on individual projects depends on where a

[1]GAO-18-280SP.

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 analyzed questionnaire data from our prior reviews.

To assess the cost and schedule performance of NASA's major projects, we compared cost and schedule data as of June 2018 provided on questionnaires by NASA for the 17 projects in the implementation phase during our review to previously established cost and schedule baselines.[2] The Commercial Crew Program has a tailored project life cycle and project management requirements, so it was excluded from some analyses. In addition, we assessed development cost and schedule performance for NASA's portfolios of major projects for 2009 to June 2018 to examine longer-term trends. To determine cost performance, we compared the projects' baseline development costs and development costs as of June 2018. For projects that had launched, we used the final development cost data from the project's Key Decision Point E memorandum.

All cost information in this report is presented in nominal then-year dollars for consistency with budget data. Current baseline costs for all projects are adjusted to reflect the cost accounting structure in NASA's fiscal year 2009 budget estimates. For the fiscal year 2009 budget request, NASA changed its accounting practices from full-cost accounting to reporting only direct costs at the project level. To determine schedule performance, we compared the project's baseline launch readiness or completion date and current launch readiness or completion date as of June 2018. To understand how NASA is managing large and complex missions within the current budget environment, we examined NASA's budget documentation. We also spoke to officials about NASA's plans for upcoming lunar efforts and to what extent these efforts may become major projects in the future. If a project had a major decision event, such as establishing a cost and schedule baseline, before the end of December 2018, we included that data in our analysis. In addition, NASA provided an updated cost estimate for the Space Launch System as of September 2018 that we included in our analysis.

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

To assess technology maturity, we asked project officials to complete a questionnaire that provided the technology readiness levels of each of the project's critical and heritage technologies at various stages of project development including the preliminary design review. We did not verify or validate project office supplied data on the technology readiness level of technologies, or the classification of technologies as critical or heritage. For the 16 projects that had held a preliminary design review and identified critical or heritage technologies, we compared those levels against our technology maturity best practice to determine the extent to which the portfolio was meeting the criteria. Our work has shown that reaching a technology readiness level 6—which indicates that the representative prototype of the technology has been demonstrated in a relevant environment that simulates the harsh conditions of space—by the preliminary design review is the level of maturity needed to minimize risks for space systems entering product development. Originally developed by NASA, technology readiness levels are measured on a scale of one to nine, beginning with paper studies of a technology's feasibility and culminating with a technology fully integrated into a completed product. See appendix IV for the definitions of technology readiness levels. We compared this year's results against those in prior years to assess whether NASA was improving in this area.

We did not assess technology maturity for those projects that had not yet reached the preliminary design review at the time of this assessment or for projects that reported no critical or heritage technologies. We also excluded 2009 from our analysis since the data were only for critical technologies and did not include heritage technologies. We compared the number of critical technologies being developed per project with those in prior years to determine how the number of critical technologies developed per project had changed. We also collected information on the use of heritage technologies in the projects including what heritage technologies were being used; what effort was needed to modify the form, fit, and function of the technology for use in the new system; and whether the project considered the heritage technology as a risk to the project.

Further, we examined a subset of six projects—those that had not yet passed preliminary design review as of the beginning of our review—to provide observations on the extent to which technology risk across NASA's major projects is reported. Specifically, we collected and analyzed specific information from each project that had not passed preliminary design review as of the beginning of our review on the definitions, processes, and documentation used for identifying critical and heritage technologies. We compared these findings to GAO best

practices related to identifying and evaluating technologies as noted in the Technology Readiness Assessment Guide to determine the extent to which technologies and technology maturity levels are identified consistently across NASA's projects and to determine the extent to which technology maturity is underreported. As a case study example, we completed a record of analysis on technology readiness on one project that had not yet reached preliminary design review to determine to what extent the project complied with best practices for technology readiness. We selected the case study project, Europa Clipper, for several reasons including its high life-cycle cost estimate and because the project was approaching its preliminary design review, which is the point in time when projects are expected to have matured their critical technologies. While the case study provides us with a more in-depth understanding of NASA's process for selecting and evaluating critical technologies, we cannot generalize findings from this case study to all of the major projects in NASA's portfolio.

To assess design stability, we asked project officials to complete a questionnaire that provided the number of engineering drawings completed or projected for release by the preliminary and critical design reviews and as of our current assessment.[3] We did not verify or validate project office supplied data on the number of released and expected engineering drawings. However, we collected the project offices' rationale for cases where it appeared that only a small percentage of the expected drawings were completed by the time of the design reviews or where the project office reported significant growth in the number of drawings released after the critical design review. In accordance with best practices, projects were assessed as having achieved design stability if at least 90 percent of projected drawings were released by the critical design review. We compared this year's results against those in prior years to assess whether NASA was improving in this area. For this year's assessment, 12 projects had held a critical design review and reported data on design drawings. We did not assess the design stability for those projects that had not yet reached the critical design review at the time of this assessment. To assess completion of project validation and

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

verification plans, we asked project officials to complete a questionnaire that provided data on whether a plan was completed by the critical design review.

Our work was performed primarily at NASA headquarters in Washington, D.C. In addition, we and other GAO teams working on related reviews visited Goddard Space Flight Center in Greenbelt, Maryland; the Jet Propulsion Laboratory in Pasadena, California; Kennedy Space Center in Merritt Island, Florida; Johnson Space Center in Houston, Texas; and Marshall Space Flight Center in Huntsville, Alabama.

Project Profile Information on Each Individual Project Assessment

This year, we developed individual project assessments for 21 projects in the portfolio with an estimated life-cycle cost greater than $250 million. We did not complete individual assessments for projects that launched during our review. For each project assessment, we included a description of each project's objectives; information concerning the NASA center, and international partners involved in the project, if applicable; the project's cost and schedule performance; a schedule timeline identifying key project dates; and a brief narrative describing the current status of the project. We also provided a detailed discussion of project challenges for selected projects as applicable.

To assess the cost and schedule changes of each project, we obtained data directly from NASA's Office of the Chief Financial Officer through our questionnaire. For the Commercial Crew program, we obtained cost and schedule data directly from the program. When applicable, we compared the level of cost and schedule reserves held by the project to the level required by center policy.

The project's timeline is based on acquisition cycle time, which is defined as the number of months between the project's start, or formulation start, and the projected or actual launch date. Formulation start generally refers to the initiation of a project; NASA refers to a project's start as key decision point (KDP)-A, or the beginning of the formulation phase. The preliminary design review typically occurs toward the end of the formulation phase, followed by a review at KDP-C, known as project confirmation, which allows the project to move into the implementation phase. The critical design review is generally held during the latter half of the final design and fabrication phase of implementation and

demonstrates that the maturity of the design is appropriate to support continuing with the final design and fabrication phase. The manifested launch date is the launch date which the project is working toward, and when a launch vehicle is available to launch the project. This date is only a goal launch date for the project, not a commitment that it will launch on this date. The committed launch readiness date is determined through a launch readiness review that verifies that the launch system, spacecraft, and payloads are ready for launch. The implementation phase includes the operations of the mission and concludes with project disposal.

Project Challenges Discussion on Each Individual Project Assessment

To assess the status, risk, and challenges for each project, we submitted a questionnaire to each project office. In the questionnaire, we requested information on the maturity of critical and heritage technologies, the number of releasable design drawings at project milestones, and international partnerships.[4] We also held interviews with representatives from all of the projects to discuss the information on the questionnaire. We then reviewed project documentation—including monthly status reports, project plans, schedules, risk assessments, and major project review documentation—to corroborate any testimonial evidence we received in the interviews. These reviews led to identification of further challenges faced by NASA projects. The second page of our project assessments highlights key challenges facing that project that have or could affect project performance. For this year's report, we identified challenges across the projects we reviewed in the categories of cost, schedule, launch, contractor, development partner, design, technology, and integration and test. These challenges do not represent an exhaustive or exclusive list and are based on our definitions and assessments, not those of NASA.

To supplement our analysis, we relied on our work over past years examining acquisition issues across multiple agencies. These reports cover such issues as contracting, program management, acquisition best practices, and cost estimating. We also have an extensive body of work related to challenges NASA has faced with specific system acquisitions, financial management, and cost estimating. This work provided the

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

historical context and basis for large parts of the general observations we made about the projects we reviewed.

Data Limitations

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

We conducted this performance audit from April 2018 to May 2019 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Appendix II: Major NASA Projects Assessed in GAO's 2019 Report

In 2019, we assessed 24 major NASA projects. Figure 10 shows the preliminary launch readiness data and cost estimates for projects in the formulation phase, and the current launch readiness dates and cost estimates for projects in the implementation phase.

Figure 10: Cost and Schedule of Major NASA Projects Assessed in GAO's 2019 Report by Phase

	Acronym	Project name	Preliminary launch readiness date	Preliminary cost estimate (in millions)
Formulation	Clipper	Europa Clipper	July 2023	$3,100 – $4,000
	IMAP	Interstellar Mapping and Acceleration Probe	October 2024	$565
	PACE	Plankton, Aerosol, Cloud, ocean Ecosystem	Aug. 2022 – Apr. 2023	$805 – $850
	Psyche	Psyche	August 2022	$907.3 – $957.3
	Restore-L	Restore-L	June – Dec. 2020	$626 – $753
	WFIRST	Wide-Field Infrared Survey Telescope[a]	Sep. 2025 – Sep. 2026	$3,200 – $3,800

			Current launch readiness date	Current cost estimate (in millions)
Implementation	CCP	Commercial Crew Program—Boeing[b]	January 2020	$7,122.9
	CCP	Commercial Crew Program—SpaceX[b]	September 2019 (under review)	
	DART	Double Asteroid Redirection Test	February 2022	$313.9
	EGS	Exploration Ground Systems	June 2020	$3,230.7
	ICESat-2	Ice, Cloud, and Land Elevation Satellite-2[c]	September 2018	$1,056.1
	ICON	Ionospheric Connection Explorer	TBD	$252.7
	InSight	Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport[c]	May 2018	$813.8
	JWST	James Webb Space Telescope	March 2021	$9,662.7
	L9	Landsat 9	November 2021	$885.0
	LBFD	Low Boom Flight Demonstrator	January 2022	$582.4
	LCRD	Laser Communications Relay Demonstration	Under revision	Under revision
	Lucy	Lucy	November 2021	$981.1
	Mars 2020	Mars 2020	July 2020	$2,460.4
	NISAR	NASA Indian Space Research Organisation Synthetic Aperture Radar	September 2022	$896.9
	Orion	Orion Multi-Purpose Crew Vehicle	April 2023	$11,658.1
	PSP	Parker Solar Probe[c d]	August 2018	$1,548.2
	SGSS	Space Network Ground Segment Sustainment[e]	June 2021	$1,123.0
	SLS	Space Launch System	June 2020	$10,724
	SWOT	Surface Water and Ocean Topography	April 2022	$754.9

Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-19-262SP

Note: the life cycle for NASA space flight projects consists of two phases—formulation, which takes a project from concept to preliminary design, and implementation, which includes building, launching, and operating the system, among other activities. For projects in implementation, the current launch readiness date and cost estimate are the project's established cost and schedule baseline or the latest cost estimate and schedule if the project has experienced cost or schedule growth above the project's baseline.

[a]The cost range for the WFIRST project represents the Science Mission Directorate contribution. The Space Technology Mission Directorate will also contribute an additional $134 million to the project.

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

[c]The IceSat-2, InSight, and Parker Solar Probe projects launched in 2018.

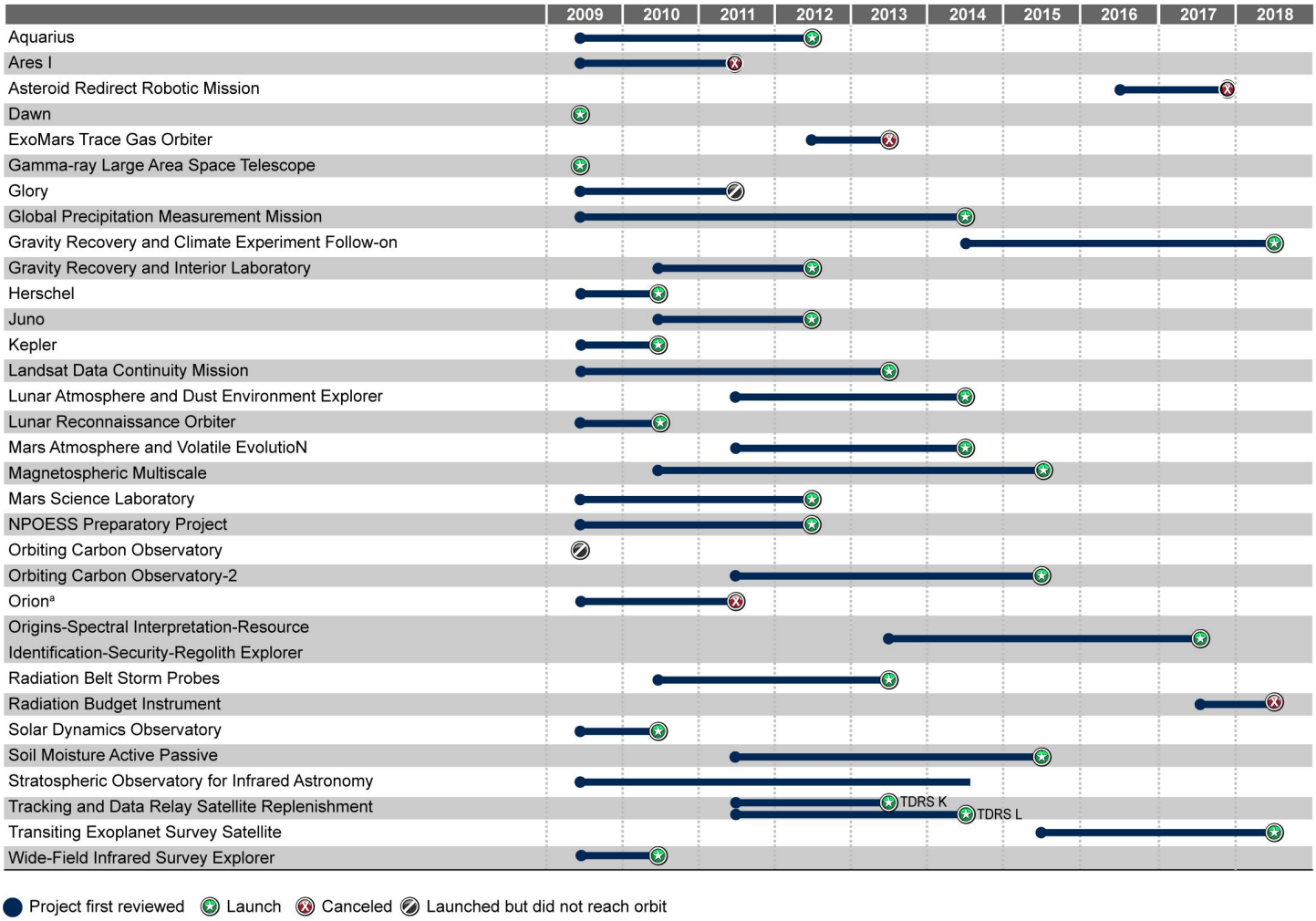
[d]In May 2017, NASA renamed the Solar Probe Plus project as the Parker Solar Probe project.

[e]In 2016, NASA reclassified Space Network Ground Segment Sustainment (SGSS) as a hybrid sustainment effort, rather than a major project. A hybrid sustainment effort still includes development work. As a result, we continue to include SGSS in our assessment.

Appendix III: Major NASA Projects Reviewed in GAO's Annual Assessments

We have reviewed 56 major National Aeronautics and Space Administration (NASA) projects or programs since our initial review in 2009. Figure 11 provides a list of projects included in our assessments from 2009 to 2018. These projects were not included in the 2019 review because they launched, were canceled, or launched but failed to reach orbit.

Figure 11: Major NASA Projects Reviewed in GAO's Annual Assessments from 2009-2018

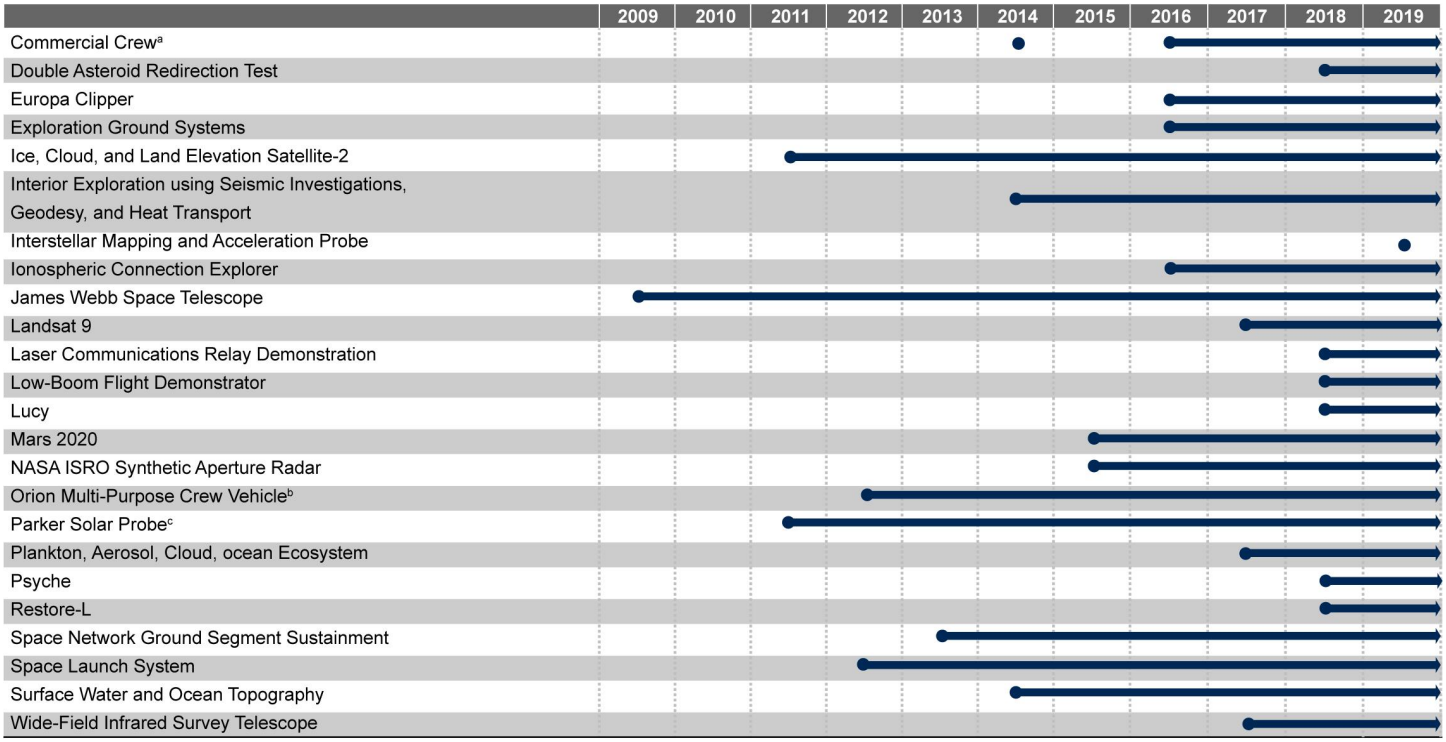


Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-19-262SP

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

Figure 12 provides a list of projects included in our 2019 assessment, including when the projects were first included in the review.

Figure 12: Major NASA Projects Reviewed in GAO's 2019 Assessment



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-19-262SP

[a]A bid protest was filed on September 26, 2014, after NASA awarded Commercial Crew contracts. GAO issued a decision on the bid protest on January 5, 2015, which was after our review of projects had concluded; therefore, we excluded the Commercial Crew Program from the 2015 review.

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

[c]In May 2017, NASA renamed the Solar Probe Plus project as the Parker Solar Probe project.

Appendix IV: Technology Readiness Levels

Table 3: Characteristics of Technology Readiness Levels

Technology readiness level	Description	Hardware	Demonstration environment
1. Basic principles observed and reported.	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties.	None (paper studies and analysis).	None.
2. Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be invented. The application is speculative and there is no proof or detailed analysis to support the assumption. Examples are still limited to paper studies.	None (paper studies and analysis).	None.
3. Analytical and experimental critical function and/or characteristic proof of concept.	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.	Analytic studies and demonstration of nonscale individual components (pieces of subsystem).	Lab.
4. Component and/or breadboard Validation in laboratory environment.	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of ad-hoc hardware in a laboratory.	Low fidelity breadboard (demonstrates function without considering form or fit). Integration of nonscale components to show pieces will work together. Not fully functional or form or fit but representative of technically feasible approach suitable for flight articles.	Lab.

Technology readiness level	Description	Hardware	Demonstration environment
5. Component and/or breadboard validation in relevant environment.	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so that the technology can be tested in a simulated environment. Examples include high-fidelity laboratory integration of components.	High-fidelity breadboard. Functionally equivalent but not necessarily form and/or fit (size, weight, materials, etc.). Should be approaching appropriate scale. May include integration of several components with reasonably realistic support elements/subsystems to demonstrate functionality.	Lab demonstrating functionality but not form and fit. May include flight demonstrating breadboard in surrogate aircraft. Technology ready for detailed design studies.
6. System/subsystem model or prototype demonstration in a relevant environment.	Representative model or prototype system, which is well beyond the breadboard tested for technology readiness level 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in simulated realistic environment.	Prototype. Should be very close to form, fit, and function. Probably includes the integration of many new components and realistic supporting elements/subsystems if needed to demonstrate full functionality of the subsystem.	High-fidelity lab demonstration or limited/restricted flight demonstration for a relevant environment. Integration of technology is well defined.
7. System prototype demonstration in a realistic environment.	Prototype near or at planned operational system. Represents a major step up from technology readiness level 6, requiring the demonstration of an actual system prototype in a realistic environment, such as in an aircraft, vehicle, or space. Examples include testing the prototype in a test bed aircraft.	Prototype. Should be form, fit, and function integrated with other key supporting elements/subsystems to demonstrate full functionality of subsystem.	Flight demonstration in representative realistic environment such as flying test bed or demonstrator aircraft. Technology is well substantiated with test data.
8. Actual system completed and "flight qualified" through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this technology readiness level represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.	Flight qualified hardware.	Developmental Test and Evaluation in the actual system application.
9. Actual system "flight - proven" through successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last "bug fixing" aspects of true system development. Examples include using the system under operational mission conditions.	Actual system in final form.	Technology assessed as fully mature. Operational Test and Evaluation in operational mission conditions.

Source: GAO analysis and representation of National Aeronautics and Space Administration data from NPR 7123.1B Appendix E | GAO-19-262SP

Appendix V: Elements of a Sound Business Case

The development and execution of a knowledge-based business case for the National Aeronautics and Space Administration's (NASA) projects can provide early recognition of challenges, allow managers to take corrective action, and place needed and justifiable projects in a better position to succeed. Our prior work of best practice organizations shows the risks inherent in NASA's work can be mitigated by developing a solid, executable business case before committing resources to a new product's development.[1]

In its simplest form, a knowledge-based business case is evidence that (1) the customer's needs are valid and can best be met with the chosen concept and that (2) the chosen concept can be developed and produced within existing resources—that is, proven technologies, design knowledge, adequate funding, adequate time, and adequate workforce to deliver the product when needed. A program should not be approved to go forward into product development unless a sound business case can be made. If the business case measures up, the organization commits to the development of the product, including making the financial investment. The building of knowledge consists of information that should be gathered at these three critical points over the course of a program:

- When a project begins development, the customer's needs should match the developer's available resources—mature technologies, time, and funding. An indication of this match is the demonstrated maturity of the technologies required to meet customer needs—referred to as critical technologies. If the project is relying on heritage—or pre-existing—technology, that technology must be in the appropriate form, fit, and function to address the customer's needs

[1]GAO, *Defense Acquisitions: Key Decisions to be Made on Future Combat System,* GAO-07-376 (Washington, D.C.: Mar. 15, 2007); *Defense Acquisitions: Improved Business Case Key for Future Combat System's Success,* GAO-06-564T (Washington, D.C.: Apr. 4, 2006); *NASA: Implementing a Knowledge-Based Acquisition Framework Could Lead to Better Investment Decisions and Project Outcomes,* GAO-06-218 (Washington, D.C.: Dec. 21, 2005); and *NASA's Space Vision: Business Case for Prometheus 1 Needed to Ensure Requirements Match Available Resources,* GAO-05-242 (Washington, D.C.: Feb. 28, 2005).

within available resources. The project will generally enter development after completing the preliminary design review, at which time a business case should be in hand.

- Then, about midway through the project's development, its design should be stable and demonstrate it is capable of meeting performance requirements. The critical design review takes place at that point in time because it generally signifies when the program is ready to start building production-representative prototypes. If project development continues without design stability, costly redesigns to address changes to project requirements and unforeseen challenges can occur.
- Finally, by the time of the production decision, the product must be shown to be producible within cost, schedule, and quality targets and have demonstrated its reliability, and the design must demonstrate that it performs as needed through realistic system-level testing. Lack of testing increases the possibility that project managers will not have information that could help avoid costly system failures in late stages of development or during system operations.

Appendix VI: Comments from the National Aeronautics and Space Administration

National Aeronautics and
Space Administration
Office of the Administrator
Washington, DC 20546-0001

May 14, 2019

Ms. Cristina T. Chaplain
Director
Contracting and National Security Acquisitions
United States Government Accountability Office
Washington, DC 20548

Dear Ms. Chaplain:

The National Aeronautics and Space Administration (NASA) appreciates the opportunity to comment on the Government Accountability Office (GAO) draft report entitled: "NASA: Assessments of Major Projects" (GAO-19-262SP). This assessment provides NASA with a valued independent perspective on our major acquisitions. We appreciate the open and constructive dialogue between NASA and the GAO engagement team, and we look forward to continuing to work with the GAO to identify and address any challenges that may enable cost and schedule improvements in our current and future projects.

NASA has long recognized the inherent challenges in managing large, complex space flight programs and has accordingly worked over many years to improve policies and procedures that control cost and schedule while ensuring mission success. In light of recent challenges in cost and schedule growth experienced by several of the Agency's highest profile missions, as well as the ongoing GAO designation of NASA's acquisition management as a high-risk area, NASA established a new Corrective Action Plan (CAP) in December 2018. The CAP contains nine key initiatives designed to strengthen the Agency's cutting-edge program and project management efforts and to improve transparency for NASA's stakeholders. NASA appreciates the GAO's recognition of these initiatives in the assessment and will continue to provide the GAO with updates on our progress against the CAP as successful implementation will contribute to improved programmatic performance across the Agency in the years ahead.

While the GAO continues to apply its design stability best practice metric of 90 percent of design drawings completed by the Critical Design Review, NASA no longer uses this metric internally to measure design stability. In NASA's 2011 response to this audit series, the Agency stated that the design drawing release metric is a legacy standard developed prior to the use of computerized drawings and is no longer an applicable standard for modern NASA projects. Beginning in 2016, NASA's system engineering handbook no longer recommended the 90 percent design drawing metric. While only 40 percent of NASA's major projects had 90 percent or more of their design drawings releasable at Critical Design Reviews held between 2000 and 2018, projects that met the design drawing best practice experienced 18 percent greater cost growth and 16 percent greater schedule growth than those

that did not, reinforcing that the current metric may no longer be applicable to measuring NASA project design stability. NASA looks forward to working with the GAO to explore alternative methodologies to measuring project design stability as an indicator for potential cost and schedule issues. Alternative methodologies may include, but are not limited to, metrics identified through the CAP Research Initiative that is currently exploring enhanced implementation indicators and/or those identified through discussions with GAO regarding industry best practices.

NASA agrees with the GAO's finding that there are some instances of inconsistency across the Agency in the definitions and interpretations of technology readiness levels. In light of this recognition, one of the initiatives included in the CAP established in December 2018 is to pursue the creation of a technology readiness assessment best practices document. This effort will capture the technology readiness assessment information across the Agency, identify best practices, and serve as a reference to relevant Agency guidance documents. The intent is to provide best practice information on how to conduct technology readiness assessments as a single resource for projects to access in the formulation phase of their life cycles.

NASA appreciates the GAO's recognition of the complex portfolio budgeting that NASA exercises annually during its budget formulation period. Each year, NASA conducts a sophisticated multi-stage Agency-wide programming phase that considers the multitude of NASA stakeholder priorities and requirements against directed and projected funding availability. Given constrained resources, it is common for difficult decisions to be made in proposed budget content. Any annual appropriations that deviate from the proposed budgets are handled through the established procedures that comply with Congressional transfer limits and all other applicable laws and are executed with the intent to maximize the efficient use of appropriated funds. While appreciating the GAO's finding, NASA recognizes that the prioritization of proposed funding allocations will always represent a challenge. Complicating matters further, the frequent recurrence of Continuing Resolutions leads to uncertainty and inefficiency that can adversely impact our programs' and projects' planning and execution. As always, the Agency remains committed to ensuring good stewardship of the taxpayers' investment in its efforts on behalf of the Nation.

This year's report represents the eleventh annual iteration of the GAO's legislatively mandated assessment of NASA's major acquisitions. Since the inaugural report's issuance in 2009, the GAO has provided NASA with several highly valued insights into various aspects of our acquisition approaches, many of which have resulted in programmatic improvements and enhancements. However, in recent years, NASA perceives a concerning growth in the number of audit inquiries impacting projects and programs early in their life cycles (e.g., Gateway, IMAP, and Clipper). Information requests received during the pre-Phase A and Phase A formulation portions of the life cycle typically target these efforts when project long-term plans and commitments lack the level of detail that the GAO is accustomed to receiving from projects later in their life cycles. During the early life-cycle formulation phases, the projects are in an initial creation state and newly formed project management teams focusing on standing up their organizations often find external inquiry to be premature and overly burdensome. We are pleased the GAO makes a dedicated effort to minimize disruption to

projects wherever possible; however, there are times where disruption is unavoidable, particularly with regard to projects earlier in their life cycles during formulation. NASA would appreciate a return to the original mandate for this important assessment, which focused on major acquisitions that have attained confirmation.

NASA would like to thank the GAO for continuing to work with project subject-matter experts to consider and incorporate technical corrections as part of this audit. We appreciate the consideration of these comments, which is important for an accurate and balanced presentation of the projects' technical status. We look forward to working with the GAO to ensure the technical review process continues to add value in the future.
NASA greatly appreciates the ongoing dialogue with the GAO on this critical engagement and is committed to working jointly to address any questions or concerns related to this effort. Please contact Kevin M. Gilligan at (202) 358-4544, if you have any questions or require additional information.

Sincerely,

Stephen G. Jurczyk
Associate Administrator

Appendix VII: GAO Contact and Staff Acknowledgments

GAO Contact

Cristina T. Chaplain, (202) 512-4841 or chaplainc@gao.gov.

Staff Acknowledgments

In addition to the contact named above, Molly Traci, Assistant Director; Andrea Bivens; Brian Bothwell; Tina CotaRobles; Lorraine Ettaro; Kelly Friedman; Laura Greifner; Kurt Gurka; Erin Kennedy; Meredith Kimmett; Christopher Lee; Jonathan Munetz; Jose A. Ramos; Carrie Rogers; Daniel R. Singleton; Ryan Stott; Roxanna T. Sun; John Warren; Alyssa Weir; Robin Wilson; and Kristin Van Wychen made significant contributions to this report.

Appendix VIII: Accessible Data

Data Tables

Data Table for highlights figure, Development Cost Performance and Average Launch Delay for Major NASA Projects from 2009 through June 2018

Year	Percentage cost growth	Average launch delay (in months)
2009	12	11
2010	13.6	11
2011	14.6	8
2012	46.5	11
2013	46.4	8
2014	37.8	7
2015	25.9	7
2016	17.3	8
2017	15.6	7
Feb. 2018	18.8	12
June 2018	27.6	13

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

1) Formulation

    a) Pre-phase A Concept studies; KDP A

    b) Phase A; Concept and technology development; system definition review/mission definition review; KDP B

    c) Phase B; Preliminary design and technology completion; preliminary design review

2) Implementation

    a) KDP C ;(confirmation review); Project start Phase C Final design and fabrication; critical design review; system integration review

b) KDP D ; Phase D; System assembly, integration and test, and launch

c) KDP E ; Phase E Operations and sustainment

d) KDP F; Phase F Closeout

Data Table Figure 2: Notional Distribution of Cost Reserves for a Project Budgeted at the 70 Percent Confidence Level

Probability graph showing Probability (confidence level) of meeting cost target. Probability is on the x axis and cost estimate is on the y axis.

These cost reserves go from lowest to highest and correspond to higher probability of meeting cost target.

Project-held reserves equates to approximately 40% confidence level

Management agreement equates to 50% confidence level

Headquarters-held reserves equates tp 50 to 70% confidence level

Agency baseline commitment equates to 70% confidence level

Data Table Figure 3: Development Cost Performance and Average Launch Delay for Major NASA Projects from 2009 through June 2018

Year	Percentage cost growth	Average launch delay (in months)	Number of projects in development
2009	12	11	13
2010	13.6	11	14
2011	14.6	8	16
2012	46.5	11	15
2013	46.4	8	12
2014	37.8	7	15
2015	25.9	7	12
2016	17.3	8	12
2017	15.6	7	16
Feb. 2018	18.8	12	17
June 2018	27.6	13	17

Data Table Figure 4: Five-Year Budget Profile for NASA Major Projects Assuming a Flat Budget (Fiscal Years 2019-2023)

Dollars in millions

year	Human exploration projects	Other major projects	Gateway	Europa clipper	James webb space telescope	Non-budgeted projects
2019	3670	1800.1	504.2	264.7	304.6	531.5
2020	3790.5	1412.2	662	200.2	423	742.5
2021	3820.1	999.4	540	359.5	415.2	761.9
2022	3707.5	663.7	558.9	358.9	175.4	735.3
2023	3845.7	324.9	459.1	361	172	619.6
Total major project funding: 6543.6						

Data Table Figure 5: Average Number of Critical Technologies Reported by NASA's Major Projects in Development from 2009 through December 2018

Report year	Average number of critical technologies per project
2009	4.9
2010	4.5
2011	2.9
2012	2.8
2013	2.5
2014	2.6
2015	2.3
2016	2.3
2017	3
Jan. 2018	2.5
June 2018	2.6

Data Table Figure 6: Number of NASA's Major Projects Attaining Technology Maturity by Preliminary Design Review from 2010 through December 2018

Year	Projects meeting technology maturity criteria	Projects not meeting technology maturity criteria	Technology demonstration projects that did not meet technology maturity criteria
2010	4	10	
2011	6	10	
2012	6	10	
2013	8	5	

Year	Projects meeting technology maturity criteria	Projects not meeting technology maturity criteria	Technology demonstration projects that did not meet technology maturity criteria
2014	10	6	
2015	10	3	
2016	9	2	
2017	12	3	
Jan. 2018	12	3	2
Dec. 2018	10	4	2

Data Table Figure 7: NASA Major Projects that Released at least 90 Percent of Engineering Drawings by Critical Design Review and Average Percentage of Released Drawings at the Review from 2010 to December 2018

Report year	Projects meeting design stability best practices	Projects not meeting design stability best practices	Average Percent of drawings released
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
Jan. 2018	4	8	70
Dec. 2018	5	7	73

Data Table Figure 8: Average Percentage of Engineering Drawing Growth after Critical Design Review for NASA Major Projects from 2010 to June 2018

Report 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
Jan. 2018	19
June 2018	18

Agency Comment Letter

Text of Appendix VI: Comments from the National Aeronautics and Space Administration

Page 1

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

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Sincerely,

Stephen Cryszyk

Associate Administrator

Related GAO Products

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

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

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

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

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

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

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

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

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

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

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

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

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

GAO's Mission

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