United States Government Accountability Office

Report to Congressional Committees

May 2017

NASA

Assessments of Major Projects

Accessible Version

GAO-17-303SP

GAO Highlights

Highlights of GAO-17-303SP, a report to congressional committees

May 2017

NASA

Assessments of Major Projects

Why GAO Did This Study

This report provides GAO's annual snapshot for 2017 of how well NASA is planning and executing its major acquisition projects. In March 2016, GAO found that projects continued a general positive trend of limiting cost and schedule growth, maturing technologies, and stabilizing designs, but that NASA faced several challenges that could affect its ability to effectively manage its portfolio.

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 ninth annual assessment. This report describes (1) the cost and schedule performance of NASA's portfolio of major projects, (2) the maturity of technologies and stability of project designs at key milestones, and (3) NASA's progress in implementing initiatives to manage acquisition risk and potential challenges for project management and oversight. This report also includes assessments of NASA's 21 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

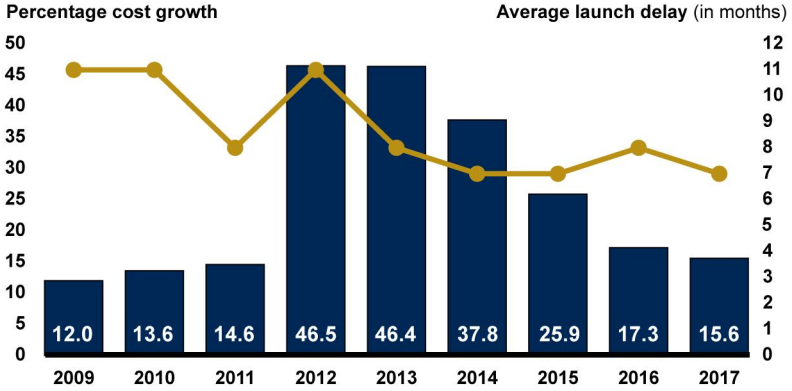
In prior reports, GAO has made related recommendations that NASA generally agreed with, but has not yet fully addressed. GAO continues to believe they should be fully addressed. NASA generally agreed with GAO's findings.

View GAO-17-303SP. 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 continued to improve, as shown in the figure below, but this trend may be difficult to sustain. The current trend is driven by two main factors: (1) most projects are being executed within their cost and schedule baselines; and (2) new projects, which are less likely to have experienced cost and schedule growth, were added to the portfolio. However, two projects—a Mars seismology instrument and lander and an upgrade to the NASA's space communications network—experienced significant cost or schedule growth in 2016. In addition, eight projects are in the phase of development when cost and schedule problems are most likely to occur, including the Orion Multi-Purpose Crew Vehicle and Space Launch System, NASA's most expensive human spaceflight programs.

NASA's Major Project Portfolio Cost and Schedule Performance Has Continued to Improve



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-17-303SP

NASA has generally maintained recent improvements in the technology maturity and design stability of its projects, even as the number of new technologies in its most recent projects has increased. Three of the four major projects that passed preliminary design review in the past year matured all technologies to the level recommended by GAO best practices. Several NASA projects experienced late design changes, but the overall level of these changes remained relatively low and other design stability measures remained unchanged.

NASA continues to improve project management tools to manage acquisition risks but faces workforce and funding challenges. NASA has not implemented a best practice for monitoring contractor performance, as GAO recommended in November 2012, due to resource constraints. Other NASA workforce analyses have identified gaps in key areas, such as scheduling. NASA dissolved its independent assessment office in October 2015, in part to bolster its mission directorate and center workforces. GAO is monitoring the effect this change could have on project oversight. Finally, several major projects experienced funding-related challenges, such as working to schedules that were not supported by NASA's budget plans, which could affect cost and schedule performance.

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Abbreviations

ARRM	Asteroid Redirect Robotic Mission
ATLAS	Advanced Topographic Laser Altimeter System
CCP	Commercial Crew Program
CNES	Centre National d'Etudes Spatiales
DCI	data collection instrument
DHU	data handling unit
DLR	German Aerospace Center
EGS	Exploration Ground Systems
EM-1	Exploration Mission 1
EM-2	Exploration Mission 2
ESM	European Service Module

ESA	European Space Agency
EVM	earned value management
GFAS	Ground Flight Application Software
GFZ	German Research Centre for Geosciences
GRACE-FO	Gravity Recovery and Climate Experiment Follow-On
GSLV	Geosynchronous Satellite Launch Vehicle
HP3	Heat Flow and Physical Properties Probe
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
JPSS-2	Joint Polar Satellite System 2
JWST	James Webb Space Telescope
KaRIn	Ka-band Radar Interferometer
KDP	key decision point
NASA	National Aeronautics and Space Administration
NISAR	NASA ISRO Synthetic Aperture Radar
NOAA	National Oceanic and Atmospheric Administration
NPR	NASA Procedural Requirements
OCI	Ocean Color Instrument
OLI-2	Operational Land Imager 2
Orion	Orion Multi-Purpose Crew Vehicle
OSIRIS-REx	Origins-Spectral Interpretation-Resource Identification Security-Regolith Explorer
PACE	Plankton, Aerosol, Cloud, ocean Ecosystem
RBI	Radiation Budget Instrument
RFU	radio frequency unit
SCaN	Space Communication and Navigation
SEIS	Seismic Experiment for Interior Structure
SEP	Solar Electric Propulsion
SGSS	Space Network Ground Segment Sustainment
SLS	Space Launch System
SMAP	Soil Moisture Active Passive
SPP	Solar Probe Plus
SWOT	Surface Water and Ocean Topography
TESS	Transiting Exoplanet Survey Satellite
TIRS-2	Thermal Infrared Sensor 2
ULA	United Launch Alliance
WFIRST	Wide-Field Infrared Survey Telescope

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U.S. GOVERNMENT ACCOUNTABILITY OFFICE
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May 16, 2017

Congressional Committees

In fiscal year 2017, the National Aeronautics and Space Administration (NASA) plans to spend over $6 billion on 22 major projects, with each having a life-cycle cost of over $250 million. In total, these projects represent an expected investment of over $59 billion to continue exploring Earth and the solar system as well as extending human presence beyond low Earth orbit. 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 ninth 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) NASA's progress in implementing initiatives to reduce acquisition risk and potential challenges that could affect project management, execution, and oversight. This report also includes individual assessments of 21 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. There are 22 major projects, but we did not develop an assessment for the Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer (OSIRIS-REx) project because it launched in September 2016.

[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.

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 headquarters officials, and reviewed project documentation. There are 22 major projects in total, but the information available depends on where a project is in its life cycle.[3] For the 16 projects in the implementation phase we compared current cost and schedule estimates to their original cost and schedule baselines, identified the number of technologies being developed and assessed their technology maturity against GAO-identified best practices and NASA policy, and compared the number of releasable design drawings at the critical design review against GAO-identified 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. We also analyzed prime operations cost data for projects that have launched and were included in our prior annual reviews of NASA's major projects. To assess NASA's progress in reducing acquisition management risk, we met with officials and analyzed information pertinent to ongoing NASA initiatives, including its efforts to improve cost and schedule estimation and earned value management capabilities. We also followed up on other potential acquisition management challenges that we identified during our review, such as NASA's transition to a new independent assessment model, emerging workforce issues, and project funding and budget phasing. Finally, to conduct our project assessments, we analyzed information provided by project officials, such as 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 2016 to May 2017 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

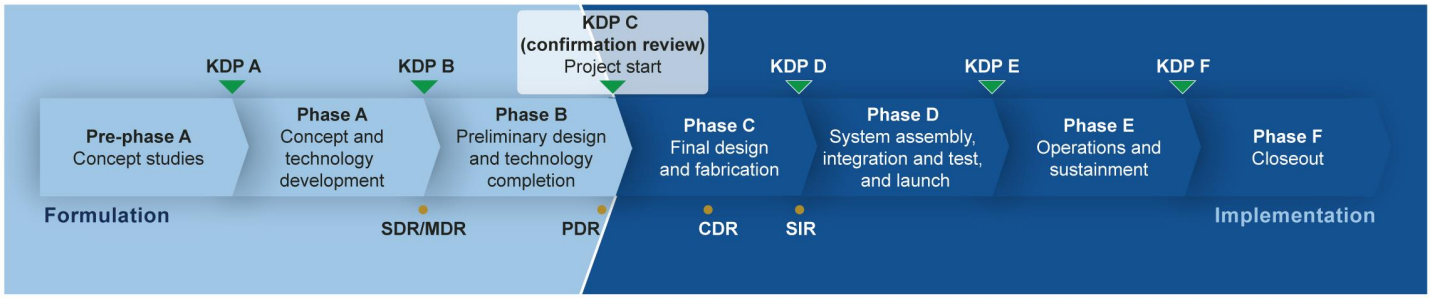
[3]Five projects were in an early stage of development called formulation when there are still unknowns about requirements, technology, and design. For those projects, we reported preliminary cost ranges and schedule estimates. The Commercial Crew Program has a tailored project life cycle and project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

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

Background

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

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-17-303SP

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.

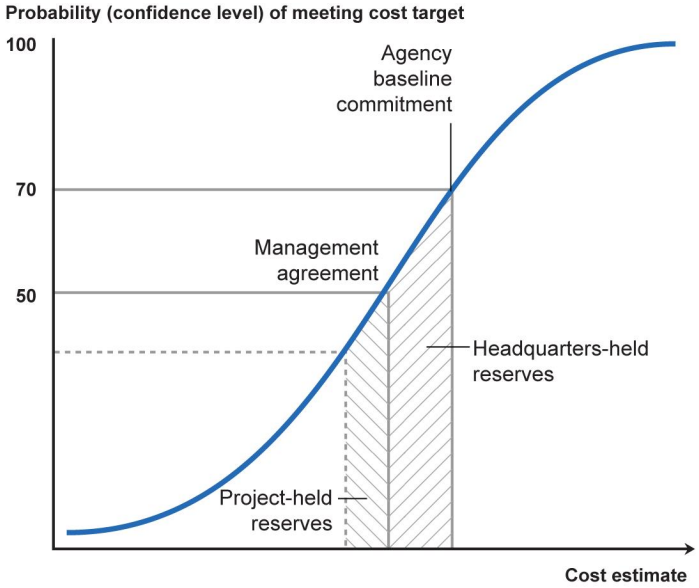
Formulation culminates in a review at key decision point C, known as project confirmation, where cost and schedule baselines are established and documented in the decision memorandum. The decision memorandum outlines the management agreement and the agency baseline commitment. The management agreement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

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

[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.

The management agreement and agency baseline commitment include cost and schedule reserves held at the project and NASA headquarters-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-17-303SP

The total amount of cost and schedule reserves held at the project level varies based on where the project is in its life cycle. Four of the six NASA centers, which are responsible for managing 18 of the 22 major projects,

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

require or recommend that projects hold a certain level of 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.

At project confirmation, NASA approves a project budget profile. This includes how much funding is needed each fiscal year through project closeout to manage the project to the agency baseline commitment. According to GAO's Cost *Estimating and Assessment Guide*, project cost estimates are time phased because they usually span many years.[7] Time phasing spreads a program's expected costs over the years in which they are anticipated to aid in developing a proper budget. Depending on the activities in the schedule for each year, some years may have more costs than others. When a project's budget does not align with its budget profile for a given fiscal year, it can experience budget phasing issues. We have previously found that budget phasing issues can lead to development delays and cost increases.[8]

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 stable enough to support proceeding with the final design and fabrication. After the critical design review and just prior to beginning phase D, the project

[6]NASA, 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 Solar Probe Plus (SPP) project 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).

[7]GAO, *GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs*, GAO-09-3SP (Washington, D.C.: Mar. 2, 2009).

[8]GAO-09-3SP.

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 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 21 major NASA projects. Four projects are being assessed for the first time this year: Landsat 9; Plankton, Aerosol, Cloud, ocean Ecosystem (PACE); the Radiation Budget Instrument (RBI); and Wide-Field Infrared Survey Telescope (WFIRST). We did not develop a project assessment for one major project, the OSIRIS-REx project, because it launched in September 2016. Figure 3 includes more information on the 21 projects we assessed. Appendix II includes a list of all the projects that we have reviewed from 2009 to 2017.

Figure 3: Major NASA Projects Reviewed in GAO's 2017 Assessment

	Acronym	Project name	Preliminary launch readiness date	Preliminary cost estimate (in millions)
Formulation	ARRM	Asteroid Redirect Robotic Mission	December 2021	$1,672 – $1,822
	Clipper	Europa Clipper	July 2023	$3,100 – $4,000
	Landsat 9	Landsat 9	Dec 2020 – Nov 2021	$851 – $928
	PACE	Plankton, Aerosol, Cloud, ocean Ecosystem	2022 – 2023	$805 – $850
	WFIRST	Wide-Field Infrared Survey Telescope	2024 – 2026	$3,200 – $3,800
			Launch readiness date	**Current cost baseline (in millions)**
Implementation	EGS	Exploration Ground Systems	November 2018	$2,812.9
	GRACE-FO	Gravity Recovery and Climate Experiment Follow-On	February 2018	$431.9
	ICESat-2	Ice, Cloud, and Land Elevation Satellite-2[a]	June 2018	$1,063.6
	ICON	Ionospheric Connection Explorer	October 2017	$252.7
	InSight	Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport	May 2018	$828.9
	JWST	James Webb Space Telescope	October 2018	$8,825.4
	Mars 2020	Mars 2020	July 2020	$2,443.5
	NISAR	NASA Indian Space Research Organisation Synthetic Aperture Radar	September 2022	$866.9
	Orion	Orion Multi-Purpose Crew Vehicle	April 2023	$11,283.5
	RBI	Radiation Budget Instrument	December 2019	$304.8
	SGSS	Space Network Ground Segment Sustainment[b]	September 2019	$1,207.9
	SLS	Space Launch System	November 2018	$9,695.4
	SPP	Solar Probe Plus	August 2018	$1,553.4
	SWOT	Surface Water and Ocean Topography	April 2022	$754.9
	TESS	Transiting Exoplanet Survey Satellite	June 2018	$378.4
	CCP	Commercial Crew Program[c]	December 2017	$6,828.6

Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-17-303SP

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.

[a]The ICESat-2 project experienced technical challenges with its instrument and the project has determined it will not launch by its committed launch readiness date of June 2018. Information on a new launch readiness date was not available at the time of our review.

[b]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. Cost and schedule information in the figure reflects SGSS's 2015 approved baseline. Its current cost and schedule are under review.

[c]Both Commercial Crew Program contractors have experienced delays and will not be able to meet their original 2017 certification dates and both expect certification to be delayed until 2018. 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.

NASA has other projects in formulation that have a life-cycle cost estimate greater than $250 million that were not included in our assessment this year because they are technology demonstration missions. They include the Restore-L satellite servicing and Laser Communication Relay Demonstration projects within the Space Technology Mission Directorate, and X-plane projects with the Aeronautics Research Mission Directorate. We may include these projects in future reviews, but before doing so, we wanted to gain a better understanding of how these projects are being managed by NASA.

Portfolio Cost and Schedule Performance Continues to Improve

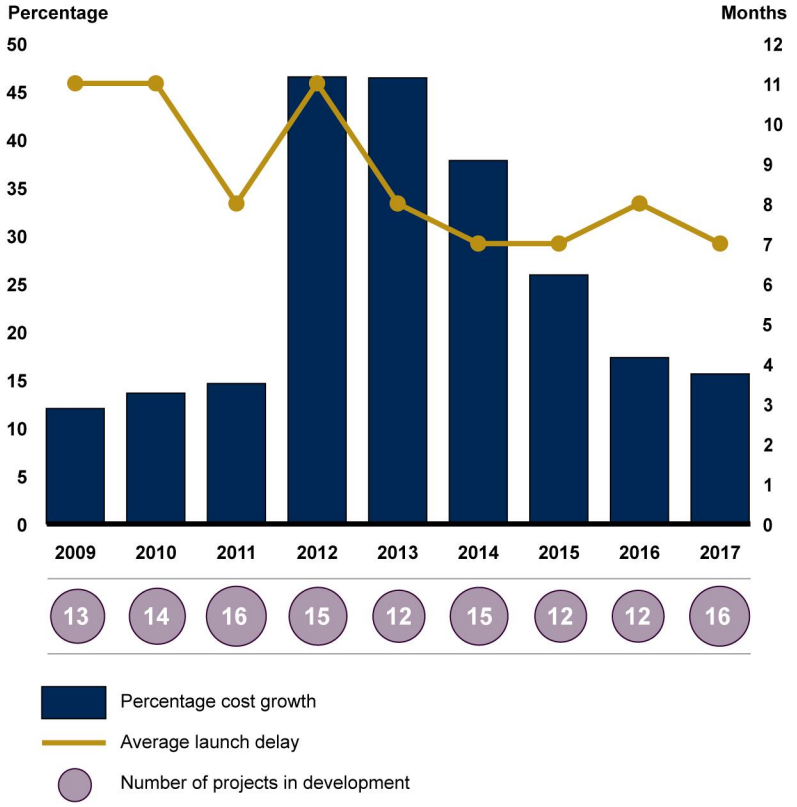
The cost and schedule performance of NASA's portfolio of major projects continues to improve. The trend has been driven by two main factors: most projects are being executed within their cost and schedule baselines and new projects, which are less likely to have experienced cost and schedule growth, have been added to the portfolio. NASA could have difficulty sustaining this trend. Half of its major projects in development are at the point in the acquisition process when cost and schedule problems are most likely to occur. These projects include the largest projects in the portfolio—the Orion Multi-Purpose Crew Vehicle (Orion) and Space Launch System—both of which face significant development risk. Lastly, while NASA has improved its development cost performance, our analysis of recently launched projects found that the majority of these projects have experienced operations cost growth.

Overall Cost and Schedule Performance Has Improved Over the Last Five Years

The overall cost and schedule performance of NASA's portfolio of major projects continues to improve—a trend that began in 2013. In 2017, the overall development cost growth for the portfolio of 16 development projects declined to 15.6 percent, down from 17.3 percent in 2016. In

addition, the average launch delay declined to 7 months, down from 8 months in 2016, due to OSIRIS-REx launching 1 month before its committed launch date. Both measures are at or near the lowest levels we have reported since we began our annual review in 2009 (see fig. 4).[9]

Figure 4: Development Cost Performance and Average Launch Delay for Major NASA Projects from 2009 through 2017



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-17-303SP

Note: Includes projects in development.

The overall cost and schedule performance of the NASA major projects

[9]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 there are other projects, such as Orion and the Space Launch System, with large development cost baselines, we decided to no longer present cost performance trends excluding JWST.

portfolio has improved, in part, due to the continued addition of new development projects. The cost and schedule performance of any portfolio is partially driven by its composition—the number, size, and average age of projects. The addition of new projects generally helps improve portfolio performance because they are less likely to have experienced cost and schedule growth than older ones. New projects can also improve a portfolio's cost performance by increasing the development baseline against which portfolio cost growth is measured. In other words, increases in the development cost baseline—which is the denominator when calculating the percentage cost growth in the portfolio—can help drive cost growth percentages down. There are four new projects in NASA's major project portfolio in 2017. These projects increased the development baseline of the portfolio by $3.1 billion or approximately 14 percent, and have not incurred any cost growth to date. If we exclude these new projects from the portfolio, development cost growth increases from 15.6 percent to 17.8 percent in 2017. We have reported similar findings on the effects of new projects on cost performance in our prior two annual assessments.[10] Figure 5 illustrates several key characteristics of NASA's portfolio of major projects in development, including the number of projects, and their combined development cost baseline.

[10]GAO, *NASA: Assessments of Major Projects,* GAO-16-309SP (Washington, D.C.: Mar. 30, 2016) and *NASA: Assessments of Selected Large-Scale Projects [Reissued on March 26, 2015],* GAO-15-320SP (Washington, D.C.: Mar. 24, 2015).

Figure 5: Total Number and Development Cost Growth for NASA Major Projects with Established Cost Baselines from 2009 through 2017

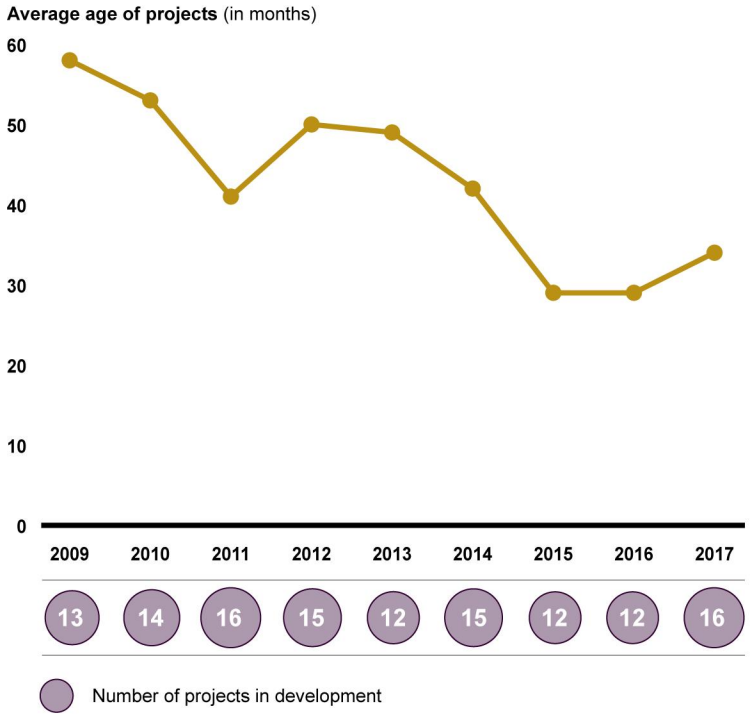
Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-17-303SP

Note: Includes projects in development.

We have also previously found that cost and schedule performance collectively improved as the projects in the portfolio have become, on average, younger.[11] Project age is calculated based on the length of time a project has been in development and is another method of capturing the newness of the portfolio. In 2017, the average age of the portfolio increased from 29 months to 34 months and cost performance still improved (see. fig. 6). If this trend continues, it would indicate that NASA's development cost performance improvements may be sustainable even when the portfolio consists of older projects that are more likely to experience cost growth.

[11]GAO-16-309SP.

Figure 6: Average Age of NASA Major Projects from 2009 through 2017



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-17-303SP

Note: The average age of projects is the average length of time projects in the portfolio have been in development.

Most Projects Performed Well in 2016, but Several Projects Have Experienced or Will Experience Cost or Schedule Growth

Most NASA major projects stayed within cost and schedule estimates in 2016, but several projects have experienced or will soon experience significant cost growth or schedule delays. On the positive side, the OSIRIS-REx project was launched in September 2016—1 month before its committed date—and completed development for $157 million or 20 percent less than was estimated in its baseline. The largest contributors to the underrun reported in 2016 were lower than expected use of reserves, which are funds set aside to address potential risks or problems, and launch vehicle costs. Several other projects did not fare well.

- The Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport (InSight) project was replanned in 2016 after it missed its committed launch date due to technical issues with its primary science instrument, which was contributed by France.[12] As a result of the problems, NASA delayed the project's launch by 26 months from March 2016 to May 2018. Development costs have increased by $131.7 million or 24 percent, primarily due to the project needing to recomplete the assembly, test, and launch operations phase.
- The Space Network Ground Segment Sustainment (SGSS) project's estimated cost grew by at least $53 million in 2016 due to continued problems with contractor performance. The rising cost of the project also led it to defer work; the project will only deploy the system at one of three planned sites. The project is currently reviewing its cost and schedule and expects there to be additional cost growth and schedule delays. SGSS was previously rebaselined in 2015.
- The ICESat-2 project's cost and schedule is under review due to technical issues with its only instrument, the Advanced Topographic Laser Altimeter System (ATLAS). A key part in the instrument's lasers failed during ATLAS thermal vacuum testing, which is the last step before system integration begins. The project is working to repair the lasers. The project expects to miss its committed launch date—June 2018—by at least 3 months due to the laser problems. ICESat-2 was previously rebaselined in 2014.
- Both Commercial Crew Program contractors have notified NASA that they will not be able to complete the development and certification of their crew transportation systems by 2017, the date originally established in their contracts. The contractors must provide NASA evidence that their crew transportation system meets its performance and safety requirements to be certified. Both contractors have experienced challenges in development and expect certification to be delayed until at least 2018.

Table 1 provides data on the cost and schedule performance for the 16 major projects in development that have cost and schedule baselines.

[12]A replan is a process initiated if development cost growth is 15 percent or more. A replan does not require a new project baseline to be established. A rebaseline is a process initiated if development cost growth is more than 30 percent. Both processes require 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. In addition, if a project or program milestone is likely to be delayed by 6 months or more, a report to the committees is required.

Table 1: Development Cost and Schedule Performance of Selected Major NASA Projects Currently in the Implementation Phase

Overall performance	Project	Confirmation date	2016 performance		Cumulative performance	
		Year	Cost (millions)	Schedule (months)	Cost (millions)	Schedule (months)
Lower than expected cost	OSIRIS-REx	2013	-$79.6	-1	-$157.8	-1
	SPP	2014	$0.0	0	-$5.4	0
	TESS	2014	$0.0	0	-$26.8	0
	GRACE-FO	2014	$0.0	0	-$0.6	0
	Orion[a]	2015	$4.7	0	-$151.7	0
Within baseline	ICON[a]	2014	$0.2	0	$0.0	0
	SLS	2014	$0.0	0	$0.0	0
	EGS[a]	2014	$0.0	0	$3.6	0
	SWOT	2016	$0.0	0	$0.0	0
	Mars 2020	2016	$0.0	0	$0.0	0
	RBI	2016	$0.0	0	$0.0	0
	NISAR	2016	$0.0	0	$0.0	0
Higher than expected cost	InSight	2014	$131.7	26	$131.7	26
Rebaseline	JWST	2008	$0.0	0	$3,607.7	52
	ICESat-2[b]	2012	$0.0	0	$204.9	13
	SGSS[b]	2013	$53.4	0	$362.1	27
Total:			**$110.4**	**25**	**$3,967.7**	**117**

Legend: OSIRIS-REx: Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer; SPP: Solar Probe Plus; ICON: Ionospheric Connection Explorer; TESS: Transiting Exoplanet Survey Satellite; GRACE-FO: Gravity Recovery and Climate Experiment Follow-On; Orion: Orion Multi-Purpose Crew Vehicle; SLS: Space Launch System; EGS: Exploration Ground Systems; SWOT: Surface Water and Ocean Topography; RBI: Radiation Budget Instrument; NISAR: NASA Indian Space Research Organisation – Synthetic Aperture Radar; InSight: Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport; JWST: James Webb Space Telescope; ICESat-2: Ice, Cloud, and Land Elevation Satellite-2; SGSS: Space Network Ground Segment Sustainment

Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-17-303SP

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

[a]The total estimated costs of the Orion, EGS, and ICON projects remain unchanged. The cost changes in the table reflect changes to how the project allocated project funding between the development and formulation phases.

[b]The ICESat-2 and SGSS projects expect to experience additional cost growth and schedule delays, but the exact magnitude is unknown. The projects were reevaluating their cost and schedules at the time of our review.

NASA's Highest Cost Projects Are in the Stage When Most Rebaselines Occur

As we found in 2016, the projects in NASA's current portfolio with the highest development costs, including Orion and the Space Launch System, are at the stage when most rebaselines occur.[13] Projects appear most likely to rebaseline between their critical design review and system integration reviews—the riskiest point in the development cycle. NASA has rebaselined one major project each year for 8 out of the last 10 years. All eight projects were rebaselined after their critical design reviews and most of the projects that held a systems integration review were rebaselined before doing so. Table 2 lists the eight projects that plan to be in that phase of development in 2017. If a rebaseline occurs on any of these projects, it could add at least between $97 million and $2.1 billion to the development cost of the portfolio. This range is based on 30.1 percent development cost growth—as a rebaseline is triggered when development cost growth exceeds 30 percent—for the projects with the lowest and highest development cost in table 2.

[13]GAO-16-309SP.

Table 2: Current Projects between Critical Design Review and Systems Integration Review

Project	Critical design review date	Systems integration review date
Exploration Ground Systems (EGS)	December 2015	May 2017
Transiting Exoplanet Survey Satellite (TESS)	August 2015	May 2017
Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport (InSight)[a]	May 2014	June 2017
James Webb Space Telescope (JWST)[b]	March 2010	September 2017
Space Launch System (SLS)[c]	July 2015	August 2018
Orion Multi-Purpose Crew Vehicle (Orion)[d]	October 2015	September 2020
Space Network Ground Segment Sustainment (SGSS)[b]	June 2013	TBD
Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2)[e]	February 2014	TBD

Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-17-303SP

Note: Projects shaded in gray have been rebaselined previously.

[a]InSight will hold a second system integration review. The project has to recomplete the system assembly, test, and launch operations phase due to technical issues with its primary instrument.
[b]The system integration review dates are for the project's rebaselined schedule.
[c]The Space Launch System does not have a system integration review. The program's next major system engineering milestone is its planned August 2018 design certification review, which is intended to ensure that the design meets functional and performance requirements and is ready for operation.
[d]The system integration review date for Orion is for Exploration Mission-2, the mission for which the program established its cost and schedule baseline. Orion held a system integration review for Exploration Mission-1 in November 2016.
[e]ICESat-2 postponed its system integration review indefinitely due to technical problems with its primary instrument.

Three of the largest projects in this critical stage of development—Exploration Ground Systems, Orion, and the Space Launch System—continue to face cost, schedule, and technical risks. In April 2017, we found that the first integrated test flight of these systems, known as Exploration Mission-1, will likely be delayed beyond November 2018.[14] NASA concurred with our findings and is currently conducting an assessment to establish a new launch date. Because NASA's assessment is ongoing, the cost implications of the schedule delay and its effect on the projects' baselines are still unknown. However, given that these three human space exploration programs represent more than half of NASA's current portfolio development cost baseline, a cost increase or delay could have substantial repercussions not only for these programs but NASA's entire portfolio.

[14]GAO, *NASA Human Exploration Programs: Delay Likely for First Exploration Mission*, GAO-17-414 (Washington, D.C.: Apr. 27, 2017).

Payload Development Was the Biggest Area of Cost Risk for Science Projects

Multiple independent studies have historically found that instrument development problems are the largest element of cost growth within the control of a project.[15] We found that still to be the case for seven current Science Mission Directorate projects that we examined.[16] The total estimated payload development costs for the seven projects increased by $250.1 million or 67 percent since they were baselined, which was more than any other cost category that NASA tracked (see table 3).

Table 3: Development Cost Changes from Project Confirmation to February 2017 for Select Science Mission Directorate Projects

Development categories	Baseline costs (in millions)	February 2017 cost (in millions)	Dollar change (in millions)	Percentage change
Payloads	$373.4	$623.5	$250.1	67%
Ground Systems	$114.4	$151.3	$36.9	32%
Aircraft and Spacecraft	$866.6	$1,079.0	$212.4	25%
Launch Vehicle	$1,116.5	$1,044.3	($72.2)	-6%
All Other Categories	$1,247.3	$966.04	($281.3)	-23%
Total Development Cost	**$3,718.1**	**$3,864.1**	**$146.0**	**4%**

Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-17-303SP

Note: "All other categories" include system integration and test, science and technology, and other direct costs. Other direct costs include project and headquarters-held cost reserves.

The total development cost for these seven projects increased by a smaller amount because launch vehicle costs were less than anticipated

[15]For example, National Research Council of the National Academies, *Controlling Cost Growth of NASA Earth and Space Science Missions* (Washington, D.C.: National Academies Press, 2010); Bob Bitten, *Perspectives on NASA Mission Cost and Schedule Performance Trends* (El Segundo, Calif.: The Aerospace Corporation, 2008); and Claude Freaner, *An Assessment of the Inherent Optimism in Early Conceptual Designs and its Effect on Cost and Schedule Growth* (El Segundo, Calif.: The Aerospace Corporation, 2008).

[16]The seven projects are Gravity Recovery and Climate Experiment Follow-On (GRACE-FO), ICESat-2, InSight, Ionospheric Connection Explorer (ICON), OSIRIS-REx, SPP, and Transition Exoplanet Survey Satellite (TESS). We choose these projects because they reported their development costs using similar cost categories and at least 6 months had passed since their cost baseline was approved. See appendix I for more information about our scope and methodology.

and the individual projects have been able to use their cost reserves to cover overruns in other development cost categories. Project officials have told us that they use higher launch vehicle cost estimates in their baselines to account for the most expensive launch vehicle option under consideration and inflation. Once a launch vehicle is selected and a contract is signed, these costs can decrease. Competition in the space launch industry may also be contributing to lower than expected prices. Cost reserves are included in the "All Other Categories" line in table 3. The amount in that category decreases as projects allocate reserves to pay for increases in categories, such as payloads and aircraft and spacecraft. The changes in most categories were primarily driven by a few projects. For example, ICESat-2 had development problems with its only instrument, resulting in a $144.7 million increase in its payload category, while OSIRIS-REx had a $45.2 million decrease in the launch vehicle category.

Operations Costs for Launched Projects Have Increased

NASA has improved the development cost performance of its projects, but operations cost performance continues to be a challenge.[17] We examined projects that were included in our annual assessments from 2009 to 2016 and found that 20 previously launched science missions experienced cumulative operations cost growth of $177.7 million (11 percent), up from $114.6 million (8 percent) in 2016. This increase was driven mostly by the OSIRIS-REx project. OSIRIS-REx launched in 2016 and its operations costs were $100 million higher than previously estimated. The project determined it needed additional funding for operations, for example, to increase staff levels for activities such as on-orbit system check out and payload calibration. The project has not exceeded its cost baseline because it underran its estimated costs for development. On the positive side, the estimated operations cost for the Mars Atmosphere and Volatile EvolutioN project decreased by $31.5 million in 2016 because the mission operated more efficiently than anticipated and needed less funding to address risks. The project is still exceeding its operations cost estimate overall.

[17]Development costs include Phases C and D of the NASA project life cycle. Our analysis of operations costs focused on prime operations costs, which are the project's planned mission operations in Phase E. The agency may elect to undertake a period of extended operations if a system is still operational after the prime mission is fulfilled. We did not consider extended operations costs in this analysis as they are not part of the project's cost baseline.

Of the 20 previously launched science missions we examined, 15 projects experienced operations cost growth and, for 3 projects those operations cost increases caused the project to exceed the cost baseline for the project as a whole. For example, the Juno project experienced operations cost growth in 2016 that resulted in the project exceeding its overall cost baseline. The project's operations costs increased by $22.8 million because it needed to change the orbit duration from 11 days to 14 days in order to reduce mission risk during operations. This change resulted in increasing the project's time in prime operations by approximately 4 months over the initial plan.

NASA has acknowledged that establishing operations cost baselines at project confirmation is a challenging task, and has efforts underway to improve operations cost estimates. For example, NASA updated the Mission Operations Cost Estimating Tool to include historical project information as well as more rigorous statistical methods. Science Mission Directorate officials have also previously told us that they have initiated studies to examine how operations costs are estimated and asked standing review boards to more carefully review these estimates at a project's confirmation review.

NASA Has Generally Maintained Improvements in Technology Maturity and Design Stability

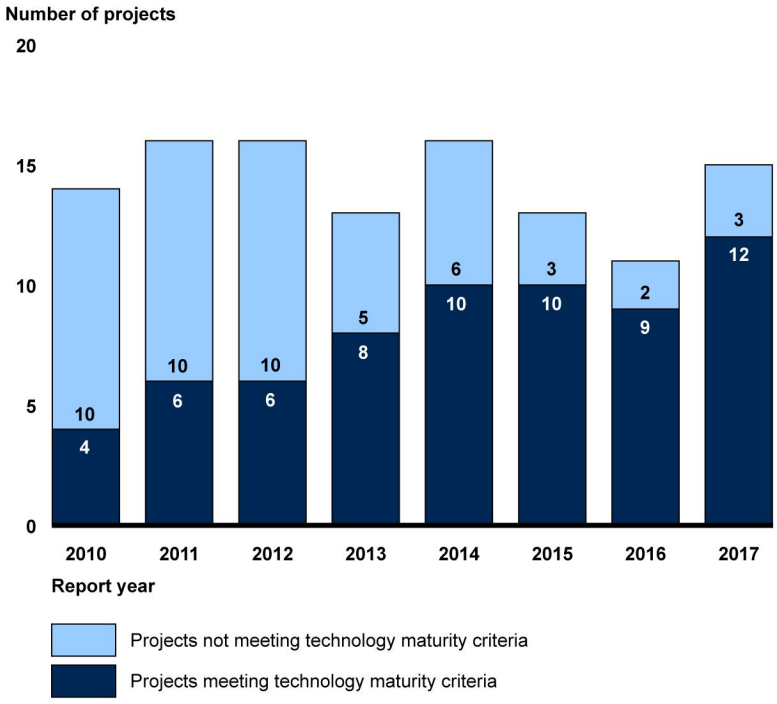
NASA has generally maintained improvements in the technology maturity and design stability of its major projects, even as the number of new technologies in its most recent projects has increased. Three out of the four projects that held preliminary design reviews in 2016 matured all their technologies to the level recommended by GAO best practices. Further, these four projects had a combined total of 17 critical technologies—nearly the same number developed by the previous 10 major projects to hold a preliminary design review. None of NASA's major projects held critical design reviews in 2016. Design changes on the projects that previously held this review increased this year, although the overall magnitude of the changes remains relatively low. Further, we found that NASA major projects that have launched within their cost and schedule baselines since 2009 tended to meet best practices for maturing technologies and minimizing design changes. In contrast, rebaselined projects were less likely to do so.

NASA Continues to Improve the Technology Maturity of Its Projects, Even as the Number of Critical Technologies Increased

Most of NASA's major projects met GAO best practices for technology maturity in 2017, even as the average number of critical technologies in projects increased. Our best practices work has shown that reaching 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 the preliminary design review can minimize risks for systems entering product development.[18] Projects falling short of this standard may experience subsequent technical problems, which can result in cost growth and schedule delays. Figure 7 shows that NASA has continued its trend to improve the technology maturity of its projects.

[18]Appendix IV 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 7: Number of NASA's Major Projects Attaining Technology Maturity by Preliminary Design Review from 2010 through 2017



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-17-303SP

Note: Includes projects that completed preliminary design review and identified critical or heritage technologies. For example, for 2017, 15 of 22 NASA major projects had held this review and identified critical or heritage technologies.

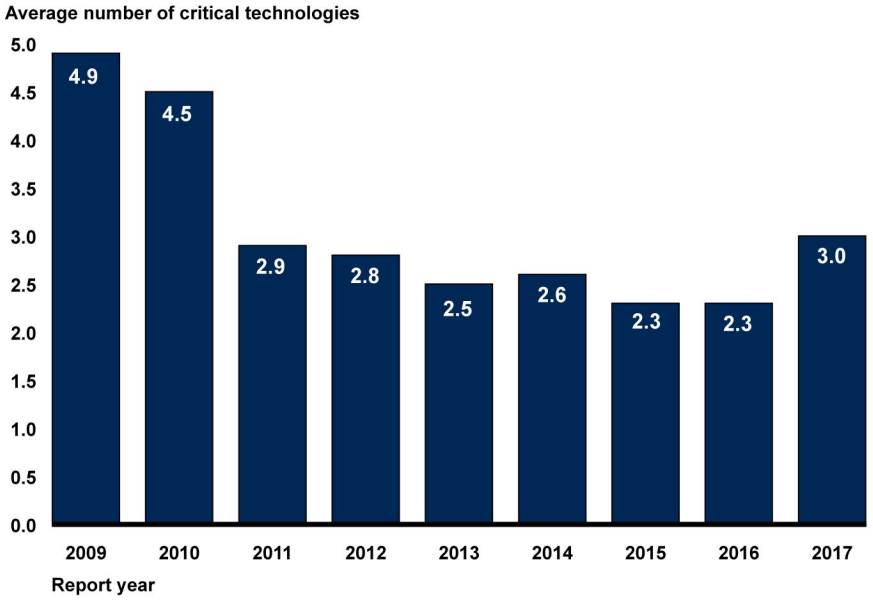
Three of the four projects that held a preliminary design review in 2016—NASA Indian Space Research Organisation – Synthetic Aperture Radar (NISAR), RBI, and Surface Water and Ocean Topography (SWOT)—matured their heritage and critical technologies to a technology readiness level 6 by that review.[19] The remaining project, Mars 2020, matured two of

[19]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. Appendix III provides a description of technology readiness levels, which are the metrics used to assess technology maturity.

its seven critical technologies and one of its two heritage technologies to the recommended level. A Mars 2020 project official said NASA held the review with immature technologies to stay on schedule and avoid delaying progress on other parts of the project. Schedule is a key driver for Mars 2020. If the project misses the 2020 launch window, it must wait 26 months before another launch opportunity is available. To help mitigate the risk of moving forward with technologies that were not mature, the project allocated a significant portion of its reserve funding to cover potential cost growth for its new and modified instruments. As of January 2017, the project stated that all its critical technologies had reached a technology readiness level 6, but it had not yet matured the one remaining heritage technology. The remaining technology is an improved sensor on Mars 2020's entry, descent, and landing instrument that could be descoped and replaced with a heritage sensor if necessary.

In 2017, NASA's average number of critical technologies increased from prior years to a level not seen in a portfolio since 2011 (see fig. 8). The increase resulted from four projects—Mars 2020, NISAR, RBI, and SWOT—that held preliminary design reviews in 2016 with a combined total of 17 critical technologies, nearly the same number developed by the previous 10 major projects to hold preliminary design review. Mars 2020 has seven critical technologies; SWOT has four critical technologies; and RBI and NISAR each have three critical technologies.

Figure 8: Average Number of Critical Technologies Reported by NASA for Major Projects in Development from 2009 through 2017



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-17-303SP

Most major projects we have reviewed since 2009 have not pushed technological innovation through the development of critical technologies. Until Mars 2020 and SWOT, the previous two major NASA projects to develop more than three critical technologies were the James Webb Space Telescope and Solar Probe Plus (SPP) which entered implementation in 2008 and 2014, respectively. About three-quarters of all NASA major projects we have reviewed had fewer than three critical technologies (see table 4). Over half of all major projects we have reviewed had either one critical technology or none at all. Several of these are upgrade or follow-on missions, which rely heavily on heritage technologies. For example, in this year's portfolio, the Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) project—a follow-on to the original GRACE mission—is not developing any critical technologies but is employing technologies developed for the original GRACE mission.

Table 4: Projects Developing Critical Technologies by Confirmation Year through 2016

Confirmation year	Number of projects developing three or fewer critical technologies	Number of projects developing four or more critical technologies
2009 or earlier	15	6
2010	3	0
2011	0	0
2012	2	0
2013	2	0
2014	5	1
2015	1	0
2016	2	2
Total	**30**	**9**

Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-17-303SP

Note: EGS did not report any critical or heritage technologies, so it was omitted from this analysis.

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. We have previously reported that maturing technologies in separate technology development efforts is a best practice that can reduce risk and improve cost and schedule outcomes in product or system development.[20]

NASA's technology demonstration missions program, which began in 2010, aims to implement this best practice of maturing new technologies outside of projects. The program's goal is to mature a technology 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. For example, NASA is maturing advanced controls, sensors, and robotics technologies in its Restore-L mission, a satellite servicing mission, and anticipates using Restore-L technologies on multiple projects including the Asteroid

[20]GAO, *Best Practices: Better Management of Technology Development Can Improve Weapon System Outcomes*, GAO/NSIAD-99-162 (Washington, D.C.: July 30, 1999).

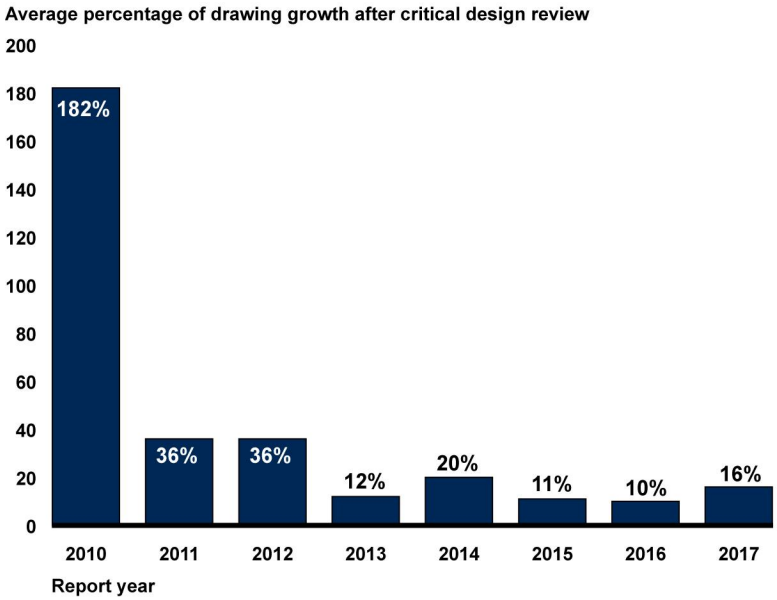
Redirect Robotic Mission (ARRM) and Orion. Likewise, NASA is maturing Deep Space and Near Earth operational systems with the optical communications technologies in its Laser Communication Relay Demonstration to be infused into other NASA and partner projects.

Several NASA Projects Experienced Late Design Changes, but Other Design Stability Measures Remained Unchanged

No NASA major projects held a critical design review during this reporting cycle, but several projects already past this milestone reported late design changes.[21] 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. If a project experiences a large amount of engineering drawing growth after this review, it may be an indicator of instability in the project design late in the development cycle. Design changes at this point can be costly to the project in terms of time and funding because hardware may need to be reengineered or reworked as a result. For the 11 projects in development that have held critical design reviews, drawing growth after the review was 16 percent, which is higher than the last 2 years, but relatively low historically (see fig. 9). The increase in 2017 was due to primarily to three projects—James Webb Space Telescope, Transiting Exoplanet Survey Satellite (TESS), and InSight. For example, the number of InSight drawings grew by 15 percent after a key instrument failed late in testing. As a result, the project added new hardware and took on work that was previously managed by its French partner.

[21]The Mars 2020 project held its critical design review after we completed our analysis for this reporting cycle.

Figure 9: Average Percentage of Engineering Drawing Growth after Critical Design Review for NASA Major Projects from 2010 through 2017



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-17-303SP

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.

Designs for NASA's major projects have remained generally stable after their critical design reviews, but often fall short of a key GAO best practice leading up this review. Our work on product development best practices shows that at least 90 percent of engineering drawings should be releasable by the critical design review to lower the risk of subsequent cost and schedule growth.[22] The NASA Systems Engineering Handbook also includes this metric. Projects that do not achieve design stability by critical design review may experience design changes and manufacturing problems. Fewer than half of NASA's current major projects released at least 90 percent of their engineering drawings by the critical design review, although projects have performed better in recent years (see fig.

[22]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."

10). The average percentage of engineering drawings released by the projects was 69 percent, roughly the same as it has been since 2013. Two projects—Mars 2020 and RBI—expect to hold critical design reviews in 2017. The RBI project has released all of its expected design drawings in advance of its planned June 2017 critical design review. The Mars 2020 project had released 72 percent of its design drawings as of January 2017, and planned to release about 80 percent by its late February 2017 critical design review. In January 2017, the NASA Inspector General recommended that the Mars 2020 project manager ensure the project met the 90 percent drawing release criteria before holding its critical design review.[23] NASA concurred with the recommendation, but stated that the current rate of drawing release on the project is acceptable.

Figure 10: Number of NASA Major Projects That Released over 90 Percent of Engineering Drawings at Critical Design Review from 2010 through 2017

Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-17-303SP

Note: Includes projects that completed critical design review and had engineering drawings. For example, for 2017, 11 of 22 NASA major projects had held this review and had engineering drawings.

[23]National Aeronautics and Space Administration Office of Inspector General, *NASA's Mars 2020 Project*, IG-17-009 (Washington, D.C.: Jan. 30, 2017).

NASA projects have performed better against other design stability metrics at their critical design review. A panel of experts convened by GAO in 2013 identified several metrics as good indicators of design stability, including maintaining adequate mass and power margins and completing requirements validation and verification plans. The NASA Systems Engineering Handbook also includes these metrics. We found that all projects for which mass and power requirements were applicable met these requirements at their critical design reviews and have continued to maintain the required levels of margin.[24] 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.[25]

NASA Project Performance Reflects Adherence to Best Practices for Maturing Technologies and Minimizing Design Changes

NASA's major projects that have launched within their cost and schedule baselines tended to have fewer critical technologies, fully mature their critical and heritage technologies before their preliminary design reviews, and minimize late design changes, although these are not the only factors that contribute to cost and schedule performance. Since we started reporting on NASA's major projects in 2009, six NASA missions have launched within cost and schedule baselines. All of these projects had three or fewer critical technologies and all but two matured their technologies to technology readiness level 6 by the preliminary design review (see table 5). In addition, these projects minimized design changes after critical design review with drawing growth below 20 percent

[24]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.

[25]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.

for all but one project. Even when projects did not meet best practices, they took other steps to mitigate potential risks. For example, we previously reported that the Gravity Recovery and Interior Laboratory project held its preliminary design review with an immature technology but set aside adequate reserves to cover subsequent delays.[26]

Table 5: Characteristics of NASA Major Projects That Launched within Their Cost and Schedule Baselines from 2009 through 2017

Project	Critical technologies	Technologies matured at preliminary design review	Drawing growth after critical design review
Juno	0	Yes	47%
Gravity Recovery and Interior Laboratory	1	No	18%
Mars Atmosphere and Volatile EvolutioN	1	Yes	3%
Soil Moisture Active Passive	1	No	0%
Landsat Data Continuity Mission	3	Yes	16%
Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer	3	Yes	3%

Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-17-303SP

In contrast, major projects that have rebaselined tended to have more critical technologies, not fully mature their critical and heritage technologies before their preliminary design reviews, and experience more late design changes. Of the eight major projects that have rebaselined over the last 10 years, five projects developed between four and nine critical technologies and none of the five projects matured their technologies prior to their preliminary design review (see table 6). In addition, the projects experienced more drawing growth—on average 54 percent—after their critical design reviews.[27] None of the projects included in this analysis met the best practice of releasing 90 percent or more of their design drawings at their critical design reviews. Therefore, we were not able to make a comparison between the projects that launched within cost and schedule and those that were rebaselined for that best practice.

[26]GAO, *NASA: Assessments of Selected Large-Scale Projects,* GAO-11-239SP (Washington, D.C.: Mar. 3, 2011).

[27]We excluded SGSS from the drawing growth calculation as this project does not use drawings.

Table 6: Characteristics of NASA Major Projects That Have Rebaselined from 2007 through 2017

Project	Critical technologies	Technologies matured at preliminary design review	Drawing growth after critical design review
Orbiting Carbon Observatory-2[a]	0	Yes	8%
Space Network Ground Segment Sustainment	0	Yes[b]	Not applicable
Ice, Cloud, and Land Elevation Satellite-2	2	Yes	15%
Glory	4	No	27%
National Polar-orbiting Operational Environmental Satellite System Preparatory Project[c]	6	No	41%
Mars Science Laboratory	7	No	147%
Stratospheric Observatory for Infrared Astronomy	9	No	93%
James Webb Space Telescope	9	No	44%

Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-17-303SP

[a]The Orbiting Carbon Observatory-2 rebaseline was driven by launch vehicle failures which were external to the project.

[b]In April 2013, we reported that although SGSS officials reported that the project's technologies were mature, a management review board determined that two heritage technologies were not at an appropriate level of maturity at the project's preliminary design review.

[c]The current name of the National Polar-orbiting Operational Environmental Satellite System Preparatory Project is the Suomi-National Partnership Program.

Both we and NASA's Inspector General have found that design and technical problems, among other factors, contributed to cost and schedule increases with these rebaselined projects. For example, the Mars Science Laboratory's launch was delayed 26 months and its development costs increased by almost $800 million due in part to technical challenges. The project did not mature any of its seven critical technologies at its preliminary design review, including its motor actuators. The actuators are responsible for moving and controlling instruments on the rover and are considered high risk because they have a complex design involving hundreds of parts. The project had to redesign the actuators after determining that the initial design was not durable enough, which significantly contributed to the project's cost and schedule growth.[28]

[28]GAO-16-309SP; GAO-11-239SP; GAO, *NASA: Assessments of Selected Large-Scale Projects,* GAO-09-306SP (Washington, D.C.: Mar. 2, 2009); IG-17-009; and *NASA's Challenges to Meeting Cost, Schedule, and Performance Goals*, IG-12-021 (Washington, D.C.: Sept. 27, 2012).

NASA Has Implemented New Tools to Reduce Acquisition Risks, but Workforce and Funding Challenges Are Emerging Issues

NASA has implemented improved project management tools to manage acquisition risks, but capacity and funding challenges are emerging issues. In October 2015, NASA decided to decentralize its independent assessment function and deploy the staff to the agency's centers, in part, to better use its workforce to meet program needs in areas such as program management, cost estimating, and resource analysis, and to fill gaps in program analysis skills at the center level. Last year, we reported on the potential risks that this change could pose for project oversight, but the transition is still ongoing and it is too early to assess its effect on areas, such as independence, the robustness of reviews, and information sharing. Finally, almost one-third of the projects we assessed reported funding challenges that have or could affect their cost and schedule. In several cases, including Orion, NASA's budget does not support the project's internal schedules.

NASA Continues to Improve Its Cost and Schedule Management Tools, but Lacks the Workforce Capacity to Fully Implement Best Practices

NASA continues to implement cost, schedule, and earned value management (EVM) tools designed to improve estimation practices and reduce acquisition risk, but is not following several key best practices in some of these areas. For several years, we have reported that high-quality joint cost and schedule confidence level (JCL) estimates that are based on reliable supporting cost and schedule estimates and monitored using EVM data are critical to reducing acquisition risks.[29] But NASA may not have the workforce capacity to fully implement these management tools.

Updating joint cost and schedule confidence level estimates: NASA's current major projects have developed JCL estimates as required, but most of these projects did not update their JCL estimates

[29]GAO-16-309SP and GAO, *High-Risk Series: An Update*, GAO-15-290 (Washington, D.C.: Feb. 11, 2015).

unless they were rebaselined. A JCL is a tool that assigns a confidence level, or likelihood, of a project meeting its cost and schedule estimates. NASA requires that programs and projects with estimated life-cycle costs of more than $250 million develop a JCL prior to project confirmation to ensure that cost and schedule estimates are realistic and projects thoroughly plan for anticipated risks. NASA policy does not require projects to update their JCLs as they progress through development and new risks emerge. However, GAO cost estimating best practices recommend that cost estimates be updated to reflect changes to a program or kept current as it moves through milestones.[30] NASA has stated that it relies on other tools to assess progress and the adequacy of resources after project confirmation. One major project—InSight—did update its JCL in 2016 after missing its committed launch date. By doing so, the project was able to provide additional information to decision makers about the probability it will meet its revised cost and schedule estimates.

Creating reliable cost and schedule estimates: NASA has updated tools aimed at improving cost and schedule estimates, but individual projects have not met best practices for producing reliable cost estimates. Workforce capacity in these disciplines is also a challenge. High-quality cost and schedule estimates are the basis for a high-quality JCL, so it is critical that these estimates are rigorous and follow best practices. Accurate cost and schedule estimates and their associated confidence levels are crucial for decision makers who must be kept informed of the true cost and schedule in order for the projects to be positioned to succeed. In 2016, NASA updated its Cost Engineering Database to provide analysts with more data, such as historical project cost information, that can be used to inform cost estimates for similar projects. However, despite this and other NASA efforts to improve cost and schedule estimating, we recently found that the cost estimate for the most expensive project in the portfolio—Orion—did not include the necessary support and the schedule estimate did not include the level of detail required for high-quality estimates.[31] NASA did not agree to update its cost and schedule estimates and JCL analysis as we recommended because it said the program was still performing within its cost and

[30]GAO-09-3SP.

[31]GAO, *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).

schedule baseline and updating them was not yet warranted. We continue to believe this recommendation should be addressed because without sound cost and schedule estimates, decision makers lack the information they need to make programmatic decisions.

In addition, NASA has identified workforce gaps that could affect its ability to develop reliable cost and schedule estimates. In 2016, NASA completed an assessment to ascertain the agency's current health in the areas of cost and schedule estimating, cost and schedule assessment, EVM, and programmatic assessment, among other areas. The assessment revealed gaps in key skill areas like schedule estimation. NASA previously decentralized its independent assessment function in 2015, in part, to bolster the agency's workforce capacity at the center level in key areas, such as cost and schedule estimating.

Implementing earned value management: NASA has made progress implementing EVM analysis—another key project management tool—but the agency has not yet fully implemented a formal EVM surveillance plan in accordance with NASA and GAO best practices.[32] When implemented well, EVM integrates information on a project's cost, schedule, and technical efforts for management and decision makers by measuring the value of work accomplished in a given period and comparing it with the planned value of work scheduled for that period and the actual cost of work accomplished. In November 2012, we recommended that NASA update its procedural requirements to include a formal EVM surveillance program in order to improve the reliability of EVM data collected by NASA programs.[33] NASA agreed with our conclusion that EVM data reliability needed improvement, but it has yet to implement a formal surveillance requirement due to resource constraints.[34] NASA has taken steps to improve the reliability of EVM data on individual projects, such as the

[32]GAO, *Schedule Assessment Guide: Best Practices for Project Schedules,* GAO-16-89G (Washington, D.C.: Dec. 22, 2015); GAO-09-3SP; and National Aeronautics and Space Administration, *Earned Value Management Implementation Handbook*, NASA/SP-2012-599 (Washington, D.C.: Feb. 15, 2013).

[33]GAO, *NASA: Earned Value Management Implementation across Major Spaceflight Projects Is Uneven*, GAO-13-22 (Washington, D.C.: Nov. 19, 2012).

[34]A formal surveillance plan involves establishing an independent surveillance organization with members who have practical experience using EVM. This organization then conducts periodic surveillance reviews to ensure the integrity of the contractor's EVM system and where necessary discusses corrective actions to mitigate risks and manage cost and schedule performance.

James Webb Space Telescope, where we have previously found EVM deficiencies. We continue to believe that this recommendation should be addressed because without implementing proper surveillance agency-wide, projects may be utilizing unreliable EVM data to inform their decision making.[35]

Implementation of NASA's New Independent Assessment Approach Is Ongoing

NASA's transition away from a centralized independent assessment function is ongoing, and the agency is still developing and updating policies, procedures, and guidance over a year later. In October 2015, NASA dissolved the Independent Project Assessment Office and devolved the responsibility for independent assessments down to mission directorates, which oversee the projects being assessed. Independent reviews provide unbiased and comprehensive assessments of the technical, schedule, cost, and risk posture of NASA's projects. They are also a key acquisition best practice that we have highlighted in prior reports.[36] NASA issued a white paper that explains the general framework for the new independent assessment model in June 2016. At the same time, the Human Exploration and Operations Mission Directorate completed an implementation plan that explains how the independent assessment function will be carried out for projects within the directorate. In addition, the Office of the Chief Financial Officer completed its implementation plan in February 2017. Other plans have lagged. The Space Technology Mission Directorate and Science Mission Directorate plan to complete implementation plans in spring 2017. NASA also updated its standing review board handbook in December 2016, which serves as a guide for projects and review boards regarding expectations, processes, and products, and outlines guidance for membership selection, reviews, and reporting results. Finally, NASA is developing a new standard operating procedure for independent assessments that will include instructions for implementing the new model and plans to complete it by March 2017—17 months after the change was announced.

[35]GAO, *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).

[36]For example, see GAO, *Defense Acquisitions: Assessments of Selected Weapon Programs [Reissued on April 9, 2015],* GAO-15-342SP (Washington, D.C.: Mar. 12, 2015).

In March 2016, we highlighted three areas that could be negatively affected by the reorganization of the independent assessment function—independence, the robustness of reviews, and information sharing.[37] NASA has taken some steps to address these areas. For example, to help maintain the robustness of the reviews, the Office of the Chief Financial Officer told us that it will review programmatic assessments produced by the mission directorates for review boards, such as JCL analyses, to ensure they are in line with agency expectations. The transition is still ongoing, so it is too early to assess the effectiveness of many of these actions.

Several major projects have held reviews using the new assessment model and offered initial thoughts on its benefits and challenges. One project stated that placing responsibility for designing the terms of reference—the ground rules for standing reviews—in the implementing organization was a positive change. Another project said that its progress was slowed because of difficulties with standing review board staffing. We will continue to monitor the potential effects of the reorganization as more projects begin to use the new model.

Funding Challenges Could Affect NASA's Ability to Efficiently and Effectively Manage Its Major Projects

At least 7 of the 22 major projects we reviewed experienced funding challenges—specifically, funding phasing issues— in 2016. The cost and schedule performance of a project depends, in part, on receiving funding in line with its budget plan. Funding phasing issues—a mismatch between the money needed in a given time period to complete work to keep the project on schedule and the money currently or projected to be available—can lead to development delays and cost increases. Funding phasing issues can arise for a variety of reasons. For example, an agency may not receive enough funding in a given year to execute all of its projects in the most efficient manner or significant cost growth could occur and force decision makers to make trade-offs between major projects.

The projects we assessed experienced several types of funding-related challenges.

[37] GAO-16-309SP.

- The Europa Clipper project and Orion program are working to schedules not supported by NASA's budget plans, which could result in funding shortfalls at the project-level. In recent years, Congress has provided more funding to these projects than NASA has requested. Up until recently, the Space Launch System has also been working to a schedule not supported by NASA's budget plans. If the projects do not continue to receive appropriations that match their plans, they may have to take actions, such as revising their current schedules. We previously found that working to an unrealistic schedule may increase a project's risk of exceeding its cost and schedule baseline.[38]
- Other projects have already experienced the effects of funding shortfalls. Prior to project confirmation, the NISAR project reported funding shortfalls in 2017 and 2018. As a result, the project stretched out its schedule by 1 year when it established its cost and schedule baselines. The project initially thought it could address the shortfalls by delaying procurements, but a detailed study showed that this would not be possible due to the need to integrate several components in parallel. Funding shortfalls have also been a problem for other projects, such as the ARRM and SGSS projects.
- In the case of WFIRST, a project early in formulation, the availability of funding in the near-term could drastically affect its eventual cost and launch date. According to project officials, receiving significant additional funding in fiscal year 2018 would allow the project to optimize the development schedule and launch in 2024, which would reduce the cost of the mission.

Project Assessments

The individual assessments of the 21 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

[38]GAO-16-620.

project.[39] The budget information is based on NASA's fiscal year 2017 budget. The budget covers fiscal years 2017 to 2021; however, NASA describes funding numbers beyond fiscal year 2017 as notional. 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 11 for an illustration of a sample assessment layout.

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

Figure 11: 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 notional 5-year budget for all major projects in the current portfolio that the project represents.
- **G** **Project Funding:** For projects in formulation, the total funding that has been allocated to the project since formulation start through the end of fiscal year 2016. For projects in implementation, the funding needed to be allocated for project completion based on its current 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-17-303SP

Agency Comments and Our Evaluation

We are not making any recommendations in this report. We provided a draft of this report to NASA for comment. In its written comments, reproduced in appendix V, NASA generally agreed with our findings. NASA also provided technical comments that were 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 VI.

Cristina T. Chaplain
Director
Acquisition and Sourcing Management

List of Committees

The Honorable Richard Shelby
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
Chairman
The Honorable José Serrano
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) NASA's progress in implementing initiatives to manage acquisition risk and potential challenges for project management, execution, and oversight. We also described the status and assessed the risks and challenges faced by NASA's 21 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. There are 22 major projects, but we did not develop an assessment for the Origins-Spectral Interpretation-Resource Identification-Security–Regolith Explorer (OSIRIS-REx) project because it launched in September 2016.

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 and schedule. 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 current cost and schedule data provided on DCIs by NASA for the 16 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 NASA's portfolios of major projects for 2009 to 2016 to examine longer-term

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

trends. As part of this analysis, we calculated the average age of these portfolios, by determining the length of time a project spent in the development phase and averaging that across the portfolio. We then compared that historical trend to the portfolio's cost and schedule performance to determine if there was a relationship. We also analyzed the development costs for seven Science Mission Directorate projects—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; OSIRIS-REx; Solar Probe Plus; and Transiting Exoplanet Survey Satellite. We chose these projects because they reported their development costs using similar cost categories and at least 6 months had passed since their cost baseline was approved. We compared the projects' baseline development costs and current development costs across these categories. To assess the accuracy of prime operation cost baselines, we used a DCI to collect data on 20 previously launched Science Mission Directorate missions. To select these projects, we considered projects that (1) were covered in our previous annual assessments of major projects and (2) have launched and are therefore either currently in prime operations or have completed prime operations. Three projects that meet these criteria were excluded from this analysis: (1) Landsat Data Continuity Mission, since the project is operated by the U.S. Geological Survey; (2) Stratospheric Observatory for Infrared Astronomy, since it is an aircraft-installed system, rather than a launched mission; and (3) Tracking and Data Relay Satellite Replenishment, since there is no project-specific operations budget for this project. For the projects that are still in the prime operation phase, our analysis used NASA's current estimates of each project's operation costs at completion, which include both the project's actual operation costs to date and the project's estimated costs to prime mission end. Our analysis compared each project's completed prime mission costs or currently estimated prime operations costs against the project's prime operation cost baseline established at the project confirmation review. 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 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. For the 15 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 III 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 was 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 did not assess the average number of critical technologies being developed per project for projects that had not entered implementation at the time of this assessment. 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

[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.

data on the number of released and expected engineering drawings. However, we collected the project offices' rationale for cases where it appeared that only a small percentage of the expected drawings were completed by the time of the design reviews or where the project office reported significant growth in the number of drawings released after the critical design review. In accordance with best practices, projects were assessed as having achieved design stability if at least 90 percent of projected drawings were released by the critical design review. We compared this year's results against those in prior years to assess whether NASA was improving in this area. For this year's assessment, 11 projects had held a critical design review and reported data on design drawings. We did not assess the design stability for those projects that had not yet reached the critical design review at the time of this assessment. To assess 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 how adherence to technology maturity and design stability best practices affected the outcomes for projects that we have reviewed since 2009, we used data collection instruments submitted by NASA from 2009 onward for each project that rebaselined or launched within its cost and schedule baselines to determine whether the project matured its technologies to a technology readiness level 6 at preliminary design review and released at least 90 percent of design drawings at critical design review. We also assessed each project's number of critical technologies and calculated the percentage of drawing growth after critical design review. We used these data to compare the performance of projects that launched under cost and within schedule to projects that had rebaselined against these metrics.[3] We also reviewed past GAO and NASA Inspector General

[3]NASA is required to report to certain committees in the House and Senate if the development cost of a program is likely to exceed the baseline estimate by 15 percent or more, or if a milestone is likely to be delayed by 6 months or more. 51 U.S.C. § 30104(e). Further, if the development cost of a program will exceed the baseline estimate by more than 30 percent, NASA is required to prepare a new baseline if the program is to be continued. 51 U.S.C. § 30104(e),(f). NASA typically refers to the programs covered by this requirement as projects.

reports to understand whether projects that rebaselined did so in part because of immature technologies or design.

To assess NASA's progress in reducing acquisition management risk, we analyzed ongoing NASA initiatives in key areas, such as cost and schedule estimation and earned value management. We also followed up on other potential acquisition management challenges that we identified during our review, such as emerging workforce issues and project funding and budget phasing. To assess NASA's efforts to improve cost and schedule estimation, we used a DCI to collect data on joint cost and schedule confidence level updates; reviewed documentation, such as briefings on new and updated cost and schedule tools; and interviewed officials. To assess the status of the independent assessment transition, we reviewed official documentation, such as the agency's independent assessment white paper; interviewed officials within the Office of the Chief Financial Officer and the Office of the Chief Engineer; and evaluated the extent to which the agency's goals were met for the reorganized independent assessment function. To assess potential workforce issues, we reviewed documentation provided regarding the transition to the new independent assessment model and information provided at the NASA Cost Symposium, and interviewed officials in the Office of the Chief Financial Officer. To assess the extent to which funding phasing issues could present problems in a constrained environment, we reviewed project documentation, interviewed project officials, and analyzed NASA's 5-year budget in the fiscal year 2017 budget request.

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 Cape Canaveral, 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 21 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 notional 5-year budget for all major projects in the current portfolio that the project represents. The budget information is based on NASA's fiscal year 2017 budget. The budget covers fiscal years 2017 to 2021; however, NASA describes funding numbers beyond fiscal year 2017 as notional. 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 2016. 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 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.[4] 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

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

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.

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.[5] 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, funding, 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 five 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

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

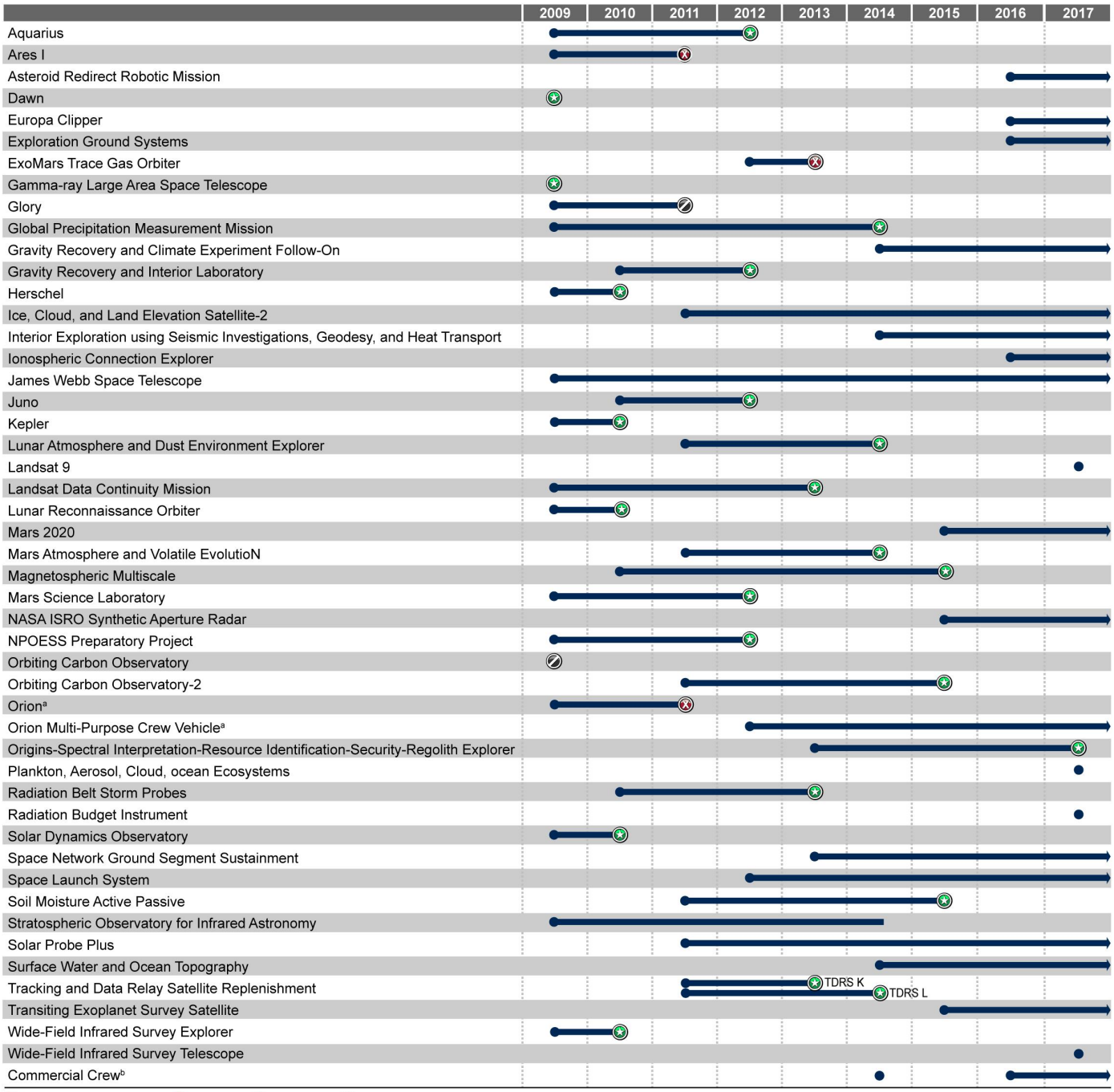
review. KDP-C reflects the life-cycle point where NASA approves a project to leave the formulation phase and enter into the implementation phase. NASA explained that preliminary estimates are generated for internal planning and fiscal year budgeting purposes at KDP-B, which occurs midstream in the formulation 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 2016 to May 2017 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 Reviewed in GAO's Annual Assessments

We have reviewed 49 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.

Figure 12: Major NASA Projects Reviewed in GAO's Annual Assessments



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-17-303SP

[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.

[b]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.

Appendix III: Technology Readiness Levels

Table 7: 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.

Source: GAO Analysis of National Aeronautics and Space Administration data. | GAO-17-303SP

Appendix IV: 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 V: Comments from the National Aeronautics and Space Administration

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

April 27, 2017

Ms. Cristina T. Chaplain
Director
Acquisition Sourcing Management
United States Government Accountability Office
Washington, DC 20548

Cristina

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-17-303SP).

The GAO's congressionally mandated annual assessment is a good occasion for NASA to receive an independent perspective on its performance in the acquisition of major programs and projects. We appreciate the open and constructive communication between NASA and the GAO assessment team and will continue to work with the GAO to identify and address any challenges that may lead to cost and schedule growth in our projects.

NASA is pleased that the GAO has recognized that the overall cost and schedule performance of NASA's portfolio of major projects has continued to improve over the last five years. We are also pleased that the GAO has highlighted NASA's maintaining improvements in the technology maturity and design stability across its portfolio of major projects, given the continuing increase in the number of new technologies in our most recent projects. NASA looks forward to working with the GAO during the next assessment period to refine the technological maturity and design stability metrics it uses, as well as the analyses the GAO performs in support of its audits, to ensure additional insight while allowing our programs and projects to continue to take on more challenging missions in both human space flight and science.

NASA is also satisfied to see that the GAO has continued to monitor our ability to independently assess our major projects. As noted in the draft report, NASA continues to make progress in its transition away from a centralized independent assessment function. Throughout this process, NASA has continued to emphasize its commitment to providing robust independent reviews to assist programs and projects as well as to inform NASA management. Specifically, Mission Directorates have successfully taken ownership of the Standing Review Board (SRB) process, have manifested and performed the reviews, and have been maintaining expected rigor and independence for all SRBs. All previous SRB expectations have been maintained within the updated Standing Review Board Handbook, released in December 2016, which reflects the new independent assessment model. NASA has also created lower-level guidance for SRB implementation with a

programmatic standard operating procedure instruction document update as well as with Mission Directorate implementation plans, all of which are being internally reviewed for release in the near future. Maintaining a strong independent evaluation function is essential to NASA's long-term success, and we look forward to the GAO's continued interest in this area.

NASA further recognizes the GAO's continued interest in the area of earned value management (EVM), which the GAO has specifically identified as a key project management tool. The GAO notes that NASA has yet to establish a formal EVM surveillance plan in accordance with GAO best practices. NASA continues to agree with the GAO regarding the relative value of EVM, and we have made substantial progress implementing several initiatives related to EVM training, tools, support, and guidance material. Examples of these initiatives include conducting EVM assessments at Key Decision Points on several projects included in the current assessment's portfolio, a practice which will continue in the future for all major projects. As the GAO notes in its report, a formal surveillance plan would involve establishing an independent surveillance organization that conducts periodic surveillance reviews to mitigate risks and manage cost and performance. NASA has considered this recommendation during previous engagements with the GAO and has communicated that NASA will not be able to implement a formal EVM surveillance plan due to resource constraints.

NASA largely approves of the new redesign of the layout for the individual project assessments found in the draft report, although we feel that there may be more intuitive and informative ways of displaying the individual project budget, funding, cost, and schedule information. We look forward to working with the GAO during the next assessment period to further refine and enhance the graphical representations of this critical data.

Finally, NASA would like to thank the GAO for continuing to work with our projects' subject matter experts to consider and incorporate technical corrections as part of this audit. We appreciate the consideration of these comments, which is important to the accurate and balanced presentation of the projects' technical status. NASA looks forward to working with the GAO to make sure the technical review process continues to add value in the future.

NASA appreciates the ongoing dialog with the GAO on this critical engagement and is committed to working jointly to address any questions related to this effort. Please contact David C. Walters at (202) 358-1364 if you have any questions or require additional information.

Sincerely,

Robert M. Lightfoot, Jr.
Administrator (Acting)

Appendix VI: 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, Ron Schwenn, Assistant Director; Andrea Bivens; Tana M. Davis; Juli Digate; Lorraine Ettaro; Lisa L. Fisher; Laura Greifner; Kristine R. Hassinger; Erin Kennedy; Daniel Kuhn; Katherine Lenane; Jose A. Ramos; Carrie Rogers; Christal Ann Simanski; Daniel Singleton; Ryan Stott; Roxanna T. Sun; Kristin Van Wychen; and John S. Warren, Jr. made significant contributions to this report.

Appendix VII: Accessible Data

Data Tables

Data Table for Highlights figure, NASA's Major Project Portfolio Cost and Schedule Performance Has Continued to Improve

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

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

	Formulation			Implementation			
Key Decision Point	KDP A at end of Pre phase A	KDP B at end of Phase A	KDP C (confirmation review) Project start at end of Phase B	KDP D at end of Phase C	KDP E At end of phase D	KDP F, at end of Phase E.	NA
Phases	Pre-phase A Concept studies	Phase AConcept and technology development	Phase B Preliminary design and technology completion	Phase C Final design and fabrication	Phase D System assembly, integration and test, and launch	Phase E Operations and sustainment	Phase F Closeout
	SDR/MDR, at end of Phase A	PDR, near end of Phase B	NA	CDR, in the middle of Phase C, SIR occurs at 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 Table Figure 2: Notional Distribution of Cost Reserves for a Project Budgeted at the 70 Percent Confidence Level

The x axis is the cost estimate

The y axis is the probability, confidence level (0 to 100) of meeting cost target.

Cost estimates go up for the following events, which also raise the confidence level of meeting the cost target.

- There is an intersection area from approximately 40% to 50% probability for Project Held reserves.
- There is an intersection at approximately 50% probability with management agreement.
- Headquarters held reserves intersect an area from approximately 50% to 70% probability.
- An agency baseline commitment intersects at 70% probability.

Data Table Figure 3: Major NASA Projects Reviewed in GAO's 2017 Assessment

	Acronym	Project name	Preliminary launch readiness date	estimate (in millions)
Formulation	ARRM	Asteroid Redirect Robotic Mission	December 2021	$1,672 – $1,822
	Clipper	Europa Clipper	July 2023	$3,100 – $4,000
	Landsat 9	Landsat 9	Dec 2020 – Nov 2021	$851 – $928
	PACE	Plankton, Aerosol, Cloud, ocean Ecosystem	2022 – 2023	$805 – $850
	WFIRST	Wide-Field Infrared Survey Telescope	2024 – 2026	$3,200 – $3,800

	Acronym	Project name	Launch readiness date	Current cost baseline (in millions)
	EGS	Exploration Ground Systems	November 2018	$2,812.9
	GRACE-FO	Gravity Recovery and Climate Experiment Follow-On	February 2018	$431.9
	ICESat-2	Ice, Cloud, and Land Elevation Satellite-2a	June 2018	$1,063.6
	ICON	Ionospheric Connection Explorer	October 2017	$252.7
	InSight	Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport	May 2018	$828.9
	JWST	James Webb Space Telescope	October 2018	$8,825.4
	Mars 2020	Mars 2020	July 2020	$2,443.5
Implementation	NISAR	NASA Indian Space Research Organisation Synthetic Aperture Radar	September 2022	$866.9
	Orion	Orion Multi-Purpose Crew Vehicle	April 2023	$11,283.5
	RBI	Radiation Budget Instrument	December 2019	$304.8
	SGSS	Space Network Ground Segment Sustainmentb	September 2019	$1,207.9
	SLS	Space Launch System	November 2018	$9,695.4
	SPP	Solar Probe Plus	August 2018	$1,553.4
	SWOT	Surface Water and Ocean Topography	April 2022	$754.9
	TESS	Transiting Exoplanet Survey Satellite	June 2018	$378.4
	CCP	Commercial Crew Programc	December 2017	$6,828.6

Data Table Figure 4: Development Cost Performance and Average Launch Delay for Major NASA Projects from 2009 through 2017

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

Data Table Figure 5: Total Number and Development Cost Growth for NASA Major Projects with Established Cost Baselines from 2009 through 2017

Year	Development cost baseline	Total cost increase from James Webb Space Telescope	Total cost increase from remaining projects	Number of projects in development
2009	5.3725	0	0.6432	13
2010	8.8836	0	1.2109	14
2011	10.3168	0.1298	1.3794	16
2012	10.1479	3.6168	1.1059	15
2013	8.2689	3.6168	0.2241	12
2014	10.1598	3.6093	0.2288	15
2015	15.0849	3.6093	0.3023	12
2016	22.3007	3.6077	0.2495	12
2017	25.4098	3.6077	0.3559	16

Data Table Figure 6: Average Age of NASA Major Projects from 2009 through 2017

Year	Average age of projects (in months)	Number of projects in development
2009	58	13
2010	53	14
2011	41	16
2012	50	15
2013	49	12
2014	42	15
2015	29	12

Year	Average age of projects (in months)	Number of projects in development
2016	29	12
2017	34	16

Data Table Figure 7: Number of NASA's Major Projects Attaining Technology Maturity by Preliminary Design Review from 2010 through 2017

Year	Projects meeting technology maturity criteria	Projects not meeting 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

Data Table Figure 8: Average Number of Critical Technologies Reported by NASA for Major Projects in Development from 2009 through 2017

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

Data Table Figure 9: Average Percentage of Engineering Drawing Growth after Critical Design Review for NASA Major Projects from 2010 through 2017

Year	Projects meeting design stability best practices	Projects not meeting design stability best practices
2010	0	9
2011	2	10
2012	1	13
2013	1	9
2014	1	8
2015	1	7
2016	4	7
2017	4	7

Data Table Figure 10: Number of NASA Major Projects That Released over 90 Percent of Engineering Drawings at Critical Design Review from 2010 through 2017

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

Data Table Figure 11: Illustration of a Sample Project Assessment

Letter	Explanation
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.

Letter	Explanation
F	Project Budget Information: The percentage of NASA's notional 5-year budget for all major projects in the current portfolio that the project represents.
G	Project Funding: For projects in formulation, the total funding that has been allocated to the project since formulation start through the end of fiscal year 2016. For projects in implementation, the funding needed to be allocated for project completion based on its current 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.

Data Table Figure 12: Major NASA Projects Reviewed in GAO's Annual Assessments

Timeline shows the project reviewed status (Data Available from GAO upon request) for:

- Aquarius
- Ares I
- Asteroid Redirect Robotic Mission
- Dawn
- Europa Clipper
- Exploration Ground Systems
- ExoMars Trace Gas Orbiter
- Gamma-ray Large Area Space Telescope
- Glory
- Global Precipitation Measurement Mission
- Gravity Recovery and Climate Experiment Follow-On
- Gravity Recovery and Interior Laboratory
- Herschel
- Ice, Cloud, and Land Elevation Satellite-2

- Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport
- Ionospheric Connection Explorer
- James Webb Space Telescope
- Juno
- Kepler
- Lunar Atmosphere and Dust Environment Explorer
- Landsat 9
- Landsat Data Continuity Mission
- Lunar Reconnaissance Orbiter
- Mars 2020
- Mars Atmosphere and Volatile EvolutioN
- Magnetospheric Multiscale
- Mars Science Laboratory
- NASA ISRO Synthetic Aperture Radar
- NPOESS Preparatory Project
- Orbiting Carbon Observatory
- Orbiting Carbon Observatory-2
- Oriona
- Orion Multi-Purpose Crew Vehiclea
- Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer
- Plankton, Aerosol, Cloud, ocean Ecosystems
- Radiation Belt Storm Probes
- Radiation Budget Instrument
- Solar Dynamics Observatory
- Space Network Ground Segment Sustainment
- Space Launch System
- Soil Moisture Active Passive
- Stratospheric Observatory for Infrared Astronomy
- Solar Probe Plus

- Surface Water and Ocean Topography
- Tracking and Data Relay Satellite Replenishment
- Transiting Exoplanet Survey Satellite
- Wide-Field Infrared Survey Explorer
- Wide-Field Infrared Survey Telescope
- Commercial Crewb

Agency Comment Letter

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

Page 1

Ms. Cristina T. Chaplain

Director

Acquisition Sourcing Management

April 27, 2017

United States Government Accountability Office

Washington, DC 20548

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Page 2

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Sincerely,

Robert M. Lightfoot, Jr. Administrator (Acting)

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