United States Government Accountability Office

Report to Congressional Committees

May 2018

NASA

Assessments of Major Projects

Accessible Version

GAO-18-280SP

GAO Highlights

Highlights of GAO-18-280SP, a report to congressional committees

May 2018

NASA

Assessments of Major Projects

Why GAO Did This Study

This report provides GAO's annual snapshot for 2018 of how well NASA is planning and executing its major acquisition projects. In May 2017, GAO found that projects were continuing a generally positive trend of limiting cost and schedule growth, maturing technologies, and stabilizing designs. But, at the same time, GAO noted that many of these projects, including some of the most expensive ones, were approaching the phase in their life cycles when cost and schedule growth is most likely.

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 10th annual assessment. This report describes the cost and schedule performance of NASA's portfolio of major projects, among other issues. This report also includes assessments of NASA's 26 major projects, each with a life-cycle cost of over $250 million. To conduct its review, GAO analyzed cost, schedule, technology maturity, design stability, and other data; reviewed monthly project status reports; and interviewed NASA officials.

What GAO Recommends

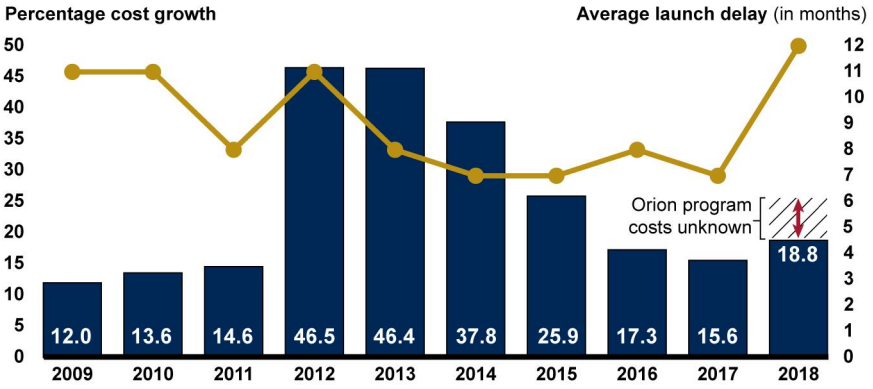
In prior reports, GAO has made related recommendations that NASA generally agreed with, but has not yet fully addressed. GAO continues to believe they should be fully addressed. NASA generally agreed with GAO's findings.

View GAO-18-280SP. For more information, contact Cristina 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 has deteriorated, but the extent of cost performance deterioration is unknown. NASA expects cost growth for the Orion crew capsule—one of the largest projects in the portfolio—but does not have a current cost estimate. In addition, the average launch delay for the portfolio was 12 months, the highest delay GAO has reported in its 10 years of assessing major NASA projects (see figure below).

NASA's Major Project Portfolio Cost and Schedule Performance Deteriorated in 2018



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-18-280SP

The deterioration in portfolio performance was the result of 9 of the 17 projects in development experiencing cost or schedule growth.

- Four projects encountered technical issues that were compounded by risky program management decisions. For example, the Space Launch System and Exploration Ground Systems programs are large-scale, technically complex human spaceflight programs, and NASA managed them to aggressive schedules and with insufficient levels of cost and schedule reserves. This made it more difficult for the programs to operate within their committed baseline cost and schedule estimates.
- Two projects ran into technical challenges that resulted in delays in the integration and test phase. For example, in December 2017, GAO found that the James Webb Space Telescope project encountered delays primarily due to the integration of the various spacecraft elements taking longer than expected, as well as resolving technical issues during testing. GAO has previously found that integration and testing is when projects are most at risk of incurring cost and schedule growth.
- Three projects experienced cost growth or schedule delays due to factors outside of the projects' control, such as delays related to their launch vehicles.

NASA continues to face increased risk of cost and schedule growth in future years due to new, large and complex projects that will enter the portfolio and expensive projects remaining in the portfolio longer than expected.

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Abbreviations

AIM	Asteroid Impact Monitor
ATLAS	Advanced Topographic Laser Altimeter System
CCP	Commercial Crew Program
CNES	Centre National d'Etudes Spatiales
DART	Double Asteroid Redirection Test
DCI	data collection instrument
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
GFAS	Ground Flight Application Software
GFZ	German Research Centre for Geosciences
GN&C	Guidance, Navigation, and Control
GRACE-FO	Gravity Recovery and Climate Experiment Follow-On
GSLV	Geosynchronous Satellite Launch Vehicle
HP3	Heat Flow and Physical Properties Probe
HVPS	high voltage power supply
ICESat-2	Ice, Cloud, and Land Elevation Satellite-2
ICON	Ionospheric Connection Explorer
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
JPL	Jet Propulsion Laboratory
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
LRI	Laser Ranging Interferometer
MAVEN	Mars Atmosphere and Volatile Evolution
NASA	National Aeronautics and Space Administration
NEXT-C	NASA's Evolutionary Xenon Thruster-Commercial
NISAR	NASA ISRO Synthetic Aperture Radar
NOAA	National Oceanic and Atmospheric Administration
NPR	NASA Procedural Requirements
OCI	Ocean Color Instrument

Orion	Orion Multi-Purpose Crew Vehicle
OSIRIS-REx	Origins-Spectral Interpretation-Resource Identification Security-Regolith Explorer
PSP	Parker Solar Probe
PACE	Plankton, Aerosol, Cloud, ocean Ecosystem
QueSST	Quiet Supersonic Technology
RBI	Radiation Budget Instrument
SCaN	Space Communication and Navigation
SCCS	Spaceport Command and Control System
SCS	Sampling and Caching System
SDO	Solar Dynamics Observatory
SEIS	Seismic Experiment for Interior Structure
SGSS	Space Network Ground Segment Sustainment
SLS	Space Launch System
SPC	Solar Probe Cup
SWOT	Surface Water and Ocean Topography
TESS	Transiting Exoplanet Survey Satellite
VBB	Very Broad Band
WFIRST	Wide-Field Infrared Survey Telescope
WICN	Workforce Information Cubes for NASA

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U.S. GOVERNMENT ACCOUNTABILITY OFFICE
441 G St. N.W.
Washington, DC 20548

May 1, 2018

Congressional Committees

The National Aeronautics and Space Administration (NASA) is planning to invest about $61 billion over the life cycle of its current portfolio of 26 major projects—those projects that have a life-cycle cost 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.[1] It includes assessments of NASA's key projects across mission areas, such as the Space Launch System for human exploration, Mars 2020 for planetary science, and Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2) for Earth science.

The explanatory statement of the House Committee on Appropriations accompanying the Omnibus Appropriations Act, 2009 includes a provision for us to prepare project status reports on selected large-scale NASA programs, projects, and activities.[2] This is our 10th 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 stability of project designs at key points in the development process, and (3) the extent to which NASA is assessing future workforce capacity challenges that may affect its ability to manage its portfolio of projects. This report also includes individual assessments of 26 major NASA projects. When NASA determines that a project has an estimated life-cycle cost of over $250 million, we include that project in our annual review up through launch or completion.

To assess the cost and schedule performance, technology maturity, and design stability of NASA's major projects, we collected information on these areas from projects using a data collection instrument, analyzed projects' monthly status reports, interviewed NASA project and

[1]GAO, *High-Risk Series: Progress on Many High-Risk Areas, While Substantial Efforts Needed on Others*, GAO-17-317 (Washington, D.C.: Feb. 15, 2017).

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

headquarters officials, and reviewed project documentation. There are 26 major projects in total, but the information available depends on where a project is in its life cycle.[3] For the 17 projects in the implementation phase, we compared cost and schedule estimates as of February 2018 to their original cost and schedule baselines, identified the number of technologies being developed, and assessed their technology maturity against GAO-identified acquisition best practices and NASA policy. 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. 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.

To assess the extent to which NASA is assessing future workforce capacity, we reviewed NASA assessments of technical capabilities and business services, interviewed officials responsible for the assessments and implementing recommendations from the assessments, including officials within the Office of Human Capital Management, and analyzed workforce data found in a NASA database. We determined that the data were sufficiently reliable for our purpose by reviewing responses to data reliability questions from knowledgeable agency officials and the data for obvious errors.

Finally, to conduct our 26 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 2017 to May 2018 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

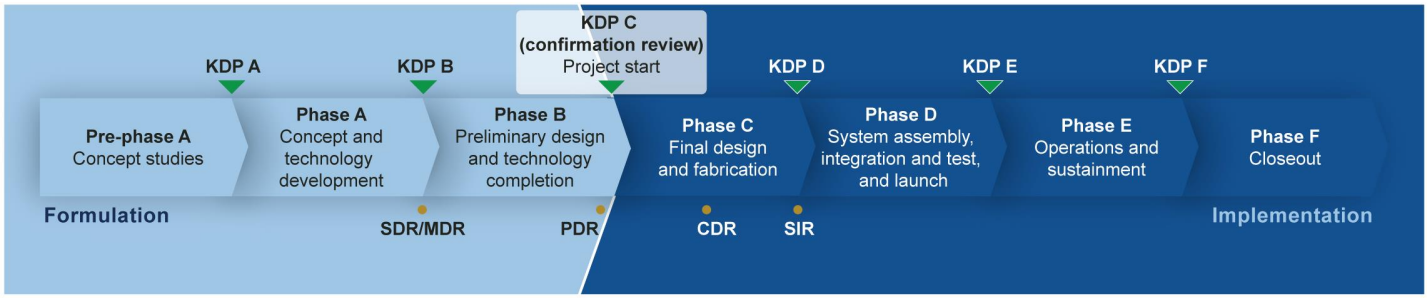
[3]Eight projects were in an early stage of development, called formulation, when there are still unknowns about requirements, technology, and design. For those projects, we reported preliminary cost ranges and schedule estimates. The Commercial Crew Program has a tailored project life cycle and project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

the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

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

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



Management decision reviews

KDP = key decision point

Technical reviews

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

Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-18-280SP

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 mass 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 a 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.

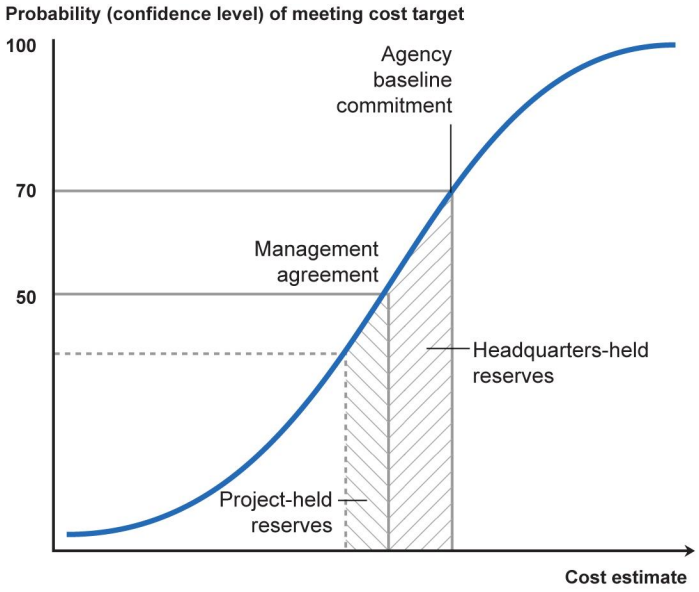
To inform the management agreement and the agency baseline commitment, each project with a life-cycle cost estimated to be greater than $250 million must also develop a joint cost and schedule confidence level (JCL). The JCL initiative, adopted in January 2009, produces a point-in-time estimate that includes, among other things, all cost and schedule elements in phases A through D, incorporates and quantifies known risks, assesses the impacts of cost and schedule to date, 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.[4]

The management agreement and agency baseline commitment include cost and schedule reserves held at the project and NASA headquarters-

[4]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.

level, respectively.[5] Cost reserves are for costs that are expected to be incurred—for instance, to address project risks—but are not yet allocated to a specific part of the project. Schedule reserves are extra time in project schedules that can be allocated to specific activities, elements, and major subsystems to mitigate delays or address unforeseen risks. Project-held cost and schedule reserves are within the project manager's control. If the project requires additional time or money beyond the management agreement—for example, if a project needs additional funds for an issue outside of the project's control—NASA headquarters may allocate headquarters-held reserves. 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-18-280SP

The total amount of cost and schedule reserves held at the project level varies based on where the project is in its life cycle. Seven NASA centers or laboratories are responsible for managing 25 NASA major projects. Of these, four centers or laboratories manage 20 of the 25 major projects and require or recommend that projects hold a certain level of cost and

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

schedule reserves at key project milestones.[6] For example, at the Goddard Space Flight Center, projects are required to hold cost reserves equal to at least 25 percent of the estimated cost remaining at the project confirmation review, and 10 percent at the time of delivery to the launch site. Projects track their reserves between phases to help ensure they hold reserves consistent with these requirements. The 26th 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 said they have not yet determined which center cost and schedule guidelines the project will follow.

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 in order 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.

NASA Projects Reviewed in GAO's Annual Assessment

NASA's portfolio of major projects ranges from satellites equipped with advanced sensors to study the Earth to a rover that plans to collect soil or rock samples on Mars to telescopes intended to explore the universe to spacecraft to transport 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. After

[6]Goddard Procedural Requirements 7120.7A, *Schedule and Budget Margins for Flight Projects* (Feb. 28, 2017); Marshall Procedural Requirements 7120.1, *Marshall Space Flight Center Engineering and Program/Project Management Requirements* (Aug. 26, 2014); Langley Research Center, *Space Flight Project Practices Handbook*, LPR 7120.5 B-1 (Mar. 17, 2014); and Jet Propulsion Laboratory, *Flight Project Practices*, *Rev. 8* (Oct. 6, 2010). The Kennedy Space Center and Johnson Space Center do not have center-specific guidance for reserves. The Johns Hopkins University Applied Physics Laboratory manages the Parker Solar Probe (PSP) and Double Asteroid Redirection Test (DART) projects and has guidelines for schedule reserves, but not for cost reserves. The Johns Hopkins University Applied Physics Laboratory SD-QP-012, Rev. b, *Space Exploration Sector (SES) Quality Procedure: Earned Value Management System (EVMS) Project Management Control System (PMCS)* (Apr. 4, 2017).

a project launches or reaches full operational capability, we no longer include an assessment of it in our annual report.

This report includes assessments of 26 major NASA projects (see table 1). Six projects are being assessed for the first time this year: Double Asteroid Redirection Test (DART), Laser Communications Relay Demonstration (LCRD), LBFD, Lucy, Psyche, and Restore-L. Prior to establishing its cost baseline, the LCRD project had an estimated life-cycle cost estimate of less than $250 million and therefore was not included in our previous reviews when the project was in formulation. For a list of the 26 projects and their current cost and schedule estimates, see appendix II. We did not complete an assessment for the Asteroid Redirect Robotic Mission project this year because, as of June 2017, the project closed out most project development activities at the direction of NASA headquarters. Appendix III includes a list of all the projects that we have reviewed from 2009 to 2017.

Table 1: Major NASA Projects Reviewed in GAO's 2018 Assessment by Phase

Projects in formulation	Double Asteroid Redirection Test (DART)
	Europa Clipper
	Low Boom Flight Demonstrator (LBFD)
	Lucy
	Plankton, Aerosol, Cloud, ocean Ecosystem (PACE)
	Psyche
	Restore-L
	Wide-Field Infrared Survey Telescope (WFIRST)
Projects in implementation	Commercial Crew Program (CCP)
	Exploration Ground Systems (EGS)
	Gravity Recovery and Climate Experiment Follow-On (GRACE-FO)
	Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2)
	Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport (InSight)
	Ionospheric Connection Explorer (ICON)
	James Webb Space Telescope (JWST)
	Landsat 9 (L9)
	Laser Communications Relay Demonstration (LCRD)
	Mars 2020
	NASA ISRO Synthetic Aperture Radar (NISAR)
	Orion Multi-Purpose Crew Vehicle (Orion)
	Parker Solar Probe (PSP) (formerly Solar Probe Plus)
	Radiation Budget Instrument (RBI)
	Space Launch System (SLS)
	Space Network Ground Segment Sustainment (SGSS)
	Surface Water and Ocean Topography (SWOT)
	Transiting Exoplanet Survey Satellite (TESS)

Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-18-280SP

Over the past 6 years, we have issued several reports assessing NASA's progress acquiring its largest projects and programs in more depth.[7] We found in July 2016 that all three human spaceflight programs—the Orion Multi-Purpose Crew Vehicle (Orion), the Space Launch System (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.[8] Subsequently, in April 2017, we found that given the combined effects of ongoing technical challenges in conjunction with limited cost and schedule reserves, it was unlikely that these programs would achieve the planned November 2018 launch readiness date.[9] 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 December 2017,

[7]GAO, *James Webb Space Telescope: Actions Needed to Improve Cost Estimate and Oversight of Test and Integration*, GAO-13-4 (Washington, D.C.: Dec. 3, 2012); *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: Project Facing Increased Schedule Risk with Significant Work Remaining,* GAO-15-100 (Washington, D.C.: Dec. 15, 2014); *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 on Track but May Benefit from Improved Contractor Data to Better Understand Costs,* GAO-16-112 (Washington, D.C.: Dec. 17, 2015);*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); *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: Delay Likely for First Exploration Mission,* GAO-17-414 (Washington, D.C.: Apr. 27, 2017); *NASA Human Space Exploration: Integration Approach Presents Challenges to Oversight and Independence,* GAO-18-28 (Washington, D.C.: Oct 19, 2017); *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); and *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).

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

[9]GAO-17-414.

NASA approved a new EM-1 schedule of December 2019, with six months of schedule reserve available to extend the date to June 2020. In April 2018, NASA provided us with the letter the agency sent to Congress on its assessment of the EM-1 schedule. We are in the process of reviewing the letter to determine if it addresses our recommendation.

We have also reported for several years on the James Webb Space Telescope (JWST) project, which has experienced significant cost increases and schedule delays. 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 that found JWST was executing well from a technical standpoint, but that the baseline cost estimate did not reflect the most probable cost with adequate reserves in each year of project execution, 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.[10] In December 2017, we found that the JWST project continues to make progress towards launch, but the program is encountering technical challenges that require both time and money to fix and may lead to additional delays.[11]

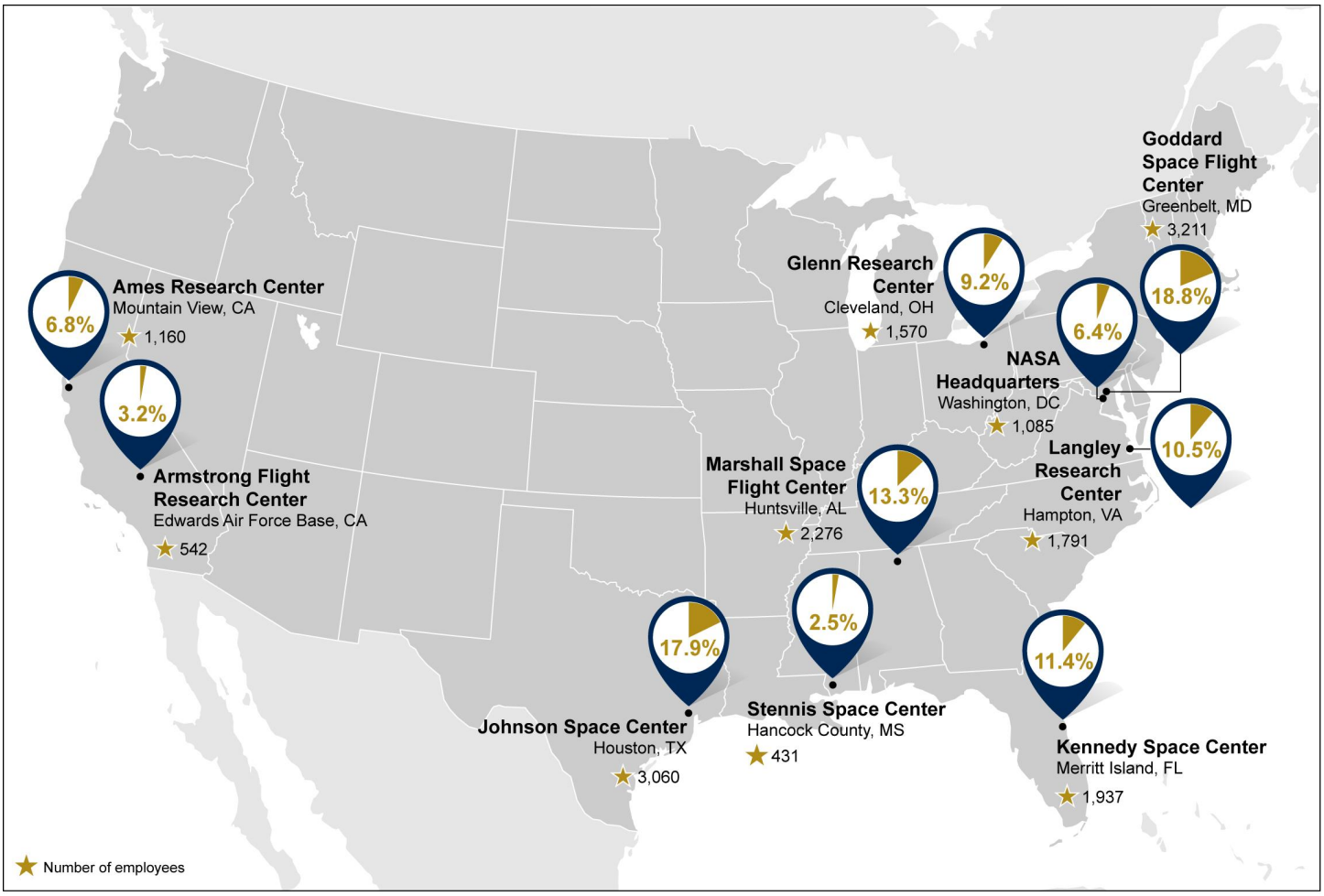
NASA's Workforce

In January 2018, NASA had a civil servant workforce of approximately 17,100 employees distributed among NASA Headquarters in Washington, D.C., and nine centers located around the country. Figure 3 shows the distribution of this workforce across NASA headquarters and the centers.

[10]A rebaseline is a process initiated if development costs increase by 30 percent or more and requires the NASA Administrator to transmit 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.

[11]GAO, *NASA: Preliminary Observations on the Management of Space Telescopes*, GAO-18-277T (Washington, D.C.: Dec. 6, 2017).

Figure 3: NASA's Workforce Distribution at NASA Headquarters and Centers as of January 2018



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-18-280SP

Note: Civil servant staff within NASA's Shared Services Center are included in the total for the Stennis Space Center because the center is located there.

NASA also relies on a contractor workforce to accomplish its mission. NASA estimated that approximately 33,100 contractors would support NASA in 2018. The Jet Propulsion Laboratory is a federally funded research and development center under contract with NASA and is managed by the California Institute of Technology. It has about 5,500 employees, who primarily conduct NASA-related work. The Applied Physics Laboratory is a research center affiliated with Johns Hopkins University and has about 6,300 employees, some of whom manage and support NASA projects.

Portfolio Cost and Schedule Deteriorated but Extent of Cost Growth Is Unknown

The cost and schedule performance of NASA's portfolio of major projects has deteriorated since last year, but the extent of cost performance deterioration is unknown. NASA lacks a current cost estimate for its Orion crew capsule—one of the largest programs in the portfolio—but expects the program will exceed its cost baseline when NASA updates the program's life-cycle cost estimate. Because the Orion program accounts for about 22 percent of all development costs, even a small percentage of cost growth for the Orion program could significantly affect cost performance. The known negative cost and schedule performance is largely driven by the cost and schedule growth of four projects—SLS, EGS, Space Network Ground Segment Sustainment (SGSS) and Mars 2020—that experienced technical problems compounded by programmatic challenges. Together, these projects experienced $638 million in cost growth and 59 months in aggregate schedule delays. Two projects—JWST and ICESat-2—experienced schedule delays due to technical challenges identified during integration and test. Another 3 projects—NASA ISRO Synthetic Aperture Radar (NISAR), Ionospheric Connection Explorer (ICON), and Gravity Recovery and Climate Experiment Follow-On (GRACE-FO)—experienced cost growth or delays largely due to factors outside of the projects' control, such as launch vehicle delays.

NASA is at risk of continued cost increases and schedule delays as newer, complex projects begin development and expensive projects linger in the portfolio longer than expected due to delays. Several projects that experienced schedule delays or cost increases will face further challenges completing integration and test—the phase of development that often reveals unforeseen challenges that can lead to cost and schedule growth—that could result in additional cost and schedule growth.

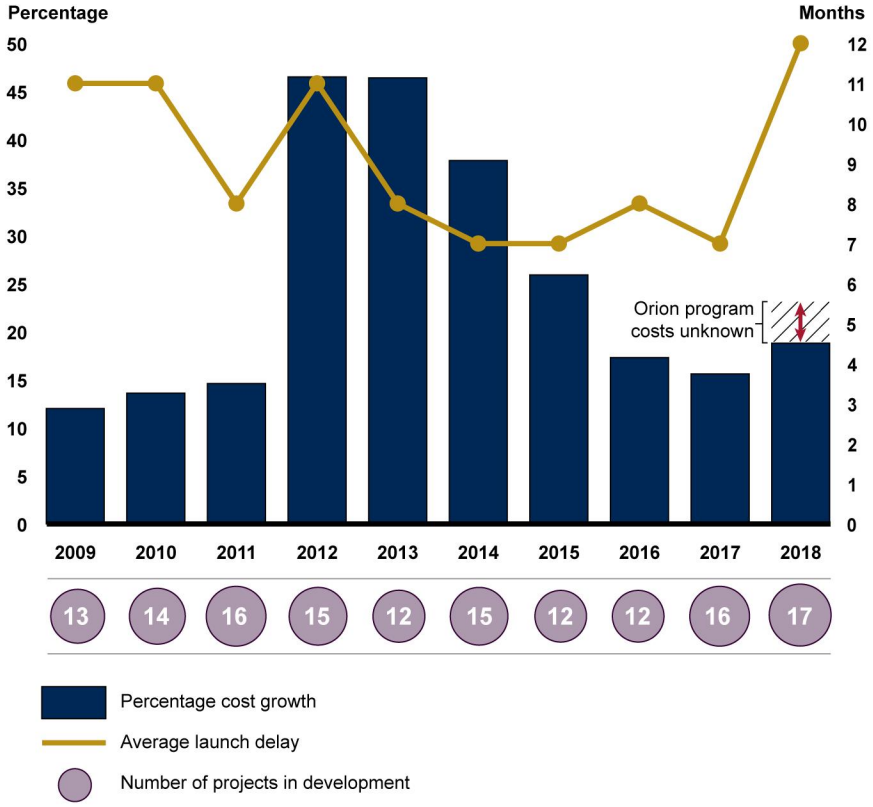
Portfolio Average Launch Delays Increased, but NASA Lacks a Current Orion Program Cost Estimate to Determine Extent of Cost Growth

Since we last reported in May 2017, the average launch delay increased to 12 months, up from 7 months in 2017—the highest schedule delay we have reported to date.[12] We are not able to determine the extent of portfolio cost growth this year because NASA does not have a current cost estimate for the Orion program—one of the largest programs in its portfolio—and officials expect the cost to increase. As of June 2017, the Orion program's development cost was about $6.6 billion and based on that estimate it accounts for 22 percent of the portfolio's estimated $30.1 billion of development costs. As a result, a small percentage of cost growth for the Orion program could significantly affect cost performance. Even without including Orion cost growth, the overall development cost growth for the portfolio of 17 development projects increased to 18.8 percent, up from 15.6 percent in 2017 (see figure 4).[13]

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

[13]We have historically presented cost and schedule performance including and excluding the James Webb Space Telescope (JWST) because, prior to 2015, it had a development cost baseline significantly larger than other projects and the magnitude of its cost growth masked the performance of the remainder of the portfolio. Now that other projects in the portfolio, such as Orion and the Space Launch System, have large development cost baselines, we no longer present cost performance trends excluding JWST.

Figure 4: Development Cost Performance and Average Launch Delay for Major NASA Projects from 2009 to 2018



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-18-280SP

Note: The years in the figure are the year we issued our report. Cost and schedule performance is compared across each report period.

Senior-level NASA officials told us that they expect that the Human Exploration and Operations Mission Directorate and the Orion program will complete an updated life-cycle cost estimate in June 2018. This would be approximately 10 months after the program raised to senior-level officials' attention that the program expects cost growth over its cost baseline to the second combined mission, Exploration Mission 2 (EM-2), during an August 2017 briefing concerning potential cost increases related to the EM-1 launch delay.

Seven of 17 NASA major projects stayed within cost and schedule estimates since we last reported in May 2017, but 9 projects experienced cost growth or schedule delays and cost growth is expected for the Orion program. Table 2 provides data on the cost and schedule performance for the 17 major projects in development that have cost and schedule

baselines since we last reported on the portfolio's performance in May 2017.[14]

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

Overall performance	Project	Confirmation date	Changes since May 2017		Cumulative performance	
		Year	Cost (millions)	Schedule (months)	Cost (millions)	Schedule (months)
Lower than expected cost	PSP	2014	$0.0	0	-$5.4	0
	GRACE-FO	2014	-$1.6	3	-$2.2	3
	TESS	2014	-$13.1	-2	-$39.9	-2
Within baseline	ICON	2014	$0.0	8	$0.0	8
	SWOT	2016	$0.0	0	$0.0	0
	LCRD	2017	$0.0	0	$0.0	0
	Landsat 9	2017	$0.0	0	$0.0	0
Higher than expected cost	Mars 2020[a]	2016	$12.9	0	$10.7	0
	NISAR	2016	$22.0	0	$22.0	0
Replan[c]	InSight	2014	$0.0	0	$131.7	26
	EGS (EM-1)	2014	$417.8	19	$421.4	19
	SLS (EM-1)	2014	$147.8	19	$147.8	19
Rebaseline[c]	JWST	2008	$0.0	19	$3,607.7	71
	ICESat-2	2012	$1.4	4	$206.3	17
	SGSS[b]	2013	$59.5	21	$421.6	48
Canceled	RBI	2016	$0.0	0	$0.0	0
Under revision	Orion (EM-2)[d]	2015	$0.0	0	-$151.7	0
Total:			**$646.7**	**91**	**$4,770.0**	**209**

Legend: PSP: Parker Solar Probe; GRACE-FO: Gravity Recovery and Climate Experiment Follow-On; TESS: Transiting Exoplanet Survey Satellite; ICON: Ionospheric Connection Explorer; SWOT: Surface Water and Ocean Topography; NISAR: NASA Indian Space Research Organisation – Synthetic Aperture Radar; LCRD: Laser Communications Relay Demonstration; InSight: Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport; EGS: Exploration Ground Systems; SLS: Space Launch System; EM-1: Exploration Mission 1; JWST: James Webb Space Telescope; ICESat-2: Ice, Cloud, and Land Elevation Satellite-2; SGSS: Space Network Ground Segment Sustainment; RBI: Radiation Budget Instrument; Orion: Orion Multi-Purpose Crew Vehicle; EM-2: Exploration Mission 2.

Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-18-280SP

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

[a]The Mars 2020 project used $2.2 million in funds originally budgeted for development for formulation activities. This partially offsets an increase of $12.9 million in development cost growth primarily due to increased costs associated with a technology demonstration instrument and entry, descent, and landing instrument.

[14]GAO-17-303SP.

[b]The SGSS project reported cost growth up through its first operational readiness review, which is currently planned for the end of fiscal year 2019. However, the project expects that there could be additional cost and schedule growth beyond what is reported here.

[c]A replan is a process initiated if development costs increase by 15 percent or more. NASA replanned the SLS program even though 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 development costs increase by 30 percent or more. Both processes require NASA to submit a report to relevant congressional committees. In addition, if a project or program milestone is likely to be delayed by 6 months or more, this report is also required.

[d]NASA officials said they are revising the Orion program's life-cycle cost estimate and expect to complete a new estimate in June 2018. The new cost is expected to exceed the program's development cost baseline. The current costs in the table reflect the estimate provided in June 2017. The cumulative cost change reflects the program shifting $151.7 million of funding previously budgeted for the development phase to the formulation phase.

The deteriorating cost and schedule performance of the portfolio in 2018 is the result of

- four projects—SLS, EGS, SGSS, and Mars 2020—addressing technical challenges that were compounded by risky programmatic decisions;
- two projects—JWST and ICESat-2—experiencing delays due to technical challenges identified during integration and test; and
- three projects—NISAR, ICON, and GRACE-FO—experiencing cost growth or delays largely due to factors outside of the projects' control.

We elaborate on these three scenarios below.

Technical challenges compounded by risky programmatic decisions. Together, SLS, EGS, SGSS, and Mars 2020 experienced $638 million in cost growth and 59 months in aggregate schedule delays due to technical problems that were compounded by programmatic challenges since our May 2017 report.[15] The SLS and EGS programs experienced cost growth and schedule delays associated with EM-1, their first combined mission along with the Orion program. We have found for several years that the human spaceflight programs—Orion, SLS, and EGS—are making progress maturing designs and building hardware, but also are experiencing some significant engineering and manufacturing challenges. For example, the SLS program ran into numerous challenges completing the welding of its core stage element in 2017. The program stopped welding on the core stage for months to identify and resolve low weld strength in the liquid oxygen and liquid hydrogen tanks due to low weld strength measurements found in the liquid oxygen tanks caused by

[15]GAO-17-303SP.

a program and contractor decision to change the weld tool configuration during fabrication. The EGS program also experienced technical challenges, including with the design and installation of the ground support equipment and the 10 umbilicals that connect SLS and Orion to the Mobile Launcher—which supports the assembly, testing, and servicing of SLS and provides the platform on which SLS and Orion will launch.

Finally, although the Orion program has not yet reported cost growth, it also experienced technical challenges. These challenges included software delays and hardware delays, and at least 14 months of delays with the European Service Module—which provides air, water, power, and propulsion to Orion during in-space flight—since the element's critical design review in June 2016. In April 2017, we found that, according to program officials, the delays with the service module were largely due to NASA, the European Space Agency, and the European Space Agency contractor underestimating the time and effort necessary to address design issues for the first production service module and the availability of parts from suppliers and subcontractors. NASA expects the Orion program to experience cost growth over its cost baseline to the second combined mission, EM-2. However, the extent of the growth is unknown because, as noted above, NASA is currently revising its life-cycle cost estimate.

Technical challenges such as these are not unusual for large-scale programs, especially human exploration programs that are inherently complex and difficult. However, we have found that NASA has made programmatic decisions—including establishing low cost and schedule reserves, managing to aggressive schedules, and not following best practices for earned value management or creating reliable cost and schedule baselines—that have compounded the technical challenges (see table 3). As a result, the three human spaceflight programs have been at risk of cost and schedule growth since NASA approved their baselines.

Table 3: Examples of Risky Programmatic Decisions Made by NASA's Human Spaceflight Programs

Programmatic decision	Example(s)	Negative effect	GAO report(s)
NASA baselined the Exploration Ground Systems (EGS), Orion Multi-Purpose Crew Vehicle (Orion), and Space Launch System (SLS) programs with low cost and schedule reserves.	In July 2016, we found that NASA baselined the SLS program with cost reserves of less than 2 percent, even though guidance for Marshall Space Flight Center—the NASA center with responsibility for the SLS program—established standard cost reserve for launch vehicle programs of 20 percent when the baseline is approved.	Operating with low cost and schedule reserves limits a program's ability to address risks and unforeseen technical challenges.	GAO-17-414 and GAO-16-612
NASA managed the EGS, Orion, and SLS programs to an internal schedule for completing development production that was aggressive and could exacerbate delays and lead to cost overruns.	In July 2016, we found that the EGS program planned to conduct the mobile launcher's verification and validation concurrent with ground support equipment systems and umbilicals installation to support the program's internal schedule goal. We found this to be a risky practice because of uncertainties regarding how systems not yet installed may affect the systems already installed.	Working towards a more aggressive internal goal is not a bad practice; however, increasing cost and schedule risk to the program in order to pursue such a goal is not beneficial to programs in the long term.	GAO-16-620 and GAO-16-612
The SLS program did not follow best practices for using earned value management, which integrates the project scope of work with cost, schedule, and performance elements for optimum project planning and control.	In July 2016, we found that the SLS program had not positioned itself well to provide accurate assessments of progress with the core stage because it operated for several years without a performance measurement baseline that is necessary to support full earned value management reporting. The use of earned value management is advocated by both GAO's best practices for cost estimating and NASA's own guidance.	Programs that do not use earned value data are limited in their ability to have accurate assessments of project progress, produce early warning signs of impending schedule delays and cost overruns, and provide unbiased estimates of anticipated costs at completion.	GAO-16-612
The Orion and SLS programs established baselines that were not fully reliable.[a]	In July 2016, we found that the Orion program did not generally follow best practices in preparing its cost and schedule estimates, which were key inputs into the program's joint cost and schedule confidence level processes and baseline. In July 2015, we found that cost and schedule estimates for the SLS program substantially met five of six characteristics that GAO considers best practices for preparing reliable estimates, but could not be deemed fully reliable because they only partially met the sixth characteristic—credibility.	Without sound cost and schedule estimates, decision makers do not have a clear understanding of the cost and schedule risk inherent in the program or important information needed to make programmatic decisions.	GAO-16-620 and GAO-15-596

Source: GAO analysis of prior GAO reports. | GAO-18-280SP

[a]We did not assess EGS's cost and schedule estimates compared to best practices.

In December 2017, NASA announced the new internal launch readiness date for EM-1 is now December 2019, and has allocated 6 months of schedule reserve available to extend the date to June 2020 for possible manufacturing and production schedule risks. This represents a delay of 13-19 months for EM-1. It is too soon to know if NASA has addressed the programmatic challenges identified above but we will continue to follow up through future reviews.

Similarly, the SGSS project experienced new cost growth of $59.5 million and delayed its completion by 21 months. Project officials attributed the cost growth and delays to the contractor's incomplete understanding of its requirements, which led to poor contractor plans and late design changes. But project management has been a challenge as well.[16] The project has historically struggled to manage contractor performance and has faced both contractor and project staffing shortfalls, as we found in our prior reports starting in 2013.[17] For example, NASA managers noted concerns with contractor plans and staffing estimates in 2013 during project confirmation. In March 2015, we found that the project was being rebaselined due to the contractor's poor cost and schedule performance and limitations that NASA placed on the funding available to the contractor in fiscal years 2014 and 2015. The contractor was also operating with a limited number of staff at that time. In May 2017, we found that the project continued to experience contractor performance problems and had experienced cost growth and schedule delays over the 2015 rebaseline even as the project decreased its scope. In addition, the project experienced staff shortfalls in key areas, such as systems engineering and business management.

The Mars 2020 project experienced $12.9 million in development cost growth, but no schedule delays. The cost growth was primarily due to technical challenges on a technology demonstration instrument and

[16]In 2016, NASA announced it was reclassifying SGSS as a hybrid sustainment project for the Space Network. A hybrid sustainment effort is a sustainment effort that still includes development work. The SGSS project expects to experience additional cost growth and schedule delays, but the exact magnitude is unknown. The project was reevaluating its cost and schedules through its final acceptance review at the time of our review.

[17]GAO, *NASA: Assessments of Selected Large-Scale Projects*, GAO-13-276SP (Washington, D.C.: Apr. 17, 2013); *NASA: Assessments of Selected Large-Scale Projects*, GAO-14-338SP (Washington, D.C.: Apr. 15, 2014); *NASA: Assessments of Selected Large-Scale Projects*, GAO-15-320SP (Washington, D.C.: Mar. 24, 2015); *NASA: Assessments of Major Projects,* GAO-16-309SP (Washington, D.C.: Mar. 30, 2016); and GAO-17-303SP.

higher than anticipated integration costs for an entry, descent, and landing instrument. Both instruments are funded by the Human Exploration and Operations and Space Technology Mission Directorates. NASA officials attributed the cost growth of the technology demonstration instrument—which is designed to convert carbon dioxide to oxygen—to the complexity of the technology development for the effort. At the project's preliminary design review in February 2016, a critical technology for the technology demonstration instrument did not meet the recommended level of maturity, which we have found can increase risk for systems entering product development. The project had matured the technology to this recommended level by its critical design review in February 2017. However, as a result of the focus on maturing this particular technology, other components of the instrument fell behind the planned schedule. Project costs for Mars 2020 also increased for an entry, descent, and landing instrument, due, in part, to cost increases for integration and to add additional staff to the instrument team to maintain schedule.

Finally, the RBI project would have likely exceeded its cost baseline if NASA had not decided to cancel the project in January 2018. According to NASA's cancellation memorandum, the project was canceled because of continued cost growth, technical issues, and poor contractor performance. In 2017, we found that the project was working to an aggressive schedule, and the prime contractor continued to experience cost overruns even after NASA added a deputy project manager and increased site visits and meetings with the contractor.[18] Subsequently, the project—which was developing an instrument to be hosted on a National Oceanic and Atmospheric Administration satellite—determined that it would not be able to meet its delivery date for integration with the satellite without requiring additional funding in excess of the project's cost baseline if other technical issues arose. In its cancellation memorandum, NASA stated continuing to fund RBI from within the Earth Science Division budget would slow other important activities.

Technical challenges identified during integration and test. The JWST and ICESat-2 projects experienced technical challenges during integration and test that delayed their schedules. Both projects were previously rebaselined before entering system-level integration and testing, and the current schedule delays are beyond the new schedules

[18]GAO-17-303SP.

that NASA set for the projects in 2011 for JWST and in 2014 for ICESat-2.

- The JWST project delayed its launch readiness date by at least 19 months from October 2018 to May 2020. NASA announced two delays for the project since our last portfolio-wide review in May 2017.[19] First, as we found in February 2018, the project delayed its launch readiness date by up to 8 months primarily due to the integration of the various spacecraft elements taking longer than expected.[20] Specifically, execution of spacecraft integration and test tasks, due to complexity of work and cautious handling given the sensitivity of flight hardware, was slower than planned. In addition, before the delay, the project used all of its schedule reserves to its prior launch readiness date. This was the result of various contractor workmanship errors, particularly with respect to the spacecraft propulsion systems, as well as the resolution of various technical issues, including a test anomaly on the telescope and sunshield hardware challenges. Second, in March 2018, NASA announced that it had delayed the project's launch readiness date by an additional 11 months to approximately May 2020 and planned to establish an external independent review board to analyze the project's organizational and technical issues to inform a more specific launch time frame.

  The announcement also stated that after a new launch date is established, NASA would provide a new cost estimate that may exceed the $8 billion congressional cost cap that was established in 2011. NASA plans to finalize the project's cost and schedule in June 2018. Because the additional delays were announced while a draft of this report was with NASA for comment, we plan to follow up on the reasons for the additional delays and the results of the analysis in a future review.

- The ICESat-2 project delayed its launch readiness date by 4 months from June to October 2018 due to technical issues with its only instrument, the Advanced Topographic Laser Altimeter System. A key part in the instrument's lasers failed during instrument environmental testing, which delayed the project's system integration review—the start of system-level integration and test. The manufacturer determined the primary cause of the anomaly was a flaw in the design

[19]GAO-17-303SP.

[20]GAO-18-273.

of the mount that ensures a component of the optical module remains in a specific, precise position. The spare flight laser encountered the same problem during earlier testing, which indicated a systemic problem. The project redesigned and repaired the lasers and is proceeding through integration and test.

External factors. External factors—including responding to requests for additional data collection and delays due to launch-vehicle related issues—contributed to cost increases or schedule delays for the NISAR, ICON, and GRACE-FO projects.

- The NISAR project experienced cost growth as the result of an increase in the scope of data collection in response to additional data needs being identified by an interagency working group. The additional data includes soil moisture and natural hazard data that would be of value for other federal agencies and the science community. NASA officials said the additional funding for development would be used to upgrade the ground stations so that they can receive the additional data at a higher downlink data rate and volume.
- The ICON project missed its committed launch readiness date because of an accident involving its launch vehicle. In January 2017, two of the Pegasus launch vehicle's three stages were involved in a transport accident. The stages were subsequently returned to the launch vehicle contractor facility for inspection and testing, and no damage was found. The project had been on track to launch early. Subsequently, in September 2017, an anomaly found in testing of the launch vehicle bolt cutter assemblies resulted in additional delays, but the magnitude of these delays is not yet known; an investigation is underway.
- The GRACE-FO project delayed its launch readiness date from February to May 2018 due to issues with its planned launch vehicle and launch site. The launch vehicle is the responsibility of NASA's partner on the project—German Research Centre for Geosciences (GFZ). GRACE-FO had planned to launch at a Russian launch site. In February 2016, GFZ reported that it was notified by the Russian Federal Space Agency that the Dnepr launch vehicle was no longer available for GRACE-FO. GFZ, in June 2016, arranged to launch the two GRACE-FO spacecraft, along with commercial satellites, on a SpaceX Falcon 9.

In addition, the Commercial Crew Program also experienced delays, which are not included above because the program does not have a schedule baseline. Since the award of the current Commercial Crew

contracts in September 2014, the program, Boeing, SpaceX, and multiple independent review bodies have all identified the contractors' delivery schedules as aggressive. In February 2017, we found that Boeing and SpaceX had determined that neither could meet their original 2017 dates for NASA to certify their systems for human spaceflight.[21] In January 2018, we found that both contractors had notified NASA that final certification dates have slipped again and are now in the first quarter of calendar year 2019.[22] The Commercial Crew Program's schedule analysis indicates that certification may be further delayed to December 2019 for SpaceX and February 2020 for Boeing.

NASA Is at Risk of Continued Cost Increases and Schedule Delays as Newer, Complex Projects Begin Development and Expensive Projects Linger

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.[23] Of the 14 projects in NASA's current portfolio of major projects that have held a critical design review, 3 had to rebaseline before holding a system integration review. An additional 4 projects experienced cost growth after critical design review, but the cost growth did not require a rebaseline. Further, most of the projects that have experienced cost growth during this risky point in the development cycle are not small projects. All but one has a current life-cycle cost estimate of over $1 billion and include NASA's flagship missions, like JWST and Mars 2020. The total development cost growth for these 7 projects is about $4.9 billion to date, but additional cost growth could occur as the projects are not yet complete.

The composition of the portfolio in the coming years is expected to include similarly large and complex projects, putting NASA at risk of continued cost increases and schedule delays. Specifically, NASA plans to have complex projects enter the development portfolio in the next few years as they hold confirmation reviews and set cost and schedule baselines. This includes the Europa Clipper project and potentially the Wide-Field Infrared Survey Telescope (WFIRST) project. In February

[21]GAO-17-137.

[22]GAO-18-317T.

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

2018, the President's 2019 Budget Request proposed canceling the WFIRST project due to the project's significant costs and higher priorities in the agency. However, the project may continue if funding is received. Together, preliminary estimates indicate that these two projects could cost as much as $7.8 billion. In addition, NASA expects to begin other large, complex projects like the Lunar Orbital Platform-Gateway—currently being discussed as a space station or outpost in lunar orbit—and a Europa Lander project in the coming years. A December 2017 space policy directive also instructed NASA to return astronauts to the moon for long-term exploration and to pursue human exploration of Mars and the broader solar system.

To its credit, NASA recently took steps to put a process in place to control the costs of two projects while in formulation, which may prove useful if properly executed.

- The Europa Clipper project implemented a process whereby cost growth threats would be offset by descoping instruments in whole or in part. For example, if an instrument exceeds its development cost by 20 percent, the project would propose a descope option to NASA that brings instrument cost below that threshold. NASA has not descoped any instruments to date.
- The WFIRST project is responding to findings from an independent review that was conducted to ensure the mission's scope and required resources are well understood and executable. The review found that the mission scope is understood, but not aligned with the resources provided and concluded that the mission is not executable without adjustments and/or additional resources. For example, the study team found that NASA's current forecasted funding profile for the WFIRST project would require the project to slow down activities starting in fiscal year 2020, which would result in an increase in development cost and schedule. NASA agreed with the study team's results and directed the project to reduce the cost and complexity of the design in order to maintain costs within the $3.2 billion preliminary cost target.

But even with these efforts, NASA's cost and schedule performance may be further tested in upcoming years as some expensive, complex projects linger in the portfolio longer than expected.

- As previously discussed, the Orion program expects cost growth and faces other schedule and technical risks as it moves through the integration and test phase for EM-1 into at least 2019 and then

through 2023 for EM-2. As of August 2017, NASA officials expected that new hardware and addressing development challenges would be the factors contributing to increased cost for the program. For example, there was a cost impact when the program moved from a single-piece, or monolithic, heatshield design to one that employs blocks in order to improve its structural strength. Program officials said they are also assessing schedule delays for EM-2, and noted that the EM-2 launch date depends on the outcome of the EM-1 launch date.

- The SLS and EGS programs continue to face cost, schedule, and technical risks as they move through the integration and test phase into at least 2019. For example, SLS will have to complete a “green run” test which requires multiple first-time efforts. Specifically, the test is the culmination of the development effort and includes the core stage integration with its four main engines, fully fueling with cryogenic hydrogen and oxygen, and then firing all four engines for about 500 seconds. NASA currently has no schedule reserve to its target December 2019 launch readiness date for two key areas in the core stage schedule. First, there is no reserve between the end of core stage production and the delivery of the core stage to the test facility. Second, there is no reserve between the end of the testing and delivery to Kennedy Space Center for final integration and testing prior to launch.
- As previously discussed, the JWST project is at risk of exceeding its congressional cost cap, and faces schedule risks as it completes its remaining integration and test work. These activities have taken considerably longer than planned due to a variety of challenges, including reach and access limitations on the flight hardware. Additionally, the project faces significant work ahead. For example, the project must complete integration of spacecraft element hardware and conduct deployment and environmental tests of the integrated sunshield and spacecraft. Further, it must integrate the telescope element with the spacecraft element to form the JWST observatory, and complete another set of challenging environmental tests on the full integrated observatory. At the same time, the project will need to mitigate dozens of remaining hardware and software risks to acceptable levels and address the project’s many potential single point failures to the extent possible.
- The SGSS project expects to experience additional cost growth through the final acceptance review because the full scope of the effort has not been included in the cost. NASA only approved its new cost estimate through the initial operational readiness review,

currently planned for September 2019. A project official said NASA headquarters asked the project to determine if there are ways to reduce the cost between the operational readiness review and the final acceptance review. NASA plans to conduct an independent review of the project in mid-2018 to inform a decision on whether to continue the project past the operational readiness review. If NASA decides to continue the project past this review, additional cost growth is expected for SGSS when NASA revisits project costs through future budget cycles.

NASA Generally Maintained Technology Maturity of Its Projects but Performance in Design Stability Measures Is Mixed

NASA has generally maintained the technology maturity and number of critical technologies of its major projects, but had mixed performance in design stability measures. Most of NASA's major projects in development matured their technologies to the level recommended by best practices by their preliminary design review—continuing a trend since 2015. 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. Of the three projects that held preliminary design review in 2017, one matured its technologies to the level recommended by GAO best practices. The average number of critical technologies decreased in 2018 because new projects in the portfolio reported one or no critical technologies. NASA has maintained the level of design stability at critical design review, but projects continued to experienced late design changes. Of the three projects that had held critical design review in 2017, one met the best practice of releasing 90 percent of engineering drawings by this review. In addition, the average percentage of released drawings for the portfolio—meaning the average of the percentage of drawings released for each project in the portfolio for each reporting period—has remained generally consistent with the past 5 years. We have previously found that releasing at least 90 percent of engineering drawings lowers the risk of projects experiencing design changes and manufacturing problems that can lead to cost and schedule growth.

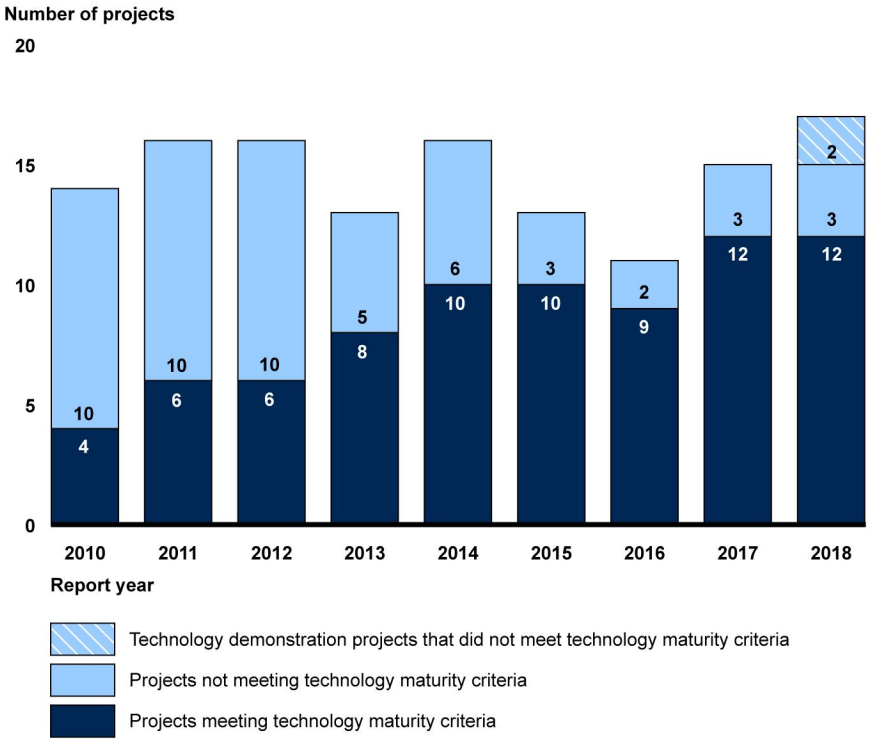
NASA Generally Maintained the Technology Maturity of Its Projects

Most of NASA's major projects in development—12 of 17 projects—met the best practice of maturing all technologies to a technology readiness level 6 by their preliminary design review, which is a generally consistent trend since 2015 (see figure 5).[24] 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.[25] Projects falling short of this standard may experience subsequent technical problems, which can result in cost growth and schedule delays. Appendix IV provides a description of technology readiness levels, which are the metrics used to assess technology maturity.

[24]NASA distinguishes critical, or new, technologies from heritage technologies. Our product development best practices do not make this distinction. We describe critical technologies as those that are required for the project to successfully meet customer requirements, which can include both existing or heritage technology or new technology. Therefore, to assess overall technology maturity, we analyzed the maturity of heritage and critical technologies that NASA reported for projects in our data collection instrument. In other analyses, which focus on the number of new technologies being used by programs, we maintain NASA's distinction between critical and heritage technologies.

[25]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.

Figure 5: Number of NASA's Major Projects Attaining Technology Maturity by Preliminary Design Review from 2010 to 2018



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-18-280SP

Note: Includes projects that completed preliminary design review and identified critical or heritage technologies. For example, for 2018, 17 of 26 NASA major projects had held this review and identified critical or heritage technologies.

This year, we removed one project—Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer (OSIRIS-REx)—from our analysis of technology maturity because it launched in September 2016. We added three projects—Landsat 9, LCRD, and Restore-L—which held their preliminary design review before February 2018. Of the three projects that were added, only one—Landsat 9—matured its technologies to a technology readiness level 6. The other two projects—Restore-L and LCRD—did not meet our technology maturity best practice.

The LCRD and Restore-L projects are technology demonstrations managed by the Goddard Space Flight Center, and the center's policy does not require technology demonstrations to mature all of their

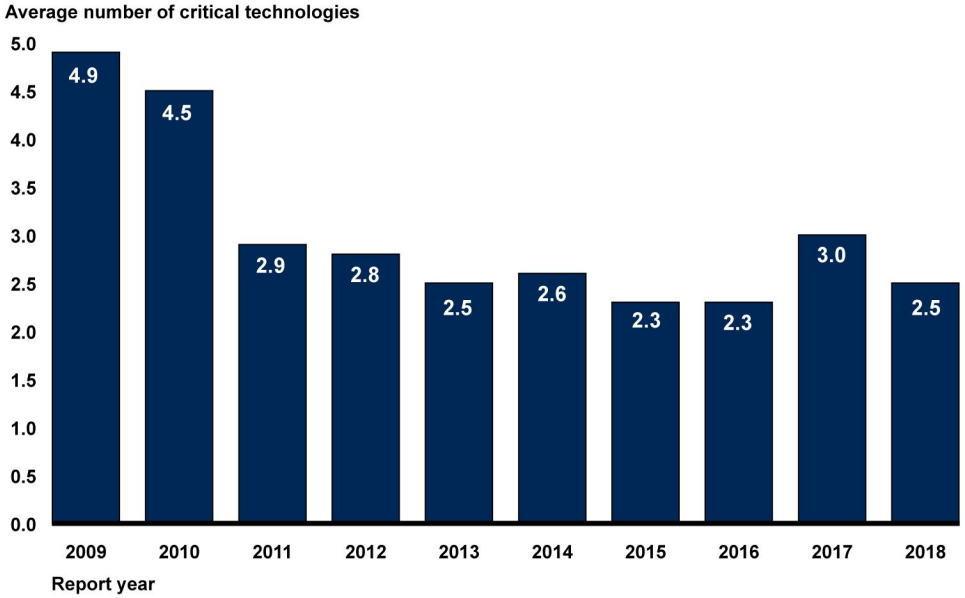
technologies to technology readiness level 6 by preliminary design review.[26] NASA officials explained that this is because the purpose of some technology demonstration projects is to mature new technologies to technology readiness level 6 or higher by the end of the demonstration, making it not feasible 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. Therefore, the same risks of subsequent technical problems that can result in cost growth and schedule delays identified in our best practices work applies to these projects. The LCRD project matured its technologies to technology readiness level 5 by its preliminary design review and to a technology readiness level 6 by its critical design review. The Restore-L project matured all but one of its technologies. The project changed its vision navigation system shortly before its preliminary design review because its prior vision navigation system did not meet requirements and the contractor was unable to resolve the issue. Restore-L project officials stated that they have a plan in place to mature the new system to a technology readiness level 6 by summer 2018, prior to the project's planned critical design review in January 2019.

NASA's major projects continue to report low numbers of critical technologies.[27] The average number of critical technologies for the projects in development declined to 2.5 compared to last year's average of 3 critical technologies; however, the average is consistent with the last several years (see figure 6). The decrease in critical technologies was driven by the addition of three projects—Landsat 9, LCRD, and Restore-L—that reported one or no critical technologies and the exclusion of OSIRIS-REx, which had 3 critical technologies.

[26]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.

[27]Projects self-report the number of their critical technologies.

Figure 6: Average Number of Critical Technologies Reported by NASA's Major Projects in Development from 2009 to 2018



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-18-280SP

NASA's most recent Discovery project selections—Lucy and Psyche—continue its trend of low reported critical technologies, but are not yet included in our analysis because they have not held preliminary design review. These projects reported no critical technologies and plan to use a design that is based heavily on heritage technologies with modifications. Both projects reported that their heritage technologies are mature, but plan to modify some technologies. We have previously found that mature technologies must be demonstrated in a relevant environment and should be very close to form, fit, and function. Therefore, these two projects will likely have developmental work despite using high-heritage, mature technologies in their designs.

GAO's best practices criteria do not focus on the number of new technologies, but rather their maturity, when considering their effect on cost and schedule risk. Therefore, the issue is not whether to push innovation through technology development, but rather the steps projects take to increase the likelihood of mission success by maturing these technologies to a high level prior to entering the implementation phase.

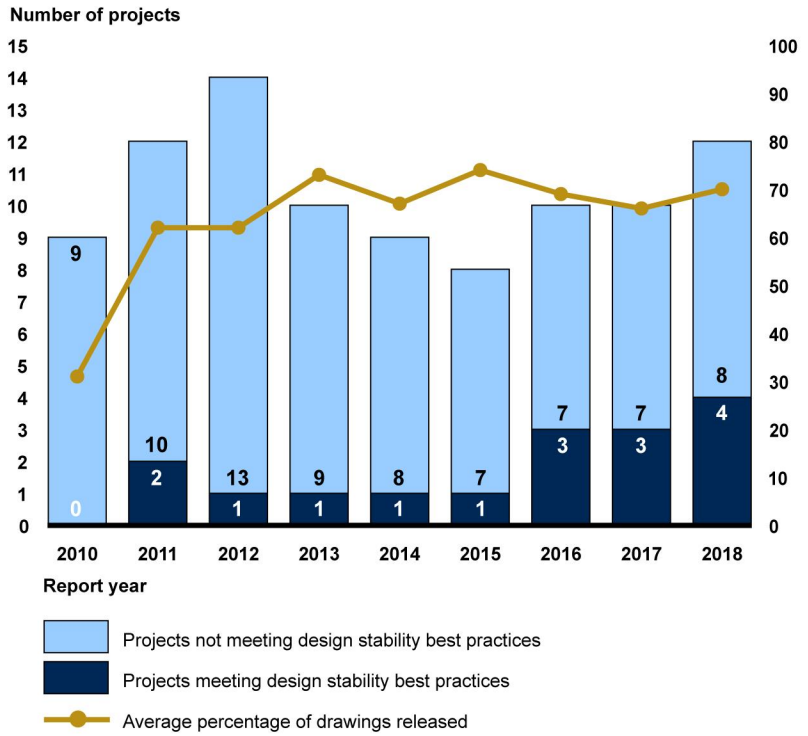
NASA Has Maintained the Level of Design Stability at Key Design Review, but Late Design Changes Still Occurred

NASA has maintained the number of projects with stable designs at critical design review. The critical design review is the time in the project's life cycle when the integrity of the project design and its ability to meet mission requirements is assessed. 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 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, four released at least 90 percent of their current projected engineering drawings (see figure 7).[28] In addition, the average percentage of released drawings for the portfolio has remained generally consistent with the past 5 years.

[28]We used the number of drawings released at the critical design review as a fraction of the total number of drawings currently projected. Therefore, the denominator in the calculation may have been larger than what was projected at the critical design review. We believe this calculation more accurately reflects the design stability of the project.

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



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-18-280SP

Note: Includes projects that completed critical design review and had engineering drawings. For example, for 2018, 12 of 26 NASA major projects had held this review and had engineering drawings.

This year, in analyzing the number of projects that met the best practice, we added 3 projects and removed 1 project. One of the 3 projects that were added to the analysis this year—RBI—met the best practice. The other two projects, LCRD and Mars 2020, did not meet the best practice. The LCRD project released over 90 percent of its design drawings in December 2016 at its critical design review, but reported design drawing growth in January 2018. As a result of the drawing growth, the metric of drawings released at this review decreased to 78 percent, which is below the best practice. The Mars 2020 project held its critical design review before it had a stable design, at which point it had released about 72 percent of its expected design drawings. Project officials stated that they held the design review earlier than normal to avoid delaying the development of heritage technologies, which make up a large percentage of the Mars 2020 rover. As a result of holding the review early, new and

highly complex developments were not stable at the time of the design review.

Our analysis of design drawings dropped one project—OSIRIS-REx—in 2018 and removed the EGS program from prior years' analyses. We excluded EGS from prior years because program officials told us that the prior data submissions were not inclusive of all subsystems and they did not have a way to replicate previous data submissions to include all of the subsystems. Further, EGS program officials stated they do not use design drawings as a management tool. EGS program officials said that the program used a different approach for tracking design maturity because the program contains several major construction and facilities efforts. This approach included tracking requirements stability, internal and cross-program technical assessments, interface control document maturation, and closure of open work. However, because some of these efforts required new development work, tracking the release of and changes to engineering design drawings at the program level would have been a valuable metric for the program to monitor. We will follow up on this issue in a future review.

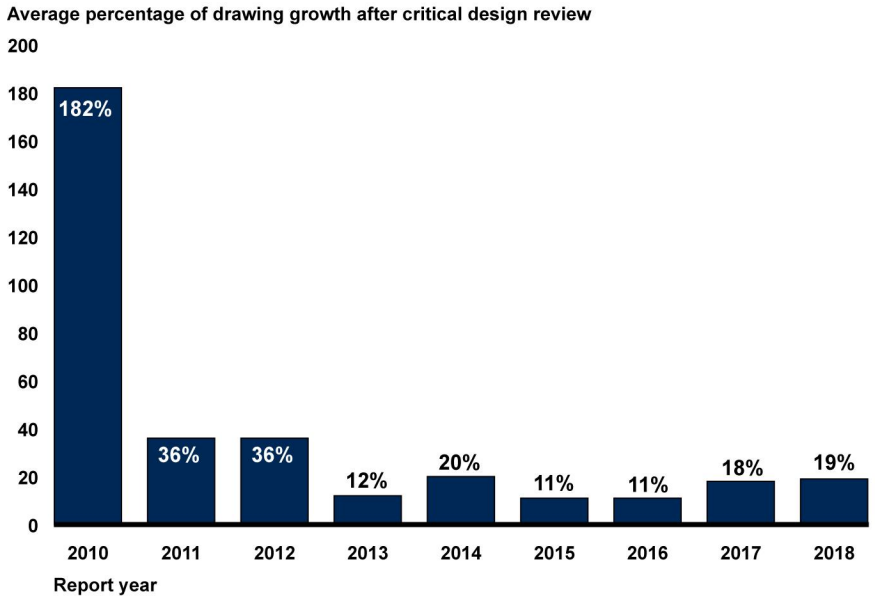
Despite an increase in the number of projects meeting GAO's best practice, some of the 8 projects that did not meet the best practice released a low percentage of their drawings by the critical design review. Five of the 8 projects that did not meet the best practice released fewer than 60 percent of their projected engineering drawings. For example, in 2016 we found that the Parker Solar Probe project held its critical design review with only 34 percent of its design drawings released, significantly lower than the best practice of 90 percent.[29] The project demonstrated it had a stable design at its system integration review in May 2016—over one year after its critical design review, the point at which product development best practices recommend having a stable design.

In addition to maintaining the level of design stability at critical design review, NASA major projects also experienced design changes at a similar level as last year. The average percentage of drawing growth for the entire portfolio slightly increased from 18 percent to 19 percent (see figure 8). Of the 12 projects included in this year's analysis, 11 experienced drawing growth after their critical design review, ranging from 2 to 52 percent. If a project experiences a large amount of engineering

[29]GAO-16-309SP.

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 reengineered or reworked as a result. This analysis dropped OSIRIS-REx in 2018 and the EGS program in prior years for reasons discussed above.

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



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-18-280SP

Note: 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.

NASA projects have continued to perform well against other design stability measures, such as maintaining center-specified mass and power margins, and completing a validation and verification plan.[30] Most projects for which mass and power requirements were applicable met these requirements at their critical design reviews and have continued to

[30]Validation is defined as the continuous process of ensuring that requirements are well-formed (clear and unambiguous), complete (agrees with customer and stakeholder needs and expectations), consistent (conflict free), and individually verifiable and traceable to a higher level requirement or goal. Verification is defined as proof of compliance with requirements and specifications.

maintain the required levels of margin.[31] Further, all projects that were required to complete a validation and verification plan by their critical design review met the requirement. NASA requires that projects complete a validation and verification plan by this review to ensure that projects have a plan in place to track the completion of verification and validation events and activities.

Too Early to Determine Outcome of NASA's Efforts to Address Workforce Challenges

Several projects covered in our review were experiencing workforce challenges, such as not having enough staff or staff with the right skills. While it is difficult to tie these workforce challenges to increases in cost, there have been instances where projects have reported schedule delays or late design changes as a result of workforce shortages. Our work has generally found that the shortage of trained acquisition personnel hinders agencies from managing and overseeing acquisition programs and contracts that have become more expensive and increasingly complex.[32] Moreover, NASA's own assessments indicate that there are broader workforce-related challenges that can have a negative impact on programs over the long run, if not addressed in a strategic manner. NASA is taking steps to address its findings, but it is too early to determine the outcomes. One is focused on developing a strategic workforce plan, including determining what mix of skills and capabilities are needed in the future, and the other is focused on leveraging skills across NASA's centers. We will be tracking NASA's progress in this area in future reviews as capacity—having the right people and resources to resolve risk—is one of two criteria that NASA has not yet met for removal from our high-risk list.[33]

[31]Mass is a measurement of how much matter is in an object. It is related to an object's weight, which is mathematically equal to mass multiplied by acceleration due to gravity. Margin is the spare amount of mass or power allowed or given for contingencies or special situations. Some centers provide guidance on the percentage of mass margin required at various points in project development, with required margins ranging from 30 to 0 percent, depending on where a project is in the development cycle.

[32]GAO, *Acquisition Workforce: Federal Agencies Obtain Training to Meet Requirements, but Have Limited Insight into Costs and Benefits of Training Investment,* GAO-13-231 (Washington, D.C.: Mar. 28, 2013).

[33]GAO-17-317.

NASA Has Experienced Workforce Challenges on Major Projects

During the course of our review, we found that several major projects identified workforce challenges, including not having enough staff or staff with the right skills. To accomplish its scientific and space exploration missions, NASA relies on having a skilled civil servant and contractor workforce. While it is difficult to tie these workforce challenges to increases in cost, there have been instances where projects have reported schedule delays or late design changes as a result of workforce shortages. Further, our work has generally found that the shortage of trained acquisition personnel hinders agencies from managing and overseeing acquisition programs and contracts that have become more expensive and increasingly complex.[34] Examples of workforce challenges identified by projects include:

- The Mars 2020 project, which is managed by the Jet Propulsion Laboratory, experienced workforce shortages in several key areas such as flight software and for the development of a sampling and caching system that will collect and cache Martian soil and rock samples. Project officials said not having staff with the right level of experience within its sampling and caching system development contributed to the project being behind in releasing its engineering drawings. As of June 2017, project officials said the Jet Propulsion Laboratory has been able to address these workforce challenges largely because laboratory management prioritized staffing for the project over other projects.
- The Europa Clipper project, which is managed by the Jet Propulsion Laboratory, experienced workforce shortages in several key areas, including avionics, since October 2016. The project has revised staffing plans several times, but continues to face workforce shortages even with NASA headquarters involvement. Project officials said these shortages have delayed development in some areas and have led the project to outsource some work to contractors. As of January 2018, project officials reported that they have seen improvements in addressing workforce shortages.
- The SGSS project, managed by the Goddard Space Flight Center, faced staffing shortfalls in key areas, such as systems engineering

[34] GAO-13-231.

and business management, which contributed to late design changes. For example, a project official said the systems engineering was not done correctly before, which led to the software not being coded to the right requirements. As of January 2018, NASA officials stated that these workforce issues had largely been resolved because some positions were filled by reassigning staff to these areas and others are no longer needed.

- The EGS program, which is managed by Kennedy Space Center, is working with its contractors to increase its software development staff retention rate, which has been a challenge. Program officials said the current retention rate is about 70 percent, but the program would like that to be higher in order to avoid additional delays in its software development efforts due to losing staff. The officials attributed the contractor workforce challenges to competition in the space industry near the center in Florida.

Further, in January 2018, the NASA Office of Inspector General found that the SWOT project, which is managed by the Jet Propulsion Laboratory, experienced workforce shortages in key fields to design and develop its instruments.[35] The report stated that the staffing problems were driven by conflicting priorities among several other Jet Propulsion Laboratory projects, including Mars 2020, that also needed those skills. The Office of Inspector General recommended that the Jet Propulsion Laboratory director evaluate current and future critical technical staffing requirements and make adjustments as necessary to ensure that the laboratory has the technical support needed for their missions. The director plans to address the recommendation through its existing processes and forums for assessing and addressing staffing resources at the laboratory.

NASA's Assessments Indicate Broader Workforce Challenges

NASA's own assessments indicate that there are broader workforce challenges in disciplines that are necessary to effectively manage its major projects. Since 2012, NASA has been conducting capability assessments of its technical disciplines and business services to assist in establishing a more efficient operating model that maintains critical

[35]NASA Office of Inspector General, *NASA's Surface Water and Ocean Topography Mission*, IG-18-011 (Washington, D.C.: Jan. 17, 2018).

capabilities and meets current and future mission needs. Through these efforts, NASA identified capacity gaps in the following areas:

- **Guidance, Navigation, and Control (GN&C) disciplines.** An assessment of technical capabilities conducted in 2016 identified GN&C research and technology development as a discipline area that was inadequately positioned to meet mission requirements. In a follow-up assessment in 2017, NASA determined there have been no significant changes to the GN&C workforce since 2015. The assessment found, though, that the risk is stabilizing due, in part, to adding more early career hires. These assessments determined the GN&C workforce needs to be reshaped over the next decade to build future workforce skills.
- **Scheduling, earned value management, and cost estimating.** A budget business services assessment conducted in 2016 recommended that the agency work with centers to regionalize access to these specialty capabilities and to leverage access to these skills across centers. Officials from the Office of the Chief Financial Officer said they have made some progress in filling gaps in cost estimating and earned value management capabilities, but scheduling expertise remains a major challenge. As a result, officials said they have a scheduling effort underway to build the capability in-house by improving training and tools.
- **Cost and pricing analyst workforce.** A procurement business services assessment conducted in 2015 identified capability gaps in the cost and pricing analyst workforce. As part of assessing options to strengthen expertise associated with source evaluation boards for contract awards, NASA found that the agency had an inadequate supply of cost and pricing analysts across centers. In response to this finding, NASA plans to form a centralized team of cost and pricing professionals to support acquisition efforts across centers. In addition, NASA established a pricing community of practice to develop and share best practices in this area, developed training courses, and, in some instances, centers are hiring cost and pricing analysts as a part of efforts to rebuild this skill set across the agency.

We have also found that other agencies have experienced challenges related to their earned value management, cost estimating, and cost and

pricing analysis workforces.[36] For example, in June 2008, we found that the Coast Guard faced challenges in recruiting and retaining a sufficient number of government employees in acquisition positions such as contract specialists and cost estimators, among other areas.[37] In addition, in December 2015, we found that the Department of Defense did not meet its workforce growth goals in 3 priority career growth areas—contracting, business, which includes cost estimating and analysis, and engineering.[38]

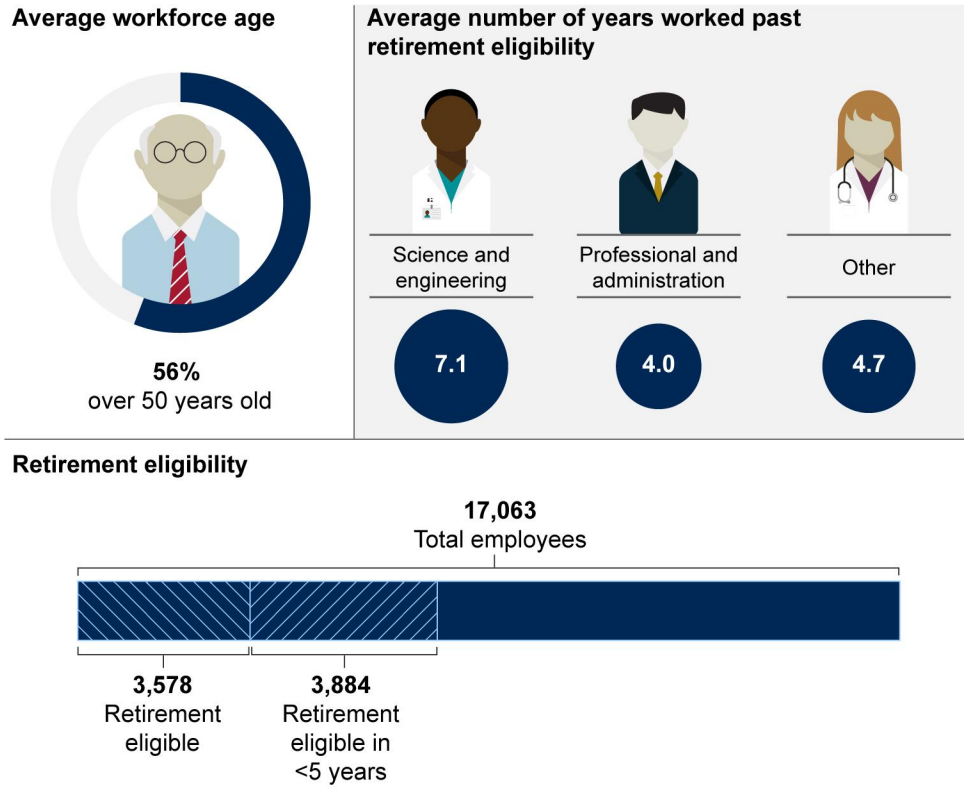
Another trend, the aging of NASA's workforce, has both negative and positive effects. About 56 percent of NASA's workforce is 50 years old and over, an increase of about 7 percentage points over the past 5 years. Officials said that NASA's workforce is aging because NASA has a low attrition rate—about 4 percent annually—and high numbers of staff stay several years past retirement. We also found that, as of the beginning of 2018, 21 percent of the workforce is retirement eligible, about another 23 percent will become eligible in less than 5 years, and the average number of years staff that stay past initial retirement eligibility varied by occupation (see figure 9). On average, individuals remain at NASA between 4-7 years past their initial retirement eligibility date, but staff in the engineering and science occupations stay on longer than other occupations, such as professional and administrative.

[36]For example, GAO, *Coast Guard: Change in Course Improves Deepwater Management and Oversight, but Outcome Still Uncertain,* GAO-08-745 (Washington, D.C.: June 24, 2008); *Defense Contract Management Agency: Amid Ongoing Efforts to Rebuild Capacity, Several Factors Present Challenges in Meeting Its Missions,* GAO-12-83 (Washington, D.C.: Nov. 3, 2011); and *Defense Acquisition Workforce: Actions Needed to Guide Planning Efforts and Improve Workforce Capability*, GAO-16-80 (Washington, D.C: Dec. 14, 2015).

[37]GAO-08-745.

[38]GAO-16-80.

Figure 9: NASA's Workforce Average Age, Retirement Eligibility, and Average Number of Years Worked Past Retirement Eligibility as of January 2018



Source: GAO analysis of National Aeronautics and Space Administration workforce data. | GAO-18-280SP

Note: The other category includes clerical, technicians, medical and other miscellaneous occupations.

Officials said there are both advantages and disadvantages to having an aging workforce. For example, human capital officials noted that having an aging workforce is good for maintaining institutional knowledge due to experienced staff staying longer, but that having a low attrition rate makes it more difficult for the agency to make changes to its workforce skill mix as needed. Officials within the Office of the Chief Engineer and Mission Support Directorate said that they were looking at ways to be more strategic in hiring or using existing capabilities to meet their skills needs.

Outcome of NASA's Strategic Workforce and Cross-Center Planning Efforts Not Yet Known

In our review of selected agency-wide assessments and through discussions with knowledgeable NASA officials, we found that NASA has two efforts underway that may help to address some workforce challenges: strategic workforce planning and cross-center collaboration. We will be tracking the progress of these efforts in future reviews, as it is too early to determine the outcomes.

Strategic Workforce Planning: In 2016, NASA completed a human capital assessment that identified a lack of agency-wide strategic workforce planning as a high-risk area under the agency's current operating model. It stated that the lack of agency-wide strategic workforce planning was at the root of many of the other findings in the assessment, such as the need for better coordination and collaboration across the centers, created uncertainty and was driving centers to think locally instead of agency-wide. To address this concern, the Office of Human Capital Management has an effort underway to begin to develop NASA's first agency-level strategic workforce plan in 2018. NASA defines strategic workforce planning as the discipline of determining the size and composition of a future workforce that is able to perform the organization's most important functions, maintain capabilities, and fulfill key business goals while maintaining agility in a dynamic environment. Human capital officials said they plan to update NASA's policy on strategic workforce planning after they have established their framework for strategic workforce planning.[39] As part of the new process, human capital officials said their office will provide guidance to the centers to develop center master plans, which are to have a 10- to15-year outlook on capabilities. Human capital officials said they will ask the centers to develop their first master plans by October 2018, and the Office of Human Capital Management is to use them to create NASA's first agency-level strategic workforce plan.

Cross-Center Collaboration: The 2016 human capital assessment also identified the need to increase cross-center collaboration to improve workforce utilization. NASA plans to develop a process to better understand where skills are needed across the centers and then use employees with those skills at any center to meet those needs. According

[39]NASA Policy Directive 3010.1A, *Strategic Workforce Planning* (Jan. 15, 2009).

to human capital officials, the Office of Human Capital Management was not the right organization to address this concern because they felt that it would require leadership at a higher level than their office to implement it. They noted that an effort such as this would require the agency to overcome the cultural barrier of NASA being a decentralized agency, with most of its work completed at the center level. This barrier has proven difficult for the agency in the past and has resulted in NASA having different approaches to implementing policies and guidance at the centers. For example, in April 2014, we found that when NASA policy gave centers wide latitude in implementing export control procedures, implementation across centers was inconsistent.[40]

NASA has taken other steps to improve cross-center collaboration by sharing mission support capabilities across the centers. For example, NASA plans to coordinate the center-level human capital and financial staff and activities through the headquarters offices, rather than at each center. NASA plans to complete this transition by the end of September 2019.[41] Other business services areas, such as procurement, also plan to move to this operational model, but have not yet started the transition. Officials within the Office of the Chief Financial Officer said the purpose of this change is for the mission support areas to become more effective and efficient, and deliver a consistent set of services across the agency.

As NASA develops its first strategic workforce plan and considers taking additional steps towards a new operating model with more cross-center collaboration, it will be vital to have senior leadership's commitment to these efforts. Capacity—having the right people and resources to resolve risk—is one of two criteria that NASA has not yet met for removal from our high-risk list; the other being demonstrating progress. We first designated acquisition management at NASA as a high-risk area in 1990 in view of NASA's history of persistent cost growth and schedule slippage in the majority of its major systems. Capacity is central to managing the complex and difficult work that NASA takes on. We have found that an effective organization includes a senior leadership team committed to

[40]GAO, *Export Controls: NASA Management Action and Improved Oversight Needed to Reduce the Risk of Unauthorized Access to Its Technologies,* GAO-14-315 (Washington, D.C.: Apr. 15, 2014).

[41]The Office of the Chief Financial Officer capabilities that are not realigned under the new model before October 2019 will be handled as part of a separate effort.

developing more effective ways of doing business, accomplishing results, and investing in human capital.[42]

Project Assessments

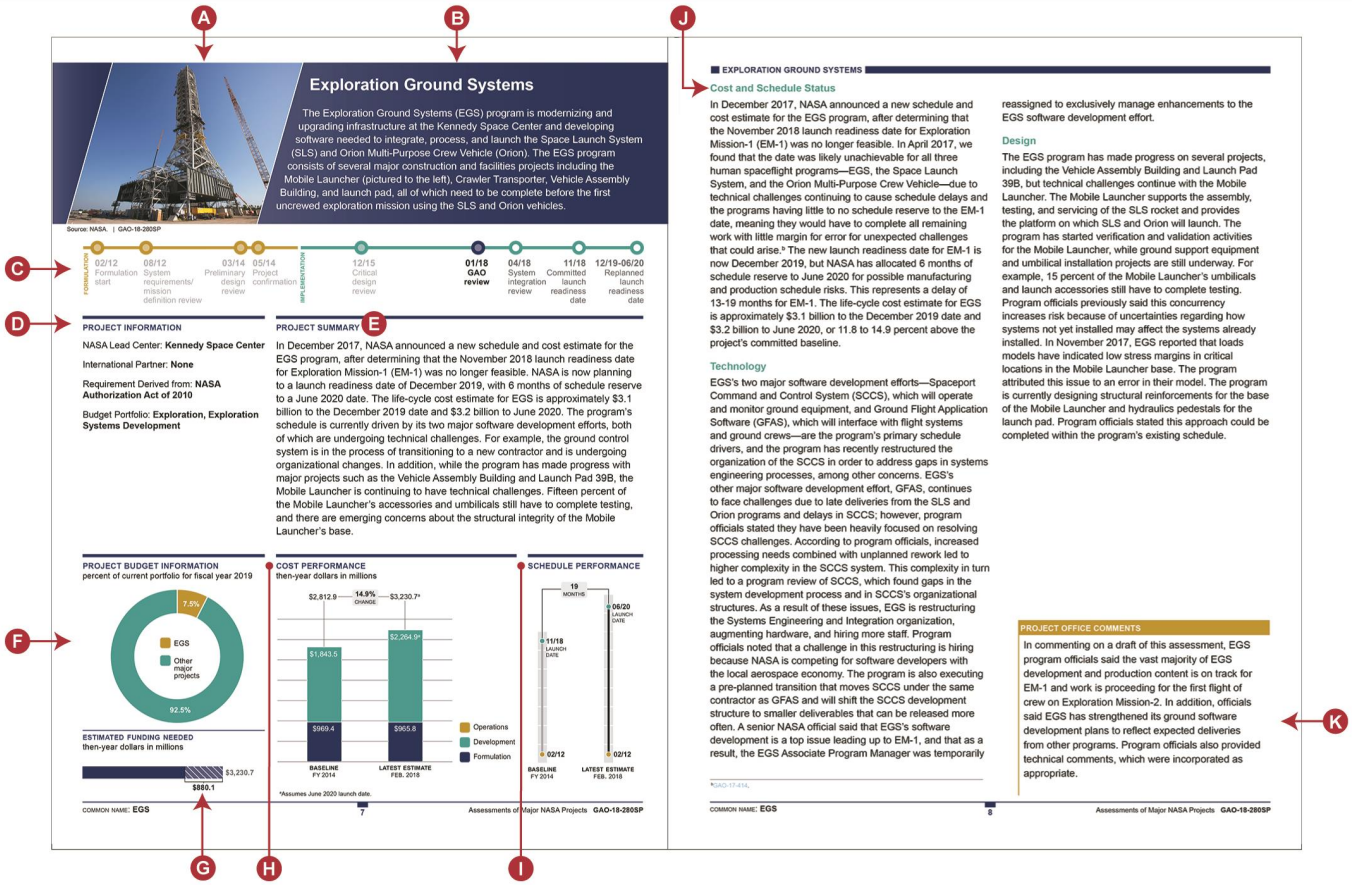
The individual assessments of the 26 projects we reviewed provide a two-page profile of each project. Each assessment includes a description of the project's objectives, information about the NASA centers and international partners involved in the project, the project's cost and schedule performance, a timeline identifying key project dates, budget information, and a brief narrative describing the current status of the project.[43] The budget information is based on NASA's fiscal year 2019 budget request. 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. 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 10 for an illustration of a sample assessment layout.

[42]GAO, *Exposure Draft: A Model of Strategic Human Capital Management,* GAO-02-373SP (Washington, D.C.: Mar. 15, 2002).

[43]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 10: 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** **Project Budget Information:** The percentage of NASA's fiscal year 2019 budget for all major projects in the current portfolio that the project represents.
- **G** **Project Funding:** For projects in formulation, the total funding appropriated to the project since formulation start. For projects in implementation, the funding needed to be allocated for project completion as of the latest life-cycle cost estimate.
- **H** **Cost:** For projects in formulation, the preliminary cost estimate. For projects in implementation, the approved cost baseline and latest estimate.
- **I** **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.
- **J** 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.
- **K** **Project Office Comments:** General comments provided by the cognizant project office.

Source: GAO analysis. | GAO-18-280SP

Description of Figure describing program assessment sections

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: Project Budget Information: The percentage of NASA's fiscal year 2019 budget for all major projects in the current portfolio that the project represents.

G: Project Funding: For projects in formulation, the total funding appropriated to the project since formulation start. For projects in implementation, the funding needed to be allocated for project completion as of the latest life-cycle cost estimate.

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

I: 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.

J: 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.

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

See Attached NASA quicklook PDF for program assessments.

Agency Comments and Our Evaluation

We provided a draft of this report to NASA for its review and comment. In its written response, NASA generally agreed with our findings and stated that the report provides NASA with a valued independent perspective on its major acquisitions. NASA also noted that we incorporated technology demonstration projects into the audit this year, and that it is important to remember that the purpose of these activities is to mature specific new technologies to a technology readiness level 6 or higher by the end of their demonstration phase in a relevant environment. As a result, it is NASA's view that our best practice to mature technologies to a technology readiness level 6 by the preliminary design review is not applicable to technology demonstration projects.

As discussed in the report, we included two technology demonstration projects—LCRD and Restore-L—in our assessment this year because these two projects each had a life-cycle cost estimate of over $250 million. In addition, we included these two projects in our analysis of NASA major projects attaining technology maturity at preliminary design review because both projects planned to mature their technologies prior to launch, not at the end of their demonstration phase in a relevant environment as NASA described in its letter. Therefore, these two projects are still susceptible to the same risks projects might experience if they fall short of the best practice of meeting a technical readiness level 6 by preliminary design review. These risks include subsequent technical problems that could result in cost growth and schedule delays. In the future, if other technology demonstration projects have a life-cycle cost estimate over $250 million and enter the portfolio of projects that we assess, we will continue to discuss project technology maturity goals for those specific projects with NASA. These discussions will inform our determination of whether we will compare those projects against our best practices on technology maturity.

NASA's written comments are reprinted in appendix VI. 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 Edward J. Markey
Ranking Member
Subcommittee on Space, Science, and Competitiveness
Committee on Commerce, Science, and Transportation
United States Senate

The Honorable John Culberson
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Ranking Member
Subcommittee on Commerce, Justice, Science, and Related Agencies
Committee on Appropriations
House of Representatives

The Honorable Brian Babin
Chairman
The Honorable Ami Bera
Ranking Member
Subcommittee on Space
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 technologies and stability of project designs at key points in the development process, and (3) the extent to which NASA is assessing future workforce capacity challenges that may affect its ability to manage its portfolio of projects. We also described the status and assessed the risks and challenges faced by NASA's 26 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 develop an assessment for the Asteroid Redirect Robotic Mission project because, as of June 2017, the project closed out most project development activities at the direction of NASA headquarters.

To respond to these objectives, we developed several standard data collection instruments (DCI). We developed multiple DCIs, which were completed by NASA's Office of the Chief Financial Officer, to gather data on each project's cost, schedule, funding, and notional 5-year budget. We used another DCI, which was completed by each project office, to gather data on project's technology and design maturity and development partners. The information available on individual projects depends on where a project is in its life cycle. For example, for projects in an early stage of development called formulation there are still unknowns about requirements, technology, and design. We also analyzed DCI data from prior reviews.

To assess the cost and schedule performance of NASA's major projects, we compared cost and schedule data as of February 2018 provided on DCIs by NASA for the 17 projects in the implementation phase during our review to previously established cost and schedule baselines.[1] The Commercial Crew Program has a tailored project life cycle and project management requirements, so it was excluded from this analysis. In addition, we assessed development cost and schedule performance for

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

NASA's portfolios of major projects for each reporting period between 2009 and 2018 to examine longer-term trends. To determine cost performance, we compared the projects' baseline development costs and development costs as of February 2018. For the Orion program, we used a June 2017 cost estimate because NASA was revising the program's life-cycle cost estimate at the time of our review. For two projects—Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) and Transiting Exoplanet Survey Satellite (TESS)—the cost performance is current as of March 2018 because NASA updated cost information after we received the cost DCI in February 2018. 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 launch readiness or completion date as of February 2018. For three projects—GRACE-FO, James Webb Space Telescope, and TESS—the schedule performance is current as of March 2018 because NASA provided an updated schedule after we received the schedule DCI in February 2018.

To assess technology maturity, we asked project officials to complete a DCI 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 17 projects that had held a preliminary design review and identified critical or heritage technologies, we compared those levels against our technology maturity best practice and NASA policy on technology maturity 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.

To assess design stability, we asked project officials to complete a DCI 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.[2] 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 omitted the Exploration Ground Systems program in this year's analysis and retroactively excluded the program from prior year analyses in 2016 and 2017 because program officials said they do not track design drawings as a management tool and we found that the prior data submissions were not inclusive all subsystems. 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

[2]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.

assess the design stability for those projects that had not yet reached the critical design review at the time of this assessment. To assess project technical margins, we gathered project mass and power information using a DCI and compared it against NASA requirements. We omitted the Exploration Ground Systems, Space Network Ground Segment Sustainment, and Space Launch System as those projects do not contain spacecraft. We excluded the Orion program because it does not have applicable metrics. To assess completion of project validation and verification plans, we asked project officials to complete a DCI that provided data on whether a plan was completed by the critical design review.

To assess the extent to which NASA is assessing future workforce capacity challenges that may affect its ability to manage its portfolio of projects, we did the following:

- Analyzed NASA major project documents, such as monthly status reports, and interviewed project officials to determine if the projects were experiencing any workforce challenges. We also discussed the process of staffing Jet Propulsion Laboratory projects with officials within the NASA Management Office at the laboratory.
- Interviewed Mission Support Directorate and Office of the Chief Engineer officials responsible for agency-wide capability assessments to identify if workforce challenges were raised as a concern in these assessments. Through an initial review of documents and discussions with officials, we identified select technical areas that workforce capability gaps were identified in the assessments for additional review, including the technical capability areas of sensors and instruments, and guidance, navigation and control. We also selected the human capital, budget, and procurement business assessments because of the relation to the acquisitions process and acquisition workforce functions that could affect NASA's ability to manage its major projects. We reviewed the recommendations in each assessment and identified those specifically related to aspects of workforce capacity and human capital management. We interviewed relevant officials on the status of implementation plans for these recommendations—including NASA's efforts to improve strategic workforce planning and cross-center collaboration—and discussed the role these efforts would play in the broader implementation of NASA's operating model.
- Analyzed publicly available workforce data from NASA's Workforce Information Cubes for NASA (WICN) to identify workforce

characteristics that could affect NASA's workforce capacity. WICN contains snapshots of workforce composition as of certain dates and are updated every two weeks by NASA's Shared Services Center. We obtained and analyzed data from WICN as of January 2018. Specifically, we examined (1) total employee staffing levels for the past 5 years, (2) age, (3) retirement eligibility, and (4) the average number of years staff stay past initial retirement eligibility by occupational category. To assess the reliability of the workforce data used in the review, we reviewed NASA's responses to questions on the database, which included information on the source of the data, how NASA uses the data, and the reliability of the data; interviewed officials with knowledge of how the database is used at the agency and how the information is compiled; and reviewed the data for errors, such as by confirming correct sums and checking the consistency of workforce totals across the data. We concluded the workforce data were sufficiently reliable for purposes of this report.

Our work was performed primarily at NASA headquarters in Washington, D.C. In addition, we and related GAO engagement teams 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 project assessments for the 26 projects in the portfolio with an estimated life-cycle cost greater than $250 million. 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 included budget information, including the percentage of NASA's fiscal year 2019 budget for all major projects in the current portfolio that the project represents. The budget information is based on NASA's fiscal year 2019 budget. For projects in formulation, we included the total funding that has been allocated to the project since formulation start through the end of fiscal year 2017. For projects in implementation, we included the funding needed to be allocated for project completion or launch through the project's current life-cycle cost estimate. 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 DCI. For the Commercial Crew program, we obtained data directly from the program on the total amount of funds obligated and the schedule. When applicable, we compared the level of cost and schedule reserves held by the project to the level required by center policy. To determine the funding received to date for each of the projects in formulation we calculated the total funding allocated to the project since formulation start.[3] For projects in implementation, we calculated the funding needed for project launch or completion through its current life-cycle cost estimate.

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 they 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.

[3]This does not include funds for studies prior to key decision point (KDP)-A, the start of formulation.

Project Challenges Discussion on Each Individual Project Assessment

To assess the status, risk, and challenges for each project, we submitted a DCI to each project office. In the DCI, 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 DCI. We then reviewed project documentation—including 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 launch, contractor, development partner, design, technology, schedule, 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 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 eight 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

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

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 2017 to May 2018 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 2018 Report

In 2018, we assessed 26 major NASA projects. Figure 11 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 11: Cost and Schedule of Major NASA Projects Assessed in GAO's 2018 Report by Phase

	Acronym	Project name	Preliminary launch readiness date	Preliminary cost estimate (in millions)
Formulation	DART	Double Asteroid Redirection Test	Dec 2020 – May 2021	$247.7 – $290.7
	Clipper	Europa Clipper	July 2023	$3,100 – $4,000
	LBFD	Low Boom Flight Demonstrator	March 2022	$390+
	Lucy	Lucy	Oct – Nov 2021	$914 – $984
	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	2024 – 2026	$3,200 – $3,800
			Current launch readiness date	**Current cost estimate** (in millions)
Implementation	EGS	Exploration Ground Systems	June 2020	$3,230.7
	GRACE-FO	Gravity Recovery and Climate Experiment Follow-On	May 2018	$431.9
	ICESat-2	Ice, Cloud, and Land Elevation Satellite-2	October 2018	$1,063.6
	ICON	Ionospheric Connection Explorer	No earlier than June 2018	$252.7
	InSight	Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport	May 2018	$828.9
	JWST	James Webb Space Telescope	May 2020	$8,825.4
	L9	Landsat 9	November 2021	$885.0
	LCRD	Laser Communications Relay Demonstration	November 2019	$262.7
	Mars 2020	Mars 2020	July 2020	$2,458.2
	NISAR	NASA Indian Space Research Organisation Synthetic Aperture Radar	September 2022	$896.9
	PSP	Parker Solar Probe[a]	August 2018	$1,548.2
	Orion	Orion Multi-Purpose Crew Vehicle[b]	April 2023	Under revision
	RBI	Radiation Budget Instrument (canceled)	December 2019	$304.8
	SGSS	Space Network Ground Segment Sustainment[c]	June 2021	$1,320.8
	SLS	Space Launch System	June 2020	$9,843.2
	SWOT	Surface Water and Ocean Topography	April 2022	$754.9
	TESS	Transiting Exoplanet Survey Satellite	April 2018	$336.7
	CCP	Commercial Crew Program[d]	Jan - Feb 2019	$6,968.4

Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-18-280SP

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

[b]NASA officials said they are revising the Orion program's life-cycle cost estimate and expect to complete a new estimate in June 2018. The new cost is expected to be over the program's cost baseline of $11,283.5 million.

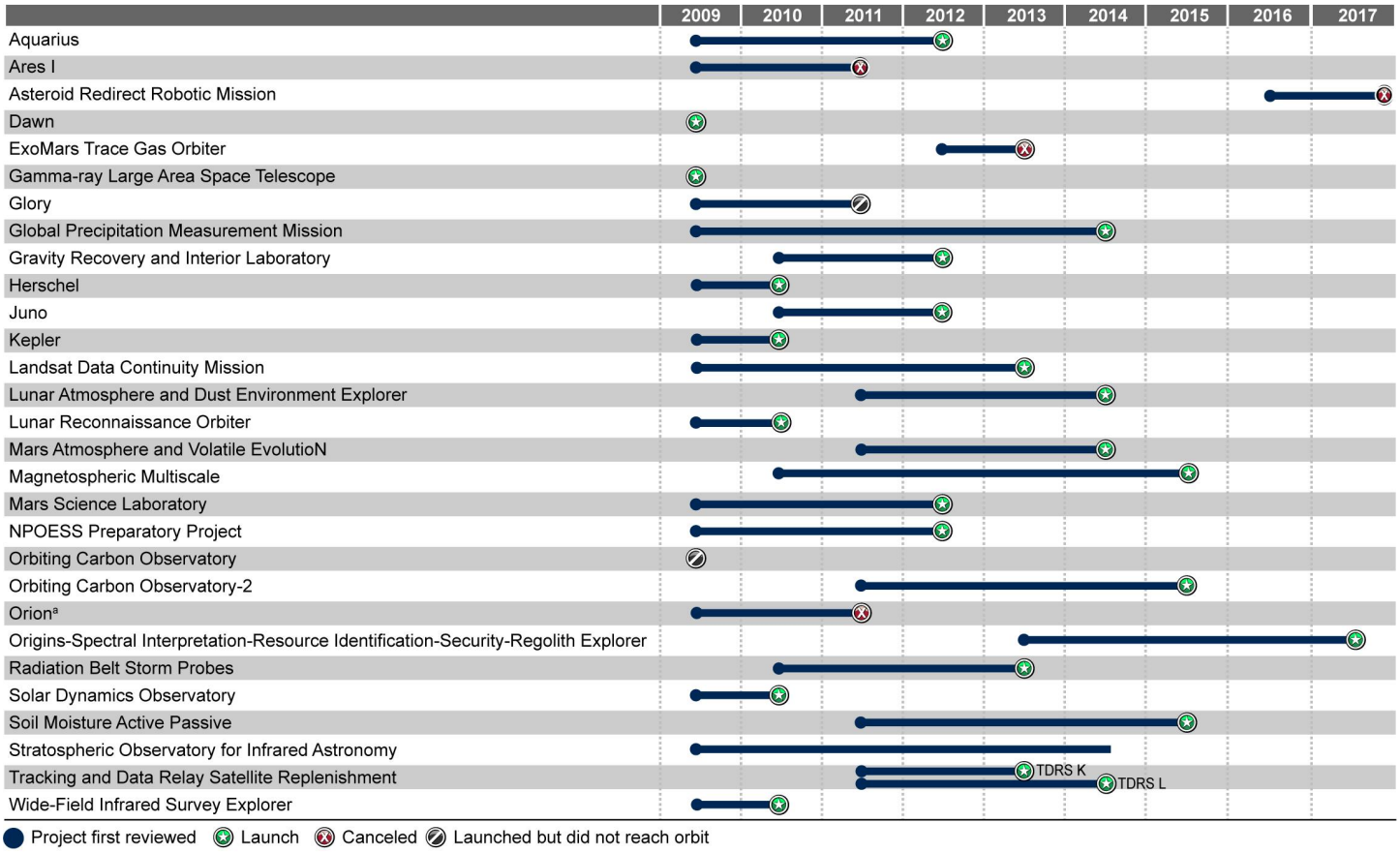
[c]In 2016, NASA reclassified the Space Network Ground Segment Sustainment (SGSS) as a hybrid sustainment effort, rather than a major project. A hybrid sustainment effort still includes development work. As a result, we continue to include SGSS in our assessment. The SGSS project reported costs are up through its first operational readiness review at the end of fiscal year 2019, and its schedule is under review.

[d]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.

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

We have reviewed 55 major National Aeronautics and Space Administration (NASA) projects or programs since our initial review in 2009. See figure 12 below for a list of projects included in our assessments from 2009 to 2017. These projects were not included in the 2018 review because they launched, were canceled, or launched but failed to reach orbit.

Figure 12: Major NASA Projects Reviewed in GAO's Annual Assessments from 2009-2017

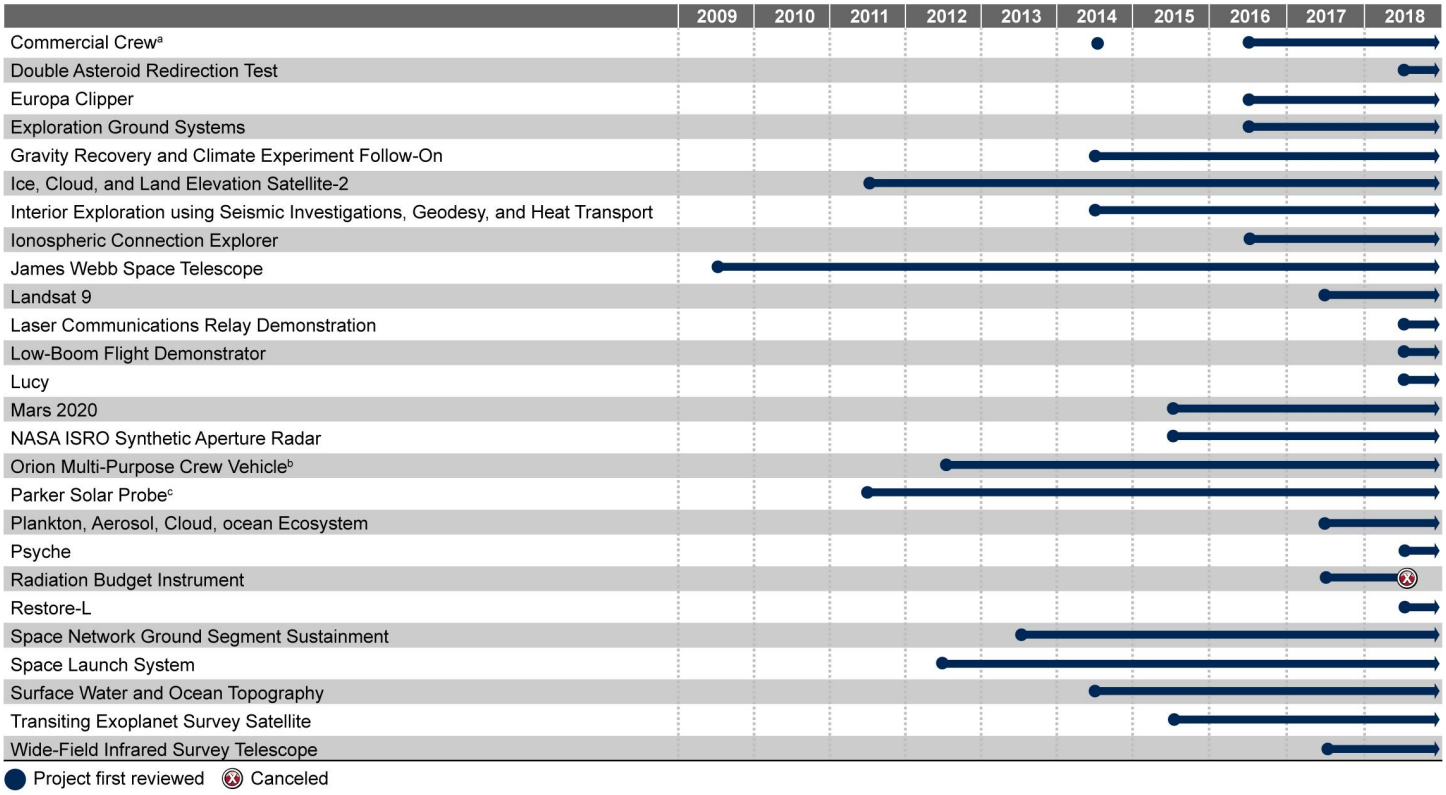


Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-18-280SP

[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.

See figure 13 below for a list of projects included in our 2018 assessment, including when the projects were first included in the review, and projects that were canceled during the review.

Figure 13: Major NASA Projects Reviewed in GAO's 2018 Assessment



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-18-280SP

[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 4: 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. 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.
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.

Technology readiness level	Description	Hardware	Demonstration environment
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 of National Aeronautics and Space Administration data. | GAO-18-280SP

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 within available resources. The project will generally enter

[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).

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

April 13, 2018

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-18-280SP). 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.

This year's report represents the tenth annual iteration of the GAO's legislatively mandated assessment of NASA's major acquisitions. The GAO has provided NASA with several highly valued insights into various aspects of our acquisition approaches since the inaugural report's issuance in 2009, many of which have resulted in programmatic improvements and enhancements. However, the number of projects in this year's assessment portfolio is 36 percent higher than the average for this engagement. This growth may be attributed to a greater number of major spaceflight development projects in NASA's portfolio, but another driver has been the expansion of the legislative mandate to include potential major projects in formulation; technology demonstrations; and communications, tracking, and infrastructure refreshment activities. 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 prior to confirmation. While NASA appreciates the clear demonstrated value in this recurring engagement, it is equally important to recognize the growing administrative burden that is necessary to respond to GAO inquiries with valid, accurate, and timely information.

NASA appreciates the GAO's recognition of alternative approaches to managing different types of projects, such as technology demonstration spacecraft and experimental aircraft. The GAO has established best practices regarding the maturation of technologies to Technology Readiness Level 6 (TRL-6) by the Preliminary Design Review (PDR) for science and human exploration missions, and we strive to achieve this technology maturation schedule on our spaceflight missions per the NASA Procedural Requirement

(NPR) 7120.5E policy. As the GAO has now incorporated technology demonstration projects into the audit, it is important to remember that the purpose of these activities is to mature specific new technologies to TRL-6 or higher by the end of their demonstration phase in a relevant environment. As such, at PDR for these technology demonstration projects, it is anticipated that technologies would not necessarily be at TRL-6 unlike for science and human exploration missions. NASA looks forward to working with the GAO to ensure a common understanding of the ways our approach to these types of projects differ from the typical NPR 7120.5E approach.

NASA is in agreement with the GAO that there are several large, complex projects in development that comprise a large relative share of the total current major project portfolio. We also recognize some development challenges exist in these projects that have resulted in recently revised cost and schedule plans in some instances. As we work to mitigate cost, schedule, and technical risk in these critical development efforts, we would like to take this opportunity to highlight the overall positive trending of our cost and schedule estimation practices over the past twenty years. When taken in aggregate, NASA's cost and schedule performance has markedly improved, moving from 45 percent average development cost growth against established baselines in the pre-cost confidence level era in the early 2000s, to less than 2 percent average development growth since the advent of the Joint Cost and Schedule Confidence Level (JCL) policy implementation in 2009. We are continuing to assess and advance the Agency's programmatic capabilities across the cost-estimating, pricing, scheduling, and earned value management communities, as well as any strategic workforce implications or augmentations required to support future mission needs. NASA looks forward to continued maturation and application of our cost and schedule estimation practices and tools as additional large acquisitions continue along their life cycles in the years ahead.

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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 (Acting)

Appendix VII: GAO Contact and Staff Acknowledgments

GAO Contact

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

Staff Acknowledgments

In addition to the contact named above, Molly Traci, Assistant Director; Andrea M. Bivens; Lorraine Ettaro; Lisa L. Fisher; Laura Greifner; Kristine R. Hassinger; Erin Kennedy; Joy Kim; Jose A. Ramos; Carrie Rogers; Daniel R. Singleton; Juli Steinhouse; Ryan Stott; Roxanna T. Sun; Alyssa Weir; and Kristin Van Wychen made significant contributions to this report.

Appendix VIII: Accessible Data

Data Tables

Data Table for Highlights figure NASA's Major Project Portfolio Cost and Schedule Performance Deteriorated in 2018

Year	Percentage cost growth	Average launch delay
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
2018	18.7	12

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

Phase	Formulation Pre-phase A Concept studies	Formulation Phase A Concept and technology development	Formulation Phase B Preliminary design and technology completion	Implementation Phase C Final design and fabrication	Implementation Phase D System assembly, integration and test, and launch	Implementation Phase E Operations and sustainment	Implementation Phase F Closeout
Key Decision Point	KDP A occurs at the end of Pre phase A	KDP B occurs at the end of Phase A	KDP C (confirmation review) project start occurs at the end of Phase B	KDP D occurs at the end of Phase C	DDP E occurs at the end of Phase D	KDP F occurs at the end of phase E	
Review	NA	SDR/MDR review occurs at end of Phase A	PDF review occurs at the end of Phase B	CDR review occurs phase C SIR Review occurs at the end of Phase C	NA	NA	NA

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

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

- Probability (confidence level) of meeting cost target
- Agency baseline commitment
- Management agreement
- Headquarters-held reserves
- Project-held reserves
- Cost estimate

Data table for Figure 4: Development Cost Performance and Average Launch Delay for Major NASA Projects from 2009 to 2018

Year	Percentage cost growth	Average launch delay	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
2018	18.7	12	17

Data table for Figure 5: Number of NASA's Major Projects Attaining Technology Maturity by Preliminary Design Review from 2010 to 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	
2014	10	6	
2015	10	3	
2016	9	2	
2017	12	3	
2018	12	3	2

Data table for Figure 6: Average Number of Critical Technologies Reported by NASA's Major Projects in Development from 2009 to 2018

Year	Average number of critical technologies
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
2018	2.5

Data table for Figure 7: Number of NASA Major Projects That Released at least 90 Percent of Drawings by Critical Design Review and Average Percentage of Released Drawings from 2010 to 2018

Year	Projects meeting design stability best practices	Projects not meeting design stability best practices	Average percentage 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	4	7	69
2017	4	7	66
2018	4	8	70

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

Year	Average percentage of drawing growth after critical design review
2010	182
2011	36
2012	36
2013	12
2014	20
2015	11
2016	10
2017	16
2018	19

Data table for Figure 9: NASA's Workforce Average Age, Retirement Eligibility, and Average Number of Years Worked Past Retirement Eligibility as of January 2018

Average workforce age: 56% over 50 years old

Average number of years worked past retirement eligibility

- Science and engineering: 7.1
- Professional and administration: 4.0
- Other: 4.7

Retirement eligibility

- Total full-time equivalents: 17,063
- Retirement eligible: 3,578
- Retirement eligible in <5 years: 3,884

Data table for Figure 11: Cost and Schedule of Major NASA Projects Assessed in GAO's 2018 Report by Phase

Formulation

Acronym	Project name	Preliminary launch readiness date	estimate (in millions)
DART	Double Asteroid Redirection Test	Dec 2020 – May 2021	$247.7 – $290.7
Clipper	Europa Clipper	July 2023	$3,100 – $4,000
LBFD	Low Boom Flight Demonstrator	March 2022	$390+
Lucy	Lucy	Oct – Nov 2021	$914 – $984
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	2024 – 2026	$3,200 – $3,800

Implementation

Acronym	Project name	Launch readiness date	Current cost baseline (in millions)
EGS	Exploration Ground Systems	June 2020	$3,230.7
GRACE-FO	Gravity Recovery and Climate Experiment Follow-On	April 2018	$416.0
ICESat-2	Ice, Cloud, and Land Elevation Satellite-2	October 2018	$1,063.6
ICON	Ionospheric Connection Explorer	No earlier than June 2018	$252.7
InSight	Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport	May 2018	$828.9
JWST	James Webb Space Telescope	June 2019	$8,825.4
L9	Landsat 9	November 2021	$885.0
LCRD	Laser Communications Relay Demonstration	November 2019	$262.7
Mars 2020	Mars 2020	July 2020	$2,458.2
NISAR	NASA Indian Space Research Organisation Synthetic Aperture Radar	September 2022	$896.9
PSP	Parker Solar Probe	August 2018	$1,548.2
Orion	Orion Multi-Purpose Crew Vehicle	April 2023	Under revision
RBI	Radiation Budget Instrument (canceled)	December 2019	$304.8
SGSS	Space Network Ground Segment Sustainment	June 2021	$1,320.8
SLS	Space Launch System	June 2020	$9,843.2
SWOT	Surface Water and Ocean Topography	April 2022	$754.9
TESS	Transiting Exoplanet Survey Satellite	April 2018	$336.7
CCP	Commercial Crew Program	Jan - Feb 2019	$6968.4

Data table for Figure 12: Major NASA Projects Reviewed in GAO's Annual Assessments from 2009-2017

Projects (timeline available from GAO upon request

- Aquarius
- Ares I
- Asteroid Redirect Robotic Mission
- Dawn
- ExoMars Trace Gas Orbiter
- Gamma-ray Large Area Space Telescope
- Glory
- Global Precipitation Measurement Mission
- Gravity Recovery and Interior Laboratory
- Herschel
- Juno
- Kepler
- Lunar Atmosphere and Dust Environment Explorer
- Landsat Data Continuity Mission
- Lunar Atmosphere and Dust Environment Explorer
- Lunar Reconnaissance Orbiter
- Mars Atmosphere and Volatile EvolutioN
- Magnetospheric Multiscale
- Mars Science Laboratory
- NPOESS Preparatory Project
- Orbiting Carbon Observatory
- Orbiting Carbon Observatory-2
- Orion
- Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer
- Radiation Belt Storm Probes
- Solar Dynamics Observatory

- Soil Moisture Active Passive
- Stratospheric Observatory for Infrared Astronomy
- Tracking and Data Relay Satellite Replenishment
- Wide-Field Infrared Survey Explorer

Data table for Figure 13: Major NASA Projects Reviewed in GAO's 2018 Assessment

Projects (timeline available from GAO upon request

- Commercial Crew
- Double Asteroid Redirection Test
- Europa Clipper
- Exploration Ground Systems
- Gravity Recovery and Climate Experiment Follow-On
- Ice, Cloud, and Land Elevation Satellite-2
- Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport
- Ionospheric Connection Explorer
- James Webb Space Telescope
- Landsat 9
- Laser Communications Relay Demonstration
- Low-Boom Flight Demonstrator
- Lucy
- Mars 2020
- NASA ISRO Synthetic Aperture Radar
- Orion Multi-Purpose Crew Vehiclea
- Parker Solar Probe
- Plankton, Aerosol, Cloud, ocean Ecosystems
- Psyche
- Radiation Budget Instrument
- Restore-L
- Space Network Ground Segment Sustainment

- Space Launch System
- Surface Water and Ocean Topography
- Transiting Exoplanet Survey Satellite
- Wide-Field Infrared Survey Telescope

Agency Comment Letter

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

Page 1

April 13, 2018

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-18-280SP). 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.

This year's report represents the tenth annual iteration of the GAO's legislatively mandated assessment of NASA's major acquisitions. The GAO has provided NASA with several highly valued insights into various aspects of our acquisition approaches since the inaugural report's issuance in 2009, many of which have resulted in programmatic improvements and enhancements. However, the number of projects in this year's assessment portfolio is 36 percent higher than the average for this engagement. This growth may be attributed to a greater number of major spaceflight development projects in NASA's portfolio, but another

driver has been the expansion of the legislative mandate to include potential major projects in formulation; technology demonstrations; and communications, tracking, and infrastructure refreshment activities. 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 prior to confirmation. While NASA appreciates the clear demonstrated value in this recurring engagement, it is equally important to recognize the growing administrative burden that is necessary to respond to GAO inquiries with valid, accurate, and timely information.

NASA appreciates the GAO's recognition of alternative approaches to managing different types of projects, such as technology demonstration spacecraft and experimental aircraft. The GAO has established best practices regarding the maturation of technologies to Technology Readiness Level 6 (TRL-6) by the Preliminary Design Review (PDR) for science and human exploration missions, and we strive to achieve this technology maturation schedule on our spaceflight missions per the NASA Procedural Requirement

Page 2

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Sincerely,

Stephen Jurczyk

Associate Administrator (Acting)

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