United States Government Accountability Office

Report to Congressional Committees

March 2016

NASA

Assessments of Major Projects

GAO-16-309SP

GAO Highlights

Highlights of GAO-16-309SP, a report to congressional committees

March 2016

NASA

Assessments of Major Projects

Why GAO Did This Study

This report provides GAO's annual snapshot of how well NASA is planning and executing its major acquisition projects. In March 2015, 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 project status reports on selected large-scale NASA programs, projects, and activities. This is GAO's eighth annual assessment of NASA's major projects. 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 18 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

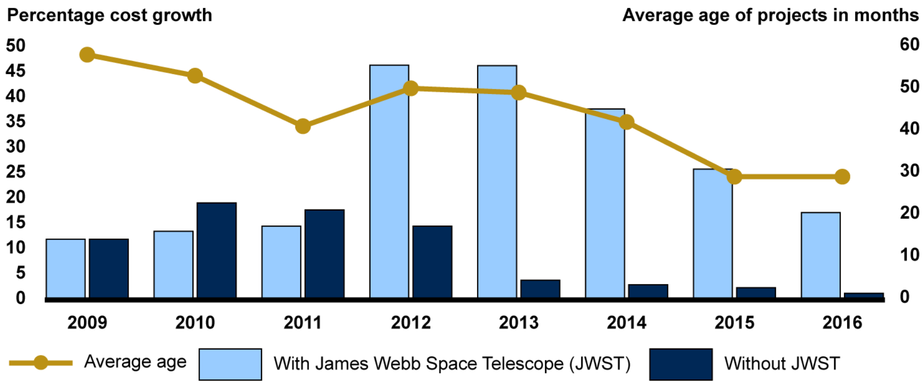
GAO is not making recommendations in this report, but in prior reports has made recommendations that NASA has not yet fully addressed. NASA generally agreed with GAO's findings.

View GAO-16-309SP. For more information, contact Cristina Chaplain at (202) 512-4841 or chaplainc@gao.gov.

What GAO Found

The cost and schedule performance of the National Aeronautics and Space Administration's (NASA) portfolio of major projects has improved over the past 5 years, and most current projects are adhering to their committed cost and schedule baselines. Over the last 2 years, eight projects in the portfolio established cost and schedule baselines. As the figure below shows, as the average age of the portfolio has decreased, the cost performance of the portfolio has improved, because new projects are less likely to have experienced cost growth.

Development Cost Performance of NASA's Major Project Portfolio Has Improved as Average Project Age Has Decreased



Source: GAO analysis of NASA data. | GAO-16-309SP

Note: GAO presents cost and schedule growth both including and excluding JWST because the magnitude of JWST's cost growth has historically masked the performance of the rest of the portfolio.

Although NASA's overall performance has improved, for 8 out of the last 9 years at least one major project has experienced significant cost or schedule growth. Such growth often occurs as projects prepare to begin system assembly, integration, and test; nine projects will be in that phase of development in 2016, including the Orion Multi-Purpose Crew Vehicle and Space Launch System, which are human spaceflight programs that have significant development risks.

NASA has maintained recent improvements in the technology maturity and design stability of its projects. As of 2015, 9 of the 11 major projects that passed preliminary design review matured all technologies to the level recommended by GAO best practices—continuing a positive trend. Projects entering implementation in recent years also appear to rely more heavily on existing technologies, but this trend could be changing on planned projects. The portfolio continued a generally positive trend in improving design stability as measured against best practices and minimizing late design changes.

NASA has continued to implement improved project management tools to manage acquisition risks, but these efforts have not always been consistent with best practices in areas such as cost estimating or fully addressed GAO's prior recommendations. Further, NASA plans to dissolve its independent program assessment office to help bolster its mission directorate workforce in key areas, however this change could impact project oversight.

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Abbreviations

ARRM	Asteroid Robotic Redirect Mission
ATLAS	Advanced Topographic Laser Altimeter System
CCP	Commercial Crew Program
CNES	Centre National d'Etudes Spatiales
CTS	crew transportation system
DCI	data collection instrument
DHU	data handling unit
EGS	Exploration Ground Systems
EM-1	Exploration Mission 1
EM-2	Exploration Mission 2
ESM	European Service Module
EVM	earned value management
FUV	Far Ultraviolet
GFAS	Ground Flight Application Software
GFZ	German Research Centre for Geosciences
GNC LIDAR	guidance, navigation, and control light detection and ranging
GRACE-FO	Gravity Recovery and Climate Experiment Follow-On
GSLV	Geosynchronous Satellite Launch Vehicle
ICESat-2	Ice, Cloud, and Land Elevation Satellite-2
ICON	Ionospheric Connection
ICPS	interim cryogenic propulsion stage
InSight	Interior Exploration using Seismic Investigations, Geodesy and Heat Transport
IPAO	Independent Program Assessment Office
ISRO	Indian Space Research Organisation

ISS	International Space Station
JCL	joint cost and schedule confidence level
JWST	James Webb Space Telescope
KaRIn	Ka-band Radar Interferometer
KDP	key decision point
MIGHTI	Michelson Interferometer for Global High-Resolution Thermospheric Imaging
MSL	Mars Science Laboratory
NASA	National Aeronautics and Space Administration
NISAR	NASA ISRO Synthetic Aperture Radar
NPR	NASA Procedural Requirements
OLA	OSIRIS-REx laser altimeter
Orion	Orion Multi-Purpose Crew Vehicle
OSIRIS-REx	Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer
RFU	radio frequency unit
SCaN	Space Communications and Navigation
SCCS	Spaceport Command and Control System
SEIS	Seismic Experiment for Interior Structure
SEP	solar electric propulsion
SGSS	Space Network Ground System Sustainment
SLS	Space Launch System
SMAP	Soil Moisture Active and Passive
SPOC	Science Processing and Operations Center
SPP	Solar Probe Plus
SWEAP	Solar Wind Electrons Alphas and Protons
SWOT	Surface Water and Ocean Topography
TESS	Transiting Exoplanet Survey Satellite
TRN	terrain relative navigation
VAB	Vehicle Assembly Building

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
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March 30, 2016

Congressional Committees

In fiscal year 2016, the National Aeronautics and Space Administration (NASA) plans to spend over $6 billion on its 18 major projects, with each having a life-cycle cost of over $250 million. In total, these projects represent an expected investment of almost $54 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 eighth annual report on this topic. This report assesses (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 points in the development process, 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 18 major projects. When NASA determines that a project will have a life-cycle cost estimate of more than $250 million for formulation and implementation, we include that project in our annual review.

To assess the cost and schedule performance, technology maturity, and design stability of NASA's major projects, we collected information on

[1]GAO, *High-Risk Series: An Update,* GAO-15-290 (Washington, D.C.: Feb. 11, 2015).

[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.

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 18 major projects in total, but the information available depends on where a project is in its life cycle. For the 12 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.[3] We also reviewed historical data on cost and schedule performance, technology maturity, and design stability for major projects from our prior reports and compared it to the performance of NASA's current portfolio of major projects. To assess NASA's progress and approach for reducing acquisition risk, we examined NASA's efforts to address issues identified in our prior work, such as the quality of the cost and schedule risk analyses and earned value management (EVM) implementation issues. We also followed up on other potential acquisition risks that arose during our review, such as the dissolution of NASA's Independent Program Assessment Office (IPAO). 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.

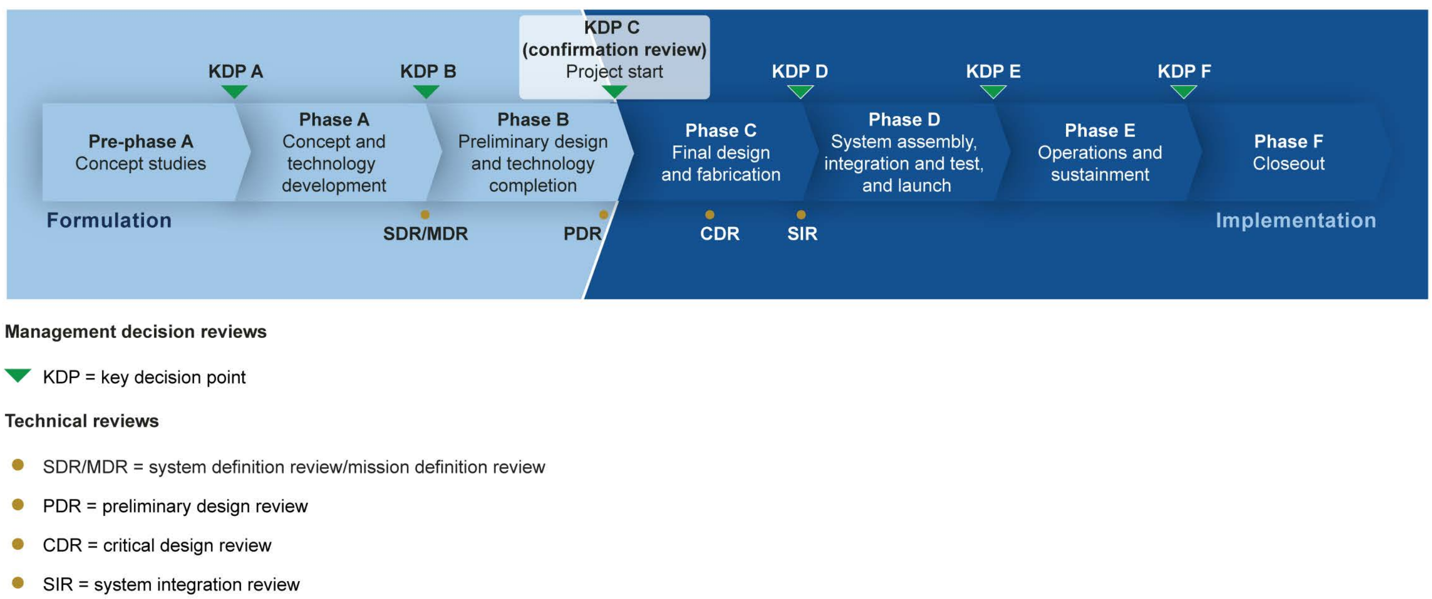
We conducted this performance audit from April 2015 to March 2016 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

[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.

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



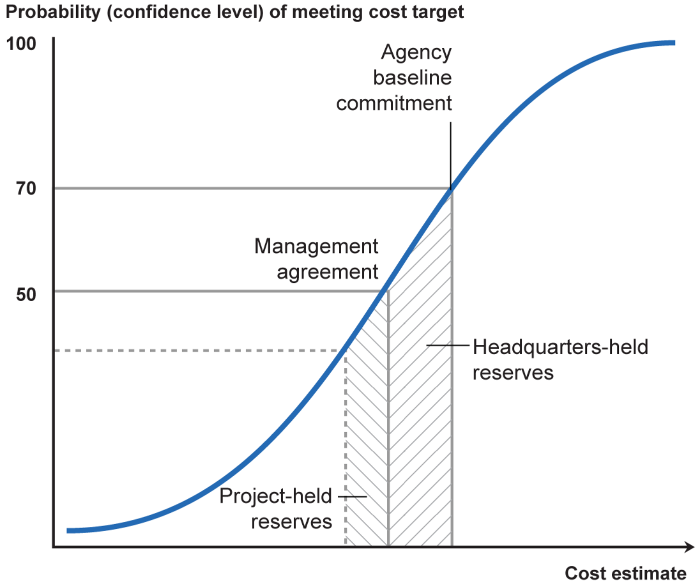
Source: NASA data and GAO analysis. | GAO-16-309SP

Project formulation consists of phases A and B, during which projects develop and define requirements, cost and schedule estimates, and system designs for implementation. NASA Procedural Requirements 7120.5E, NASA Space Flight Program and Project Management Requirements, specifies that during formulation, a 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, a project develops a range of its expected cost and schedule which is used to inform the budget planning for that project. During Phase B, the project also develops programmatic measures and technical leading indicators which track various project metrics such as requirement changes, staffing demands, and mass and power utilization. Near the end of formulation, leading up to the preliminary design review, the project team completes technology development and its preliminary design.

Formulation culminates in a review at key decision point C, known as project confirmation, where cost and schedule baselines are established and documented in a decision memorandum. The decision memorandum outlines the management agreement and the agency baseline commitment. The management agreement can be viewed as a contract between the agency and the project manager. The project manager has the authority to manage the project within the parameters outlined in the agreement. The agency baseline commitment establishes the cost and schedule baselines against which the 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, is a point-in-time estimate that, among other things, includes all cost and schedule elements, 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, which is used to set the cost and schedule targets in the agency baseline commitment, and funded at a level equivalent to at least the 50 percent confidence level, which is used to set the targets in the project management agreement.[4] According to NASA officials, this would include cost reserves held at the directorate and project level to address project risks. The total amount of reserves held at the project level varies based on where the project is in its life cycle. Figure 2 notionally depicts how NASA would allocate funding reserves for a project that was baselined in accordance with policy.

[4]NASA Procedural Requirements (NPR) 7120.5E NASA Space Flight Program and Project Management Requirements para 2.4.4 (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.

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



Source: GAO analysis of NASA policy. | GAO-16-309SP

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 second design review, the 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 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 spacecraft that will return a sample from an asteroid to a telescope intended to explore the universe to spacecraft to transport humans and cargo to and beyond low Earth orbit. When NASA determines that a project will have a life-cycle cost estimate of more than $250 million for formulation and implementation, we include that project in our next annual review. The year 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 18 major NASA projects. Four projects are being assessed for the first time this year: The Asteroid Robotic Redirect Mission (ARRM), Europa, Exploration Ground Systems (EGS), and Ionospheric Connection (ICON). We also assessed the Commercial Crew Program. We originally assessed that program in 2014, but it was excluded from last year's review due to a bid protest. Figure 3 includes more information on these projects. Appendix II includes a list of all the projects that we have reviewed from 2009 to 2016.

Figure 3: Major NASA Projects Reviewed in GAO's 2016 Assessment

	Acronym	Project name	Launch readiness date	Preliminary cost estimate (in millions)
Formulation	ARRM	Asteroid Robotic Redirect Mission	December 2020	$1,720.0
	Europa	Europa	July 2022	$3,000 – $4,000
	Mars 2020	Mars 2020	July 2020	$2,168 – $2,351
	NISAR	NASA Indian Space Research Organization Synthetic Aperture Radar	December 2020	$718 – $808
	SWOT	Surface Water and Ocean Topography	October 2020	$647 – $757
			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	June 2018	$1,063.5
	InSight[a]	Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport	March 2016	$675.1
	ICON	Ionospheric Connection	October 2017	$252.7
	JWST	James Webb Space Telescope	October 2018	$8,835.0
	OSIRIS-REx	Origins–Spectral Interpretation-Resource Identification-Security-Regolith Explorer	October 2016	$1,121.4
	Orion	Orion Multi-Purpose Crew Vehicle	April 2023	$11,283.5
	SPP	Solar Probe Plus	August 2018	$1,553.4
	SLS	Space Launch System	November 2018	$9,695.4
	SGSS[b]	Space Network Ground Segment Sustainment	September 2019	$1,207.9
	TESS	Transiting Exoplanet Survey Satellite	June 2018	$378.4
	CCP[c]	Commercial Crew Program	December 2017	$6,800.0

Source: GAO analysis of NASA data. | GAO-16-309SP

[a]In December 2015, NASA announced that InSight would not launch in March 2016 as planned due to problems with a key instrument that is being provided by an international partner. Information on the cost and schedule effects of this decision was not available at the time of our review.

[b]In February 2016, NASA reclassified SGSS as a sustainment effort, rather than a major project. Since SGSS was part of NASA's major project portfolio during our review, it is included in our assessment. Cost and schedule information in the figure reflects SGSS's July 2015 approved baseline. Its current cost and schedule is under review.

[c]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.

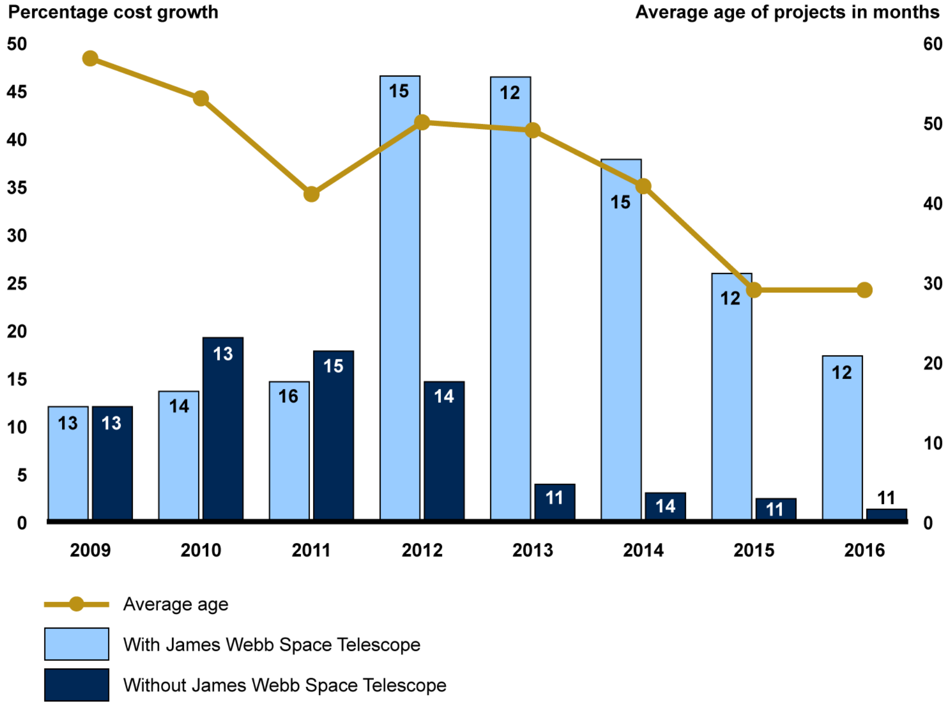
NASA Cost and Schedule Performance Continues Positive Trend, but Its Largest Projects Face Significant Risks

The cost and schedule performance of NASA's portfolio of major projects in development has improved over the past 5 years and most current projects are adhering to their committed cost and schedule baselines. Over the past 2 years, eight projects in the portfolio established cost and schedule baselines. As the average age of the portfolio has decreased, the cost performance of the portfolio has improved because new projects are less likely to have experienced cost growth. Despite NASA's improved overall performance, its portfolio of major projects continues to experience cost and schedule growth. NASA has realized significant cost or schedule growth for at least one major project for 8 out of the last 9 years. This often occurs as projects prepare to begin system assembly, integration, and test; nine projects will be in that phase of development in 2016, including the Orion Multi-Purpose Crew Vehicle (Orion) and Space Launch System, which include significant development risks.

Overall Cost Performance Continues to Improve Due to Addition of New, Large Programs

The cost and schedule performance of NASA's portfolio of major projects in development continues to improve. In 2016, overall development cost growth for the portfolio of 12 development projects, excluding the James Webb Space Telescope (JWST), fell to 1.3 percent and launch delays averaged 4 months. Both of those measures are at or near the lowest levels we have reported since we began our annual reviews in 2009 (see fig. 4). We have historically presented cost and schedule growth both including and excluding JWST because, prior to 2015, it was the only project with a development cost baseline significantly larger than the other projects in development. Further, the magnitude of JWST's cost growth is considerably larger than that of the other projects in the portfolio. Thus, it masked the performance of the remainder of the portfolio.

Figure 4: Development Cost Performance and Average Months Spent in the Development Phase for Major NASA Projects from 2009 through 2016



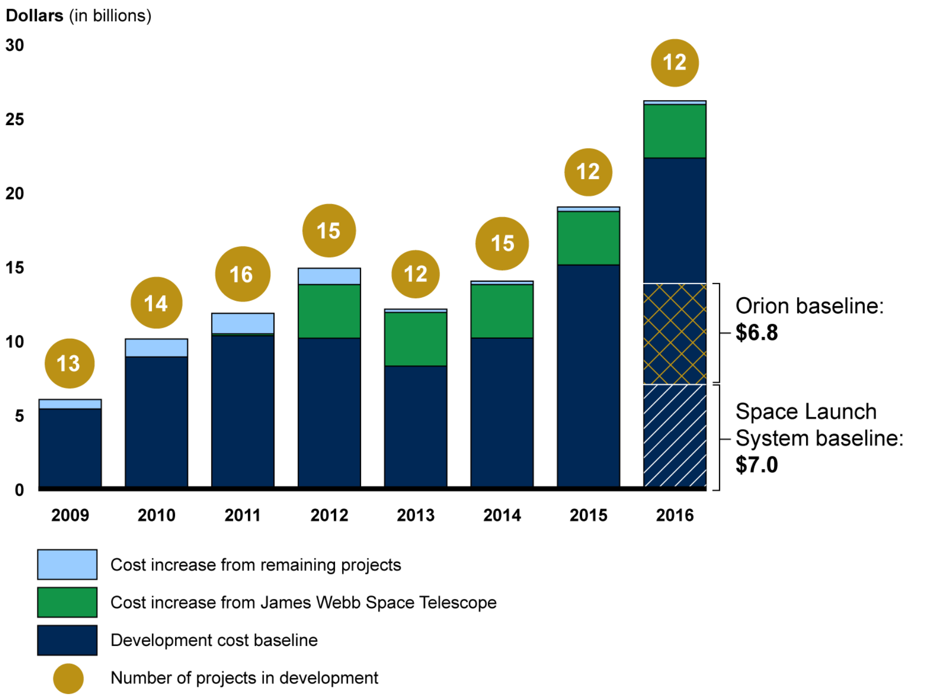
Source: GAO analysis of NASA data. | GAO-16-309SP

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

The overall cost performance of the NASA major projects portfolio has improved, in part, due to the addition of new, large programs. The cost and schedule performance of any portfolio is driven, in part, by its composition. New projects are less likely to have experienced cost and schedule growth than older ones, so they generally help improve portfolio performance. Figure 4 helps illustrate the effect new projects have on portfolio cost performance. Eight of the 12 major projects in development established baselines within the last 2 years, and cost and schedule performance collectively has improved as projects in the portfolio have become, on average, younger.

The positive effect of these new projects on the portfolio's cost performance increases when the estimated cost of those new projects is relatively large and the development baseline against which portfolio cost growth is measured also grows. In other words, large 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. For example, 5 percent portfolio cost growth becomes 2.5 percent cost growth if the size of the development baseline doubles. In the past 2 years, the addition of the Space Launch System ($7.0 billion for implementation) and Orion ($6.8 billion for implementation) to the portfolio has more than doubled the portfolio's development cost baseline and helped make the 2016 portfolio the most expensive collection of NASA projects in development since we began our annual assessments in 2009 although it is among the smallest assessed to date in terms of number of projects (see fig. 5). If those two programs are excluded, cost growth this year increases from 1.3 to 6.8 percent. We reported similar findings last year when NASA added five new projects to the portfolio.[5]

Figure 5: Total Number and Development Cost Growth of NASA Major Projects with Established Cost Baselines from 2009 through 2016



Source: GAO analysis of NASA data. | GAO-16-309SP

Note: Includes projects in development.

[5]GAO, *NASA: Assessments of Selected Large-Scale Projects [Reissued on March 26, 2015]*, GAO-15-320SP (Washington, D.C.: Mar. 24, 2015).

Most Current Projects Performed Well, but Project Rebaselines Still Occur in Most Years

Most current NASA projects have stayed within the cost and schedule estimates in their development baselines, both this year and throughout their life cycles, but the portfolio continues to experience cost and schedule growth. This growth was driven by projects that experienced significant cost growth and exceeded their development cost baselines. When a project exceeds its development cost baseline by 30 percent, it is rebaselined if it is to be continued. NASA has rebaselined a major project each year for 8 out of the last 9 years. Table 1 shows the development cost growth for each of the rebaselined projects.

Table 1: Development Cost Growth on NASA Major Projects Rebaselined from 2007 through 2015

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015
Rebaselined project	SOFIA	NPP	Glory	MSL	JWST	OCO-2[a]	None	ICESat-2	SGSS[b]
Development cost growth (in millions)	$742.9	$252.2	$170.6	$799.9	$3,607.7	$71.3	Not applicable	$204.8	$308.7

Legend: SOFIA: Stratospheric Observatory for Infrared Astronomy; NPP: National Polar-orbiting Operational Environmental Satellite System Preparatory Project; MSL: Mars Science Laboratory; JWST: James Webb Space Telescope; OCO-2: Orbiting Carbon Observatory 2; ICESat-2: Ice, Cloud, and Land Elevation Satellite-2; SGSS: Space Network Ground Segment Sustainment

Source: GAO analysis of NASA data. | GAO-16-309SP

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

[b]In July 2015, NASA approved a new cost and schedule baseline for SGSS, which is reflected in the table. Subsequently, in February 2016, NASA reclassified SGSS as a sustainment effort, rather than a major project. Since SGSS was part of NASA's major project portfolio during our review, it is included in our analysis.

The cost growth associated with rebaselined projects often overwhelms the positive cost performance within the remainder of the portfolio both on an annual and life-cycle basis. In July 2015, NASA approved a new baseline for the Space Network Ground Segment Sustainment (SGSS) project, which increased its estimated development costs from $368 million to $677 million and extended its completion date from June 2017 to September 2019. Cost growth from the SGSS project was not offset by better performing projects, such as the Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer (OSIRIS-REx) asteroid sampling mission. OSIRIS-REx reported lower than expected development costs for the second consecutive year, even though it is at a stage in the life cycle when projects often realize cost growth. The project attributes its $78.2 million decrease in development cost to several factors, including a mature mission concept and rigorous risk management process. Orion also reported a decrease in development costs of $156.4 million, but this was due to the program shifting funds from the development to the formulation phase, not improved program execution. Table 2 provides data on the cost and schedule performance for the 12 major projects in NASA’s current portfolio that are in development.

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

Overall performance	Project name	Confirmation date	Changes since March 2015		Cumulative changes since project confirmation	
		Year	Cost (millions)	Schedule (months)	Cost (millions)	Schedule (months)
Cost savings	OSIRIS-REx	2013	-$9.3	0	-$78.2	0
	GRACE-FO	2014	$0.6	0	-$0.6	0
	ICON	2014	-$0.2	0	-$0.2	0
	SPP	2014	-$5.4	0	-$5.4	0
	TESS	2014	$0.0	0	-$26.8	0
	Orion[a]	2015	-$156.4	0	-$156.4	0
Within baseline	InSight[b]	2014	$0.0	0	$0.0	0
	SLS	2014	$0.0	0	$0.0	0
	EGS[c]	2014	$3.6	0	$3.6	0
Rebaseline	JWST	2008	-$1.6	0	$3,607.7	52
	ICESat-2	2012	$0.0	0	$204.8	13
	SGSS[d]	2013	$308.7	27	$308.7	27
Total:			**$140.0**	**27**	**$3,857.2**	**92**

Legend: OSIRIS-REx: Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer; GRACE-FO: Gravity Recovery and Climate Experiment Follow-On; ICON: Ionospheric Connection; SPP: Solar Probe Plus; TESS: Transiting Exoplanet Survey Satellite; Orion: Orion Multi-Purpose Crew Vehicle; InSight: Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport; SLS: Space Launch System; EGS: Exploration Ground Systems; JWST: James Webb Space Telescope; ICESat-2: Ice, Cloud, and Land Elevation Satellite-2; SGSS: Space Network Ground Segment Sustainment

Source: GAO analysis of NASA data. | GAO-16-309SP

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

[a]The Orion program shifted funds from development to formulation. The total estimated cost remains unchanged.

[b]In December 2015, NASA announced that InSight would not launch in March 2016 as planned due to problems with a key instrument. Information on the cost and schedule effects of this decision was not available at the time of our review.

[c]The EGS program shifted funds from formulation to development, but remains within its overall cost baseline.

[d]In February 2016 NASA reclassified SGSS as a sustainment effort, rather than a major project. Cost and schedule information in the figure reflects SGSS’s July 2015 approved baseline. Its current cost and schedule is under review.

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

The projects in NASA's current portfolio with the highest development costs, including the Space Launch System and Orion, are entering the stage when most rebaselines occur. Projects appear most likely to rebaseline between their critical design and system integration reviews. All eight major projects that rebaselined during the last nine years did so after their critical design review and the three projects in the 2016 portfolio that rebaselined did so before holding their systems integration review.[6] Table 3 lists the nine projects in the current portfolio that are in this stage of development. Three projects—ICESat-2, JWST, and SGSS—have already rebaselined. If a rebaseline occurs on any of the other six projects, it could add anywhere from almost $60 million to more than $2 billion to the development cost of the portfolio. This range is based on 30 percent development cost growth—which is the percent growth that triggers a rebaseline—for the projects with the lowest and highest development cost in table 3.

Table 3: Current Projects between Critical Design Review and Systems Integration Review

Project	Critical design review date	Systems integration review date
Solar Probe Plus (SPP)	March 2015	May 2016
Ionospheric Connection (ICON)	April 2015	June 2016
Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2)[a]	February 2014	October 2016
Transiting Exoplanet Survey Satellite (TESS)	August 2015	October 2016
Exploration Ground Systems (EGS)	December 2015	February 2017
James Webb Space Telescope (JWST)[a]	March 2010	July 2017
Space Network Ground Segment Sustainment (SGSS)[a]	June 2013	August 2017
Space Launch System (SLS)[b]	July 2015	January 2018
Orion Multi-Purpose Crew Vehicle (Orion)	October 2015	September 2020

Source: GAO analysis of NASA data. | GAO-16-309SP

[a]The system integration review dates are for the project's rebaselined schedule.

[b]The Space Launch System does not have a system integration review. The program's next major system engineering milestone is its planned January 2018 design certification review, which is intended to ensure that the design meets functional and performance requirements and is ready for operation.

[6]Four of the eight rebaselined projects did not hold a systems integration review. NASA established this milestone in 2007 after four of the eight projects originally baselined and therefore it was not a requirement for these projects.

The Space Launch System and Orion, the two largest projects in this critical stage of development, face cost, schedule, and technical risks. For example, the Space Launch System program has expended significant amounts of schedule reserve over the past year to address delays with development of the core stage, which is the Space Launch System's propellant tank and structural backbone. The Orion program continues to face design challenges, which include redesigning the heat shield following the determination that the previous design used in the first flight test in December 2014 would not meet requirements for the first uncrewed flight. The standing review boards for each program have raised concerns about the programs' abilities to remain within their cost and schedule baselines. If cost overruns materialize on these programs, it could have a ripple effect on the portfolio and result in the postponement or cancellation of projects in earlier stages of development.

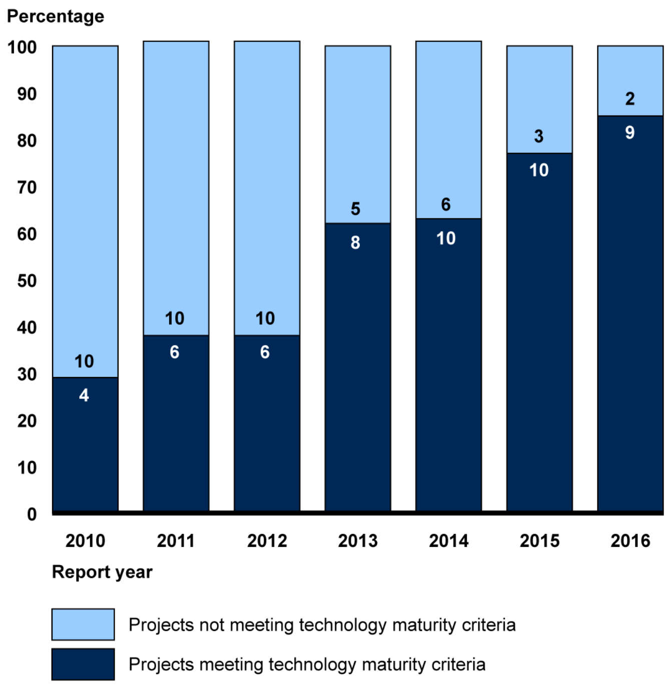
NASA Has Maintained Recent Improvements in Technology Maturity and Design Stability

NASA has maintained recent improvements in the technology maturity and design stability of its projects. As of 2015, 9 of the 11 major projects that have passed the preliminary design review have matured all technologies to the level recommended by GAO best practices—continuing a positive trend. This includes one new project since March 2015. Projects entering implementation in recent years also appear to be less technically ambitious and rely more heavily on existing technologies, but this trend could be changing on planned projects. The portfolio also sustained previous improvements in design stability as measured against GAO best practices and continued to minimize late design changes. Three of the six projects that held a critical design review in 2015 met GAO best practice for design stability.

NASA Continues to Improve the Technology Maturity of Its Projects

Most NASA projects are meeting GAO best practices for technology maturity. As of 2015, 9 of the 11 major projects in NASA's portfolio that have passed the preliminary design review have matured all heritage or critical technologies to a technology readiness level 6—a large increase since 2010 (see fig. 6).[7] The 12th project in development, EGS, did not report any critical or heritage technologies, so it was omitted from this analysis. ICON, the sole new project in this year's portfolio that held its preliminary design review and identified critical or heritage technologies, was 1 of the 9 projects that achieved the level of technology maturity recommended by our best practices.

Figure 6: Percentage and Number of NASA's Major Projects Attaining Technology Maturity by Preliminary Design Review from 2010 through 2016



Source: GAO analysis of NASA data. | GAO-16-309SP

Note: Totals may not add to 100 percent due to rounding.

[7]NASA distinguishes critical 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.

Our best practices work has shown that reaching technology readiness level 6—which indicates that a representative prototype of the technology has been demonstrated in a relevant environment that simulates the harsh conditions of space—can minimize risks for space systems entering product development. Projects falling short of this standard before the preliminary design review, a milestone that generally precedes the project's final design and fabrication phase, may experience subsequent technical problems, which can result in cost growth and schedule delays. For example, in previous years we reported that the Soil Moisture Active and Passive (SMAP) mission had not matured any of its heritage technologies by its preliminary design review, including the radar system which failed in space shortly after it began operating. During development, SMAP also encountered technology risks and experienced schedule delays associated with other heritage technologies, such as its radar reflector boom assembly.[8] In 2010, the National Research Council found that instrument development problems, including lack of detail or failure to identify technical challenges, may be the largest element of mission cost growth within the control of a project.[9]

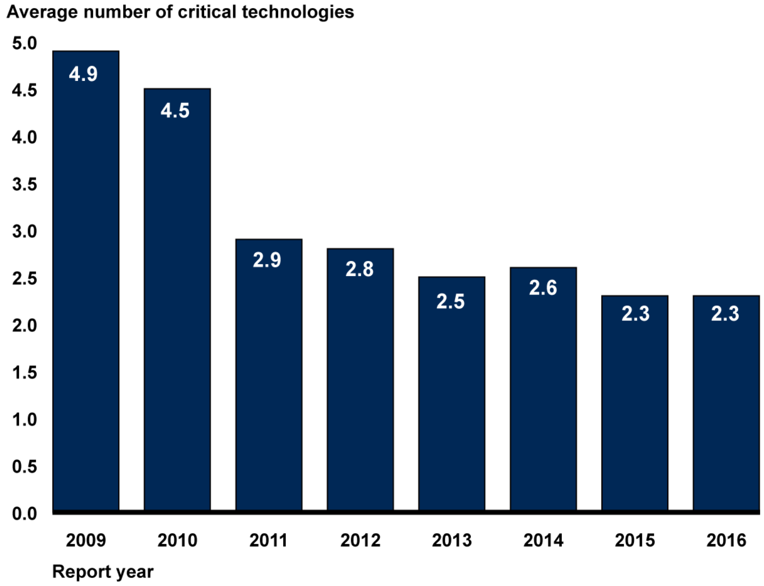
Most NASA Projects Continue to Employ Few Critical Technologies, but Planned Projects Will Require More Technology Development

The average number of critical technologies employed across NASA's portfolio of major projects in implementation remains 2.3, which is the same as last year and down from the average of 4.9 critical technologies in 2009. Over the last 4 years, the average number of critical technologies employed has not varied to any significant degree (see fig. 7). The higher averages in 2009 and 2010 were primarily driven by the Herschel project, which launched in 2010. This project developed 25 critical technologies, which represented over 35 percent of the critical technologies employed by the portfolio during 2009 and 2010.

[8]GAO, *NASA: Assessments of Selected Large-Scale Projects,* GAO-12-207SP (Washington, D.C.: Mar. 1, 2012), GAO-15-320SP.

[9]National Research Council of the National Academies, *Controlling Cost Growth of NASA Earth and Space Science Missions* (Washington, D.C.: National Academies Press, 2010), 28.

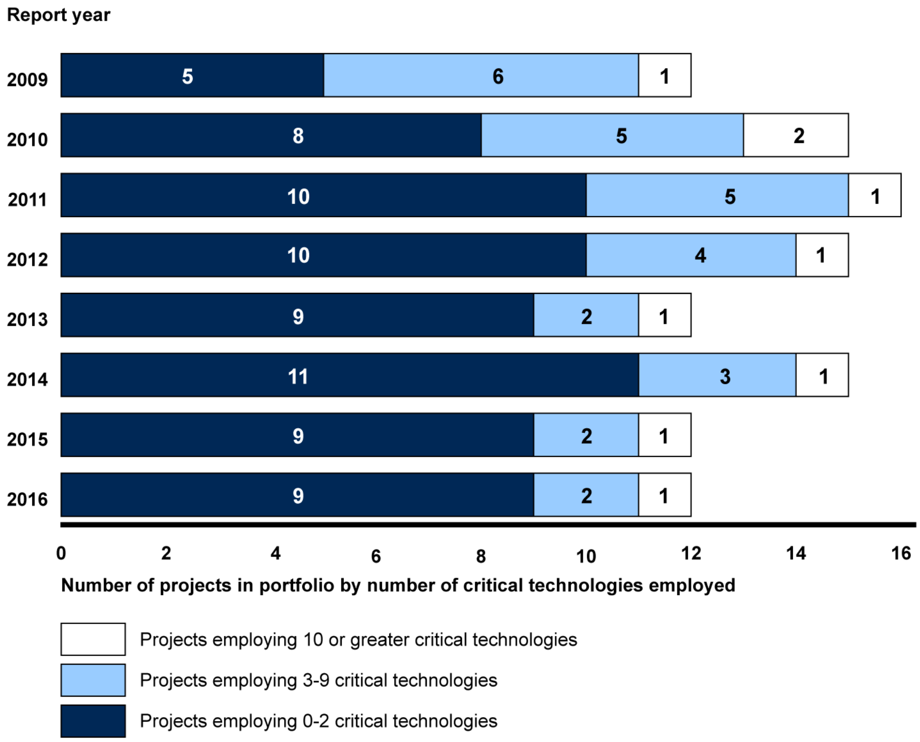
Figure 7: Average Number of Critical Technologies Reported by NASA for Major Projects in Development from 2009 through 2016



Source: GAO analysis of NASA data. | GAO-16-309SP

Since 2009, an increasing majority of NASA's major projects have relied on the use of existing or heritage technologies that have been used on previous projects or missions, with only a small number of projects containing the majority of critical technologies (see fig. 8).

Figure 8: Major Projects by Number of Critical Technologies Reported by NASA from 2009 through 2016



Source: GAO analysis of NASA data. | GAO-16-309SP

In 2009, 7 of 12 projects employed three or more critical technologies; in 2016, it was 3 of 12 projects. Additionally, 19 of the 28 critical technologies employed across this year's portfolio originate from two projects, JWST and Solar Probe Plus (SPP). The remaining 10 projects employ a combined 9 critical technologies. Five projects in this year's portfolio reported that they were not employing any critical technologies. Those projects are employing 10 heritage technologies.

NASA officials suggested that the composition of the portfolio, which now includes more competed missions, could be decreasing the level of technology innovation proposed for projects, and by extension the number of critical technologies. In the Science Mission Directorate, there are two types of missions: competed missions and directed, or strategic, missions. Competed missions intend to address science objectives through mission proposals, which are generally solicited via announcements of opportunity.[10] Directed missions are usually large and multi-purpose and are generally assigned to a NASA center to implement, with science instruments and platform components selected in open competitions. Officials from NASA's Office of the Chief Technologist told us that they believe that teams may not propose projects that utilize new technologies for competed missions because of the perceived cost or schedule risks. These officials are concerned that the pressure to meet cost and schedule could drive out more technologically ambitious projects. Our 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. The four competed Science Mission Directorate projects in this year's portfolio that are in development have a total of six critical technologies. Its four directed missions are developing twenty-one critical technologies, although this is primarily driven by SPP and JWST.

While projects entering development in recent years appear to be less technically ambitious and rely more heavily on existing technologies, this trend could be changing for science and human exploration missions. Three of the five projects currently in formulation—Mars 2020, Surface Water and Ocean Topography (SWOT), and ARRM—are developing four or more critical technologies. Mars 2020 is developing seven technologies and both SWOT and ARRM are developing four. Mars 2020 and ARRM are both developing critical technologies that include technology demonstrations for future Mars missions. For example, NASA expects ARRM to provide opportunities to demonstrate technical capabilities important for longer-duration, deep space missions, such as flight-testing solar electric propulsion.[11] For ARRM and Mars 2020, the majority of the critical technologies are currently considered immature—technology readiness level 5 or less—and will require significant development work to reach maturity by the projects' preliminary design reviews. As NASA continues to add more complex projects with a high number of critical technologies to its portfolio, ensuring that these technologies are matured

[10]For example, for NASA's Discovery program, mission proposals are solicited from teams comprised of people from universities, NASA centers, Federally Funded Research and Development Centers, industry, and small businesses, and led by a principal investigator.

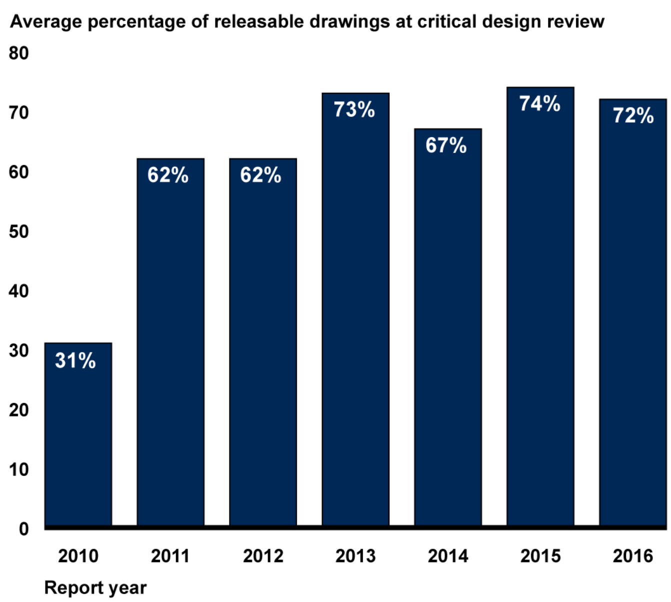
[11]Solar electric propulsion uses energy from the sun to accelerate ionized propellant, which can provide a relatively low level of thrust for months or years, allowing more mass to be transported with less propellant.

prior to project implementation will help to decrease the risk of cost and schedule growth.

NASA Has Sustained Prior Improvement in Design Stability

NASA continued to sustain improvements in the design stability of its major projects, but still falls short of GAO best practices. The average percentage of engineering drawings released at critical design review for NASA’s portfolio of major projects was 72 percent, roughly the same percentage as last year. This figure is short of the GAO best practice benchmark of 90 percent, but sustains improvements that began in previous years (see fig. 9). Further, a majority of projects in development maintained mass and power reserves that met or exceeded NASA requirements.

Figure 9: Average Percentage of Releasable Engineering Drawings for NASA Major Projects at Critical Design Review from 2010 through 2016



Source: GAO analysis of NASA data. | GAO-16-309SP

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.[12] The NASA Systems Engineering Handbook also includes this metric. In 2012, NASA established additional technical leading indicators to assess design maturity. These indicators include (1) the percentage of actual mass margin versus planned mass margin and (2) the percentage of actual power margin versus planned power margin.[13] NASA has updated its project management policy and its systems engineering policy to require projects to track these metrics. Projects that do not achieve design stability by critical design review may experience design changes and manufacturing problems, which can result in cost growth and schedule delays. For example, the cryocooler system and sunshield for the JWST had 60 percent and 34 percent of their respective drawings complete by critical design review. Each has presented technical and manufacturing challenges for the project and its contractors since that time.

Three of the six projects that passed the critical design review since March 2015 met our best practices for design stability. EGS, ICON, and the Space Launch System each released more than 90 percent of

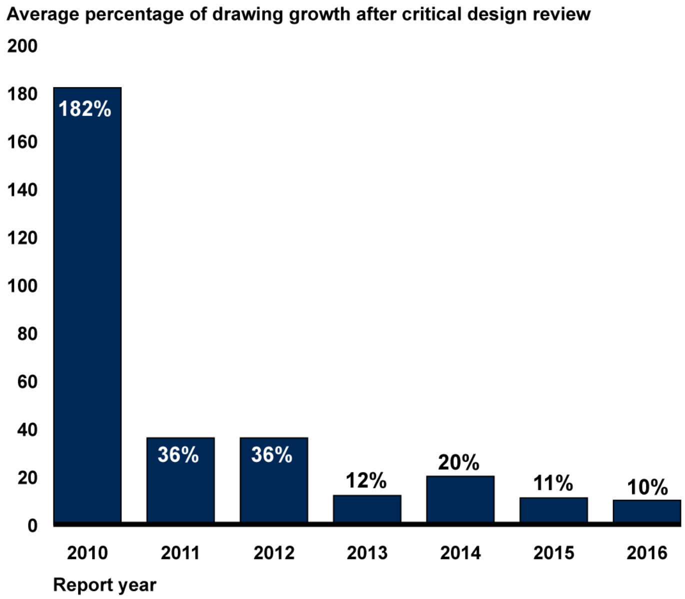
[12]Appendix IV contains detailed information about the project attributes highlighted by knowledge-based metrics at each stage of a system's development. Engineering drawings are considered to be a good measure of the demonstrated stability of a product's design because the drawings represent the language 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." 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. It is important that a project's design is stable enough to warrant continuing with the final design and fabrication phase. If a project experiences a large amount of drawing growth after critical design review, this may be an indicator of instability in the project design late in the development cycle. A stable design allows projects to "freeze" the design and minimize changes prior to beginning the fabrication of hardware, after which time reengineering and re-work efforts due to design changes can be costly to the project in terms of time and funding.

[13]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 additional guidance for mass margins including frequency of reporting and 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.

engineering drawings by their critical design reviews. Orion, SPP, and Transiting Exoplanet Survey Satellite (TESS) fell short of this metric. SPP only released 34 percent of its engineering drawings by the critical design review, which could increase the risk of future cost growth or schedule delays. The project's standing review board raised a concern about this approach and required the project to prepare a schedule for releasing the remaining design drawings. SPP project officials explained that the low drawing percentage stemmed from the project's decision to hold its critical design review early in order to begin building key components, including the flight cooling system, which would take 2 years to complete. The project has a 2018 planetary launch window and it needed to begin manufacturing the flight cooling system to remain on schedule. When the project held its critical design review, 100 percent of the flight cooling system engineering drawings had been released. As of December 2015, the project has released 84 percent of its total drawings and expects to have released the majority of the drawings by its May 2016 system integration review.

NASA projects have also continued to minimize design changes after the critical design review—another measure of design stability. For the eleven projects in development that have held critical design reviews, engineering drawing growth after the review was 10 percent, which is similar to last year (see fig. 10). This is a significant improvement since 2010 when the average drawing growth was 182 percent. By maintaining design stability following the critical design review, NASA may reduce the likelihood of cost growth and schedule delays resulting from late design changes.

Figure 10: Average Percentage of Drawing Growth after Critical Design Review for NASA Major Projects from 2010 through 2016



Source: GAO analysis of NASA data. | GAO-16-309SP

NASA Has Made Progress on Implementing Tools to Reduce Acquisition Risks, but Faces Several Challenges

NASA has continued to implement improved project management tools to manage acquisition risks, but these efforts have not always been consistent with best practices in areas such as cost estimating and earned value management (EVM). Project oversight could emerge as a new risk area due to NASA's plans to dissolve its office of independent program assessment and transfer that function to the mission directorates that manage major projects. Finally, while we have noted improvements in NASA's development cost performance, our analysis of recently launched science missions showed that NASA's operations cost baselines are often not good estimates of actual operations costs.

NASA Continues to Improve Its Cost Management Tools but Has Not Implemented Best Practices

NASA continues to implement tools to improve its cost and schedule estimates, but inconsistent application of best practices and concerns about data quality remain. In 2009, in order to ensure that cost and schedule estimates were realistic and projects thoroughly planned for anticipated risks, NASA began requiring that programs and projects with estimated life-cycle costs of $250 million or more develop a joint cost and schedule confidence level (JCL) prior to project confirmation.[14] However, there is no requirement for NASA projects to update their JCLs and our prior work has found that projects do not regularly update cost risk analyses to take into account newly emerged risks.[15] Our cost estimating best practices recommend that cost estimates should be updated to reflect changes to a program or kept current as it moves through milestones.[16] As new risks emerge on a project, an updated cost risk analysis can provide realistic estimates to decision-makers, including the Congress. In December 2012, we recommended that the JWST project update its JCL to make sure it reflected current program risks.[17] NASA concurred with our recommendation, but officials subsequently stated that they did not plan to conduct an updated joint cost and schedule confidence level analysis and the project's monthly analyses were sufficient for the project's needs.[18] NASA has since conducted other types of cost risk analysis for the project, but has not updated its JCL. Officials in the Independent Program Assessment Office (IPAO) told us that projects could benefit from updating their JCL analysis at critical design review, when they conduct another review of the project's cost estimates and schedule projections.

[14]A JCL is a tool that assigns a confidence level, or likelihood, of a project meeting its cost and schedule estimates.

[15]GAO, *Space Launch System: Management Tools Should Better Track Cost and Schedule Commitments to Adequately Monitor Increasing Risk,* GAO-15-596 (Washington, D.C.: Jul. 16, 2015), and *James Webb Space Telescope: Actions Needed to Improve Cost Estimates and Oversight of Test and Integration,* GAO-13-4 (Washington, D.C.: Dec. 3, 2012).

[16]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).

[17]GAO-13-4.

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

Additionally, NASA is taking steps to address another area in need of improvement across the agency—schedule development. Our best practices work stresses the importance of a reliable schedule because not only is it a road map for systematic project execution, but also a means by which to gauge progress, identify and resolve potential problems, and promote accountability.[19] According to NASA officials, a project's ability to efficiently execute a quality JCL analysis is directly tied to the quality of the underlying data, especially a project schedule. Independent assessors—a group of technical experts within NASA who do not actively work on a specific project or program—noted that when they are reviewing a project's JCL, one of the most common areas that projects struggle with is developing a reliable schedule. For example, the Orion program's standing review board raised concerns that the program's schedule is missing activities which could affect the program's ability to accurately identify what is driving the schedule. Officials in the Cost Analysis Division told us that various schedule related tools have been developed and already made available to projects and additional tools are in development.

NASA has also 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 best practices. EVM has been a critical part of the agency's efforts to understand project development needs and to reduce cost and schedule growth. 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. NASA rolls out EVM to its centers by using one project to implement its EVM capability process. NASA has completed this process at Goddard Space Flight Center, Marshall Space Flight Center, and Kennedy Space Center, and in 2015 expanded this effort to Johnson Space Center using the Orion project. These four centers account for 98 percent of NASA's spaceflight projects that require the use of EVM. NASA plans to roll out the EVM capabilities process to Glenn Research Center in fiscal year 2016 and Langley Research Center in fiscal year 2017. The agency is also working with the Applied Physics

[19]GAO, *GAO Schedule Assessment Guide: Best Practices for Project Schedules* GAO-16-89G (Washington, D.C.: Dec. 22, 2015).

Laboratory and Southwest Research Institute to validate their EVM systems.[20] NASA is supporting these efforts with training, including classroom and online training to projects at its various centers.

In 2012, we recommended that NASA require projects to implement formal EVM surveillance programs, but according to NASA officials, they have not implemented the recommendation due to resource constraints.[21] Proper surveillance of EVM contractor data is a best practice in the NASA Earned Value Management Implementation Handbook and GAO's Cost Estimating and Assessment Guide.[22] Without implementing proper surveillance, a project may be utilizing unreliable EVM data to inform its cost and schedule decision making. NASA has taken other steps to address the intent of our recommendation, but we continue to find issues with the quality of EVM data. According to the Office of the Chief Engineer, NASA has a two-part EVM surveillance effort at the agency level, consisting of Office of the Chief Engineer's project EVM data assessments at key decision points and EVM anomaly tools. In our December 2015 review of JWST, we found project EVM data anomalies and recommended that project officials require the contractors to explain and document all such anomalies in their monthly EVM reports.[23] A continuous surveillance program could have identified these anomalies earlier, allowing the project to pursue corrective action with its contractors. NASA concurred with this recommendation and recently sent us documentation concerning steps it has taken to address it. We are

[20]Southwest Research Institute and Johns Hopkins University's Applied Physics Laboratory are independent, nonprofit, applied research and development organizations that have previously been awarded contracts for large NASA development efforts, such as Magnetospheric Multiscale and SPP missions.

[21]Beyond reviewing cost and schedule variances and variances at completion, formal surveillance reviews ensure that the processes and procedures continue to satisfy the guidelines. 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. GAO, *NASA: Earned Value Management Implementation across Major Spaceflight Projects Is Uneven*, GAO-13-22 (Washington, D.C.: Nov. 19, 2012).

[22]GAO-09-3SP.

[23]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).

currently reviewing that information to determine if NASA has implemented the recommendation.

NASA Plans to Decentralize Its Independent Assessment Function Which Could Impact Project Oversight

In October 2015, NASA's Office of the Administrator issued a memorandum outlining its plan to decentralize its independent assessment function. NASA is still working through how this change will be implemented, and therefore, it is unclear how it might impact project oversight. 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.[24] NASA policy requires independent assessments at milestones, such as key decision points and technical reviews, for major programs and projects.[25] The memorandum dissolved IPAO, which managed these assessments, and transferred responsibility for them to the mission directorates that oversee NASA's programs and projects.[26] The memo highlighted two key reasons for this change:

1. Address workforce capacity: By deploying IPAO staff to the agency's centers, NASA can better utilize its workforce to meet program needs in areas such as program management, cost estimating, and resource analysis, and fill gaps in program analysis skills at the center level.
2. Increase accountability at mission directorate level: By dissolving the separate organization, the mission directorates with support from the centers will now be responsible for and own the independent assessments for their programs and projects, which may also make them more accountable for addressing the results.

One of the primary changes associated with the realignment of the independent assessment function will be who identifies and selects the members of the standing review boards that conduct assessments. Standing review boards are a key element of NASA's strategic framework

[24]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).

[25]Independent assessments are required at programmatic milestones for NASA programs and projects. NPR 7120.5E and NASA Systems Engineering Processes and Requirements, NPR 7123.1B.

[26]As part of this reorganization, the IPAO parent organization, the Office of Evaluation was also dissolved. The other organization in that office, the Cost Analysis Division, will be placed in the Office of the Chief Financial Officer.

to ensure appropriate management oversight in order to increase the likelihood of success. IPAO was responsible for facilitating the identification and approval of standing review board manager and other team members. IPAO members also participated on standing review boards to ensure that programs were in compliance with NASA requirements and to recommend approaches to address programmatic and technical risks. For example, an IPAO cost analyst, as a member of the standing review board, was responsible for developing an independent cost assessment of the program for each review. With the reorganization, NASA's mission directorates, in coordination with the centers, will be responsible for selecting project's standing review board chairs. The selection will be approved by NASA's Associate Administrator, who is the decision authority for high priority projects and programs. The standing review board chair will be responsible for working with the headquarters-based Office of the Chief Financial Officer and the Office of the Chief Engineer to identify the relevant programmatic and technical experts, respectively. The former IPAO director will work with NASA's Associate Administrator for the next year to oversee the transition of the independent assessment functions to the directorates and develop an overall strategy for how the agency will conduct independent assessments moving forward.

The reorganization of the independent assessment function could potentially impact project oversight. The first potential impact is on the independence of the assessments themselves. Standing review boards will still conduct their assessments independently, but the overall responsibilities for those assessments are being transferred to the directorates who directly oversee the projects being assessed. Further, the robustness of the reviews could vary by center. We have previously found policy implementation can differ when NASA devolves responsibility to the center level.[27] In December 2005, we found that NASA centers had varying approaches for implementing the agency's acquisition and project management policies and guidance, which resulted in different levels and types of knowledge being required for

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

projects at key decision points.[28] More recently, in April 2014, we found that NASA policy gave centers wide latitude in implementing export control procedures, but implementation across centers was inconsistent.[29] Finally, the sharing of information across projects could be affected. Prior to the proposed reorganization, IPAO and the Cost Analysis Division both resided in the Office of Evaluation, which NASA plans to dissolve. Officials from both IPAO and the Cost Analysis Division expressed the need to preserve the sharing of lessons learned and best practices on topics such as JCL analysis that took place naturally when both organizations were part of the Office of Evaluation. NASA officials said they are developing an implementation strategy that will address risks associated with the reorganization, as well as opportunities for improving the agency's project oversight and programmatic analysis capability. We will continue to monitor the potential impacts of this reorganization as it unfolds.

Mission Operations Cost Baselines Are Often Not a Good Estimate of Actual Costs

At confirmation, NASA's major projects are required to establish a baseline for development and operations cost; however, the operations cost baselines are often not a good estimate of actual costs.[30] Of the 19 previously launched science missions we examined, 14 projects experienced operations cost growth: 10 projects experienced growth in operations costs and also exceeded their committed agency cost baseline, while 4 projects experienced a growth in operations costs, but did not exceed their agency cost baseline.[31] The operations cost increases ranged from 1 to 110 percent, with an average increase of 39 percent. For example, the Magnetospheric Multiscale project experienced a 39 percent growth in operations costs after it was not able to develop the software needed to achieve the planned level of automation. Five

[28]GAO-06-218.

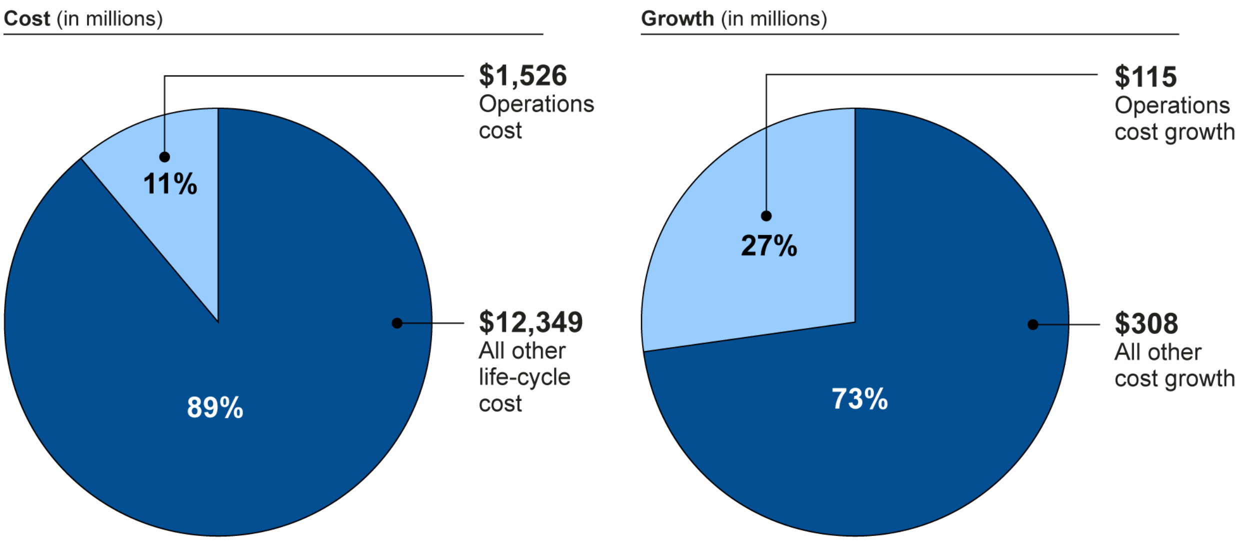
[29]GAO, *Export Controls: NASA Management Action and Improved Oversight Needed to Reduce the Risk of Unauthorized Access to Its Technologies,* GAO-14-315 (Washington, D.C.: April 15, 2014).

[30]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.

[31]We analyzed prime operations costs for projects that have launched and were included in our prior annual reviews of NASA's major projects.

projects we examined underran their operations cost baselines. The underruns for these five projects ranged from 6 to 60 percent. The 19 projects we reviewed experienced cumulative operations cost growth of $114.6 million. For these 19 projects, operations cost growth accounted for a disproportionate share of overall life-cycle cost growth relative to its overall share of the total life-cycle cost (see fig. 11).

Figure 11: Project Operations Costs and Cost Growth as a Percentage of Total Life-Cycle Cost and Cost Growth for Selected Major NASA Projects



Source: GAO analysis of NASA data. | GAO-16-309SP

NASA officials acknowledged that establishing operations cost baselines at project confirmation is a challenging task, and the agency is focusing effort on improving projects' abilities to estimate their operations cost baselines. Typically, the JCL cost estimating methodology which projects apply to development costs prior to project confirmation is not applied to operations costs. According to Cost Analysis Division officials, the JCL methodology is generally unsuitable to estimate operations costs because the JCL analysis requires a robust schedule which is difficult to develop for operations, given the number of uncertainties. Agency officials told us that projects lack specific estimating tools for operations cost and rely on a bottom-up cost estimating process that includes estimates for the various activities a project expects to perform while in operations. Cost Analysis Division officials stated that they have begun working to develop parametric cost estimating tools, which leverage historical data to enable users to model and derive cost estimates for the operations phase. The Mission Operations Cost Estimation Tool was presented at the NASA Cost Symposium in August 2015 and made available to the NASA estimating community in September 2015. Science Mission Directorate officials also 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.

Project Assessments

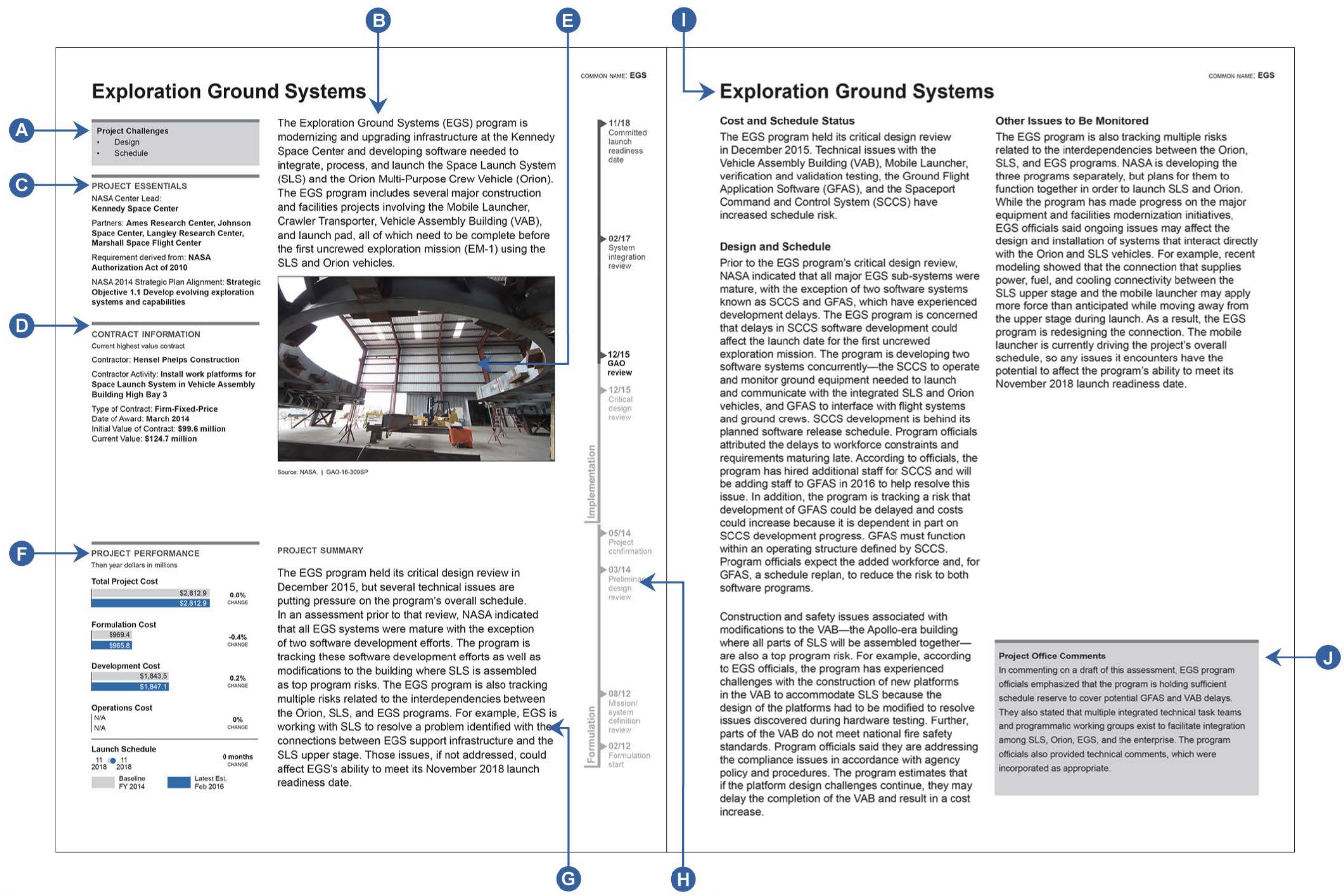
The individual assessments of the projects we reviewed provide a profile of each project and are tailored in length, from two to four pages, to capture information about the project.

Each project assessment includes a description of the project's objectives; information about the related NASA center, primary contractor(s), and external partners involved in the project; the project's cost and schedule performance; a timeline identifying key project dates; and a brief narrative describing the current status of the project.[32] The two-page assessments—17 in total—describe the challenges we identified this year, as well as challenges that we have identified in the past. On the first page, the project profile presents the standard information listed above. On the second page of the assessment, we provide an analysis of the project challenges, and outline the extent to which each project faces cost, schedule, or performance risk because of these challenges, if applicable. The four-page assessment of the Commercial Crew Program is structured similarly to the two-page assessments and captures similar information, but was expanded to focus on the two funded companies' current status, timelines, and challenges. 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.

[32]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.

See figure 12 for an illustration of a sample assessment layout.

Figure 12: Illustration of a Sample Project Assessment



- **A** **Project Challenges** Summary listing of the challenges facing the project
- **B** General description of the mission's objectives
- **C** **Project Essentials** Programmatic information including the responsible NASA center, international or domestic partners, launch information, mission duration, and the driver for the mission's requirements
- **D** **Contract Information** Current highest value contractor, contractor activity, the type of contract and when it was awarded, and initial and current value of the contract
- **E** Illustration of the spacecraft, aircraft or ground system
- **F** **Project Performance** Cost and schedule baseline estimates and the latest estimate updates
- **G** **Project Summary** Brief narrative describing the current status of the project
- **H** Schedule timeline identifying key dates for the project including when the project began formulation, major design reviews, confirmation to begin the implementation phase, and launch or operating capability information
- **I** 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 risk because of these challenges
- **J** **Project Office Comments** General comments provided by the cognizant project office

Source: GAO analysis. | GAO-16-309SP

Asteroid Redirect Robotic Mission

Project Challenges
- Funding
- Technology
- Design

PROJECT ESSENTIALS

NASA Center Lead:
Jet Propulsion Laboratory

Partners: **NASA Science Mission Directorate, NASA Space Technology Mission Directorate, Glenn Research Center, Goddard Space Flight Center, Langley Research Center**

Launch Location: **TBD**
Launch Vehicle: **TBD**

Mission Duration: **TBD**

Requirement derived from: **U.S. Space Policy**

NASA 2014 Strategic Plan Alignment: **Strategic Objective 1.1 Develop evolving exploration and capabilities**

CONTRACT INFORMATION

Current highest value contract

Contractor: **TBD**

Contractor Activity: **TBD**

Type of Contract: **TBD**
Date of Award: **TBD**
Initial Value of Contract: **TBD**
Current Value: **TBD**

PROJECT PERFORMANCE

Then year dollars

Preliminary Estimate of Project Life Cycle Cost[a]

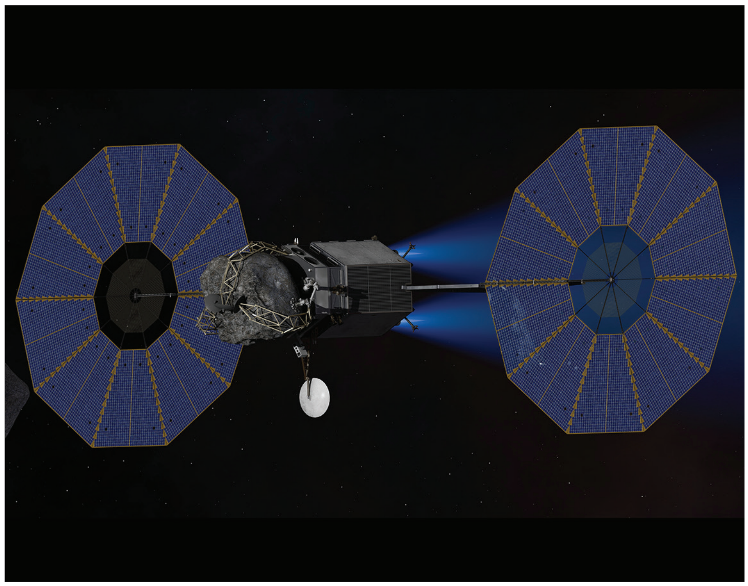
$1.72 BILLION

Latest: **February 2016**

[a]This estimate is preliminary, as the project is in formulation and there is uncertainty regarding the costs associated with the design options being explored. NASA uses these estimates for planning purposes.

Launch Schedule: **December 2020**

The Asteroid Redirect Robotic Mission (ARRM) aims to retrieve a boulder from a selected asteroid and place it into lunar orbit for future human exploration. ARRM and the planned follow-on crewed mission to the boulder are capability demonstration missions, which are primarily designed to develop systems and provide the types of operational experiences required for future human and robotic exploration of Mars. ARRM will demonstrate technologies important for longer-duration, deep-space missions, such as advanced solar electric propulsion (SEP). The mission will also demonstrate an asteroid deflection technique by gravitationally altering the asteroid's trajectory.



Source: NASA/AMA Studios. | GAO-16-309SP

PROJECT SUMMARY

The ARRM project plans to leverage technologies from development efforts managed and funded by multiple NASA directorates, which could pose challenges for the project. The project's cost and schedule estimates assume that the agency will sufficiently fund these efforts. The Space Technology Mission Directorate is responsible for advanced SEP development, which contains some of the project's most significant risks. NASA has developed and tested prototypes of major SEP components, but there is limited time to complete their development, due in part to the project's launch window. NASA is also studying options for the ARRM spacecraft design and awarded four early design study contracts in January 2016 that will inform the spacecraft development contract.

Implementation

12/20 Projected launch readiness date

07/19 System integration review

08/18 Critical design review

04/17 - 06/17 Project confirmation

04/17 Preliminary design review

02/16 Mission/ system definition review

12/15 GAO review

Formulation

04/15 Formulation start

Asteroid Redirect Robotic Mission

Cost and Schedule Status

The ARRM project entered the concept and technology development phase in April 2015. The project has set an initial development cost cap of $1.25 billion, not including a launch vehicle or mission operations, and a launch readiness date of December 31, 2020.

Funding

The ARRM project is dependent on development efforts from multiple NASA directorates and the project's cost and schedule estimates assume that the agency will sufficiently fund these efforts. The Human Exploration and Operations Mission Directorate is the lead for the effort, but the Space Technology Mission Directorate will provide technology in key areas. The project plans to leverage high-powered solar electric propulsion (SEP) technologies currently being funded and developed by the Space Technology Mission Directorate. Between fiscal years 2015 and 2019, the Space Technology Mission Directorate plans to spend $230 million to develop SEP technologies. The ARRM project also plans to leverage advanced controls, sensors, and robotics technologies from the Space Technology Mission Directorate's Restore-L satellite servicing mission, but as a result of the Consolidated Appropriations Act, 2016, funding for Restore-L cannot be used to support activities solely needed for ARRM. The project assumes that approximately $50 million to $60 million of the planned funding between fiscal years 2015 and 2019 for maturing Restore-L technologies will also support ARRM's development.

Technology

NASA has developed and tested prototypes of major components that could be used on the advanced SEP system, but the system remains a source of cost and schedule risk for the project. SEP uses energy from the sun to accelerate propellant to produce a more fuel efficient thrust, which could benefit longer missions because it requires less propellant and reduces spacecraft mass. Among the potential SEP-related risks for the project is the limited amount of time to develop the system's component technologies, such as the power processing unit and solar array hardware. Development time is limited, in part, due the mission's December 2020 target launch readiness date.

Design

The ARRM project is studying options for the spacecraft design, and hopes to achieve cost savings and reduce risk by building on a commercially available spacecraft. The project awarded four early design study contracts in January 2016 to inform the spacecraft development contract.

The ARRM project has noted that if new crew safe requirements or requirements to support the follow-on Asteroid Redirect Crewed Mission, planned for 2025, are added to the project, then development costs could significantly increase. One of the key design assumptions for ARRM is that its Asteroid Redirect Vehicle will be "crew safe," but not "human rated." ARRM will carry hardware to make it possible for the Orion Multi-Purpose Crew Vehicle to dock with the ARRM vehicle after it brings the captured boulder into lunar orbit and for astronauts to conduct a study of the captured boulder outside the vehicle. If this follow-on crewed mission requires the ARRM Asteroid Redirect Vehicle to meet human-rated systems standards, such as resistance to cracking, then the vehicle would require design changes and additional testing.

Other Issues to Be Monitored

NASA has taken steps to address potential management and funding complexities that could affect the execution of ARRM. In November 2015, the heads of the human exploration and space technology mission directorates signed a memorandum of agreement defining the programmatic relationship between the two directorates for ARRM development. The project also plans to use a streamlined process for upcoming key decision point reviews.

Project Office Comments

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

Commercial Crew Program

Project Challenges
- Schedule
- Design (new)
- Launch (new)
- Funding

PROJECT ESSENTIALS

NASA Center Lead:
Kennedy Space Center

Partners: **Boeing, SpaceX**
Blue Origin,* Sierra Nevada Corporation*

Launch Location: **Boeing-Cape Canaveral AFS, FL; SpaceX-Kennedy Space Center, FL**
Launch Vehicle: **Boeing-Atlas V; SpaceX-Falcon 9**

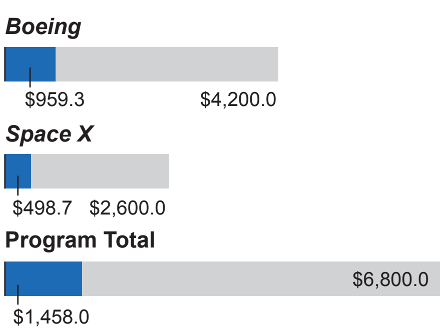
Requirement derived from: **NASA Strategic Plan**

NASA 2014 Strategic Plan Alignment: **Strategic Objective 1.3 Foster the commercialization of space transportation**

**Blue Origin and Sierra Nevada Corporation are Commercial Crew Program partners, but they do not have contracts with NASA for the Transportation Capabilities phase and therefore were not included in this assessment.*

TRANSPORTATION CAPABILITIES PHASE CONTRACTS

Then year dollars in millions



Latest: **February 2016**

Maximum potential value

Payments to date

The purpose of the Commercial Crew Program is to facilitate the development of safe, reliable, and cost-effective crew transportation systems (CTS) to carry NASA astronauts and cargo to and from the International Space Station (ISS). The program is a multi-phase effort that started in 2010 to stimulate private-sector interest in providing commercial human space transportation capabilities. The current Transportation Capabilities phase is intended to result in the final certification of CTSs for crewed flights. In September 2014, NASA awarded firm-fixed-price contracts to Boeing and SpaceX for the design, development, test, and operation of CTSs; a minimum of two, but up to six crewed missions to ISS; and special studies, tests, and analysis.

Source: United Launch Alliance (left); Space Exploration Technologies (right). | GAO-16-309SP

PROJECT SUMMARY

The Commercial Crew Program is working to an aggressive schedule to certify Boeing and SpaceX CTSs by the end of 2017, at which point they could be used for crewed flights to and from ISS. To meet this schedule, Boeing and SpaceX are concurrently developing, testing, and producing their vehicles—a high risk strategy that could lead to costly modifications to systems already being built and delays if problems are identified during testing. NASA has tried to minimize its cost risk on the program by using firm-fixed-price contracts. In addition, the program is concerned that certification could be delayed, in part, because of a lack of design maturity in the companies' crew vehicles. Both companies held critical design reviews in 2015 and each had several key crew vehicle subsystems designs that were not yet mature. The program put Boeing and SpaceX on contract in 2015 for their first post-certification missions. The companies will need to complete the certification process before these flights.

2017/2018
Post-certification missions

2017
Final certification

12/15
GAO review

11/15
SpaceX authority to proceed with first post-certification mission

05/15
Boeing authority to proceed with first post-certification mission

09/14
Transportation Capabilities phase contract awards

2012 – 2014
Integrated Capabilities phase

2010 – 2012
Development phase

Commercial Crew Program

Cost and Schedule Status

NASA held an agency review in October 2015 to establish cost and schedule baselines for the Commercial Crew Program, but it has not yet finalized its decisions from the review, including the amount of cost and schedule reserves it will hold for risk mitigation activities.

Schedule

The Commercial Crew Program is working to an aggressive schedule to certify Boeing and SpaceX's CTSs by the end of 2017. To meet this schedule, Boeing and SpaceX are concurrently developing, testing, and producing their vehicles. Overlaps between these activities increase the risk that problems identified during development or testing could lead to costly modifications to systems already being built and schedule delays. NASA has tried to minimize its cost risk on the program by using firm-fixed-price contracts. The program ordered the first post-certification missions from the companies in 2015 before they completed development or tested their CTSs. These orders are made 2 to 3 years prior to actual mission dates in order to provide time for each company to manufacture and assemble the launch vehicle and spacecraft.

Boeing and SpaceX have yet to complete the majority of their critical test events and there is little time between test events for the companies to learn from them and make changes. Both companies plan to complete their uncrewed and crewed demonstration missions that are intended to test key system capabilities including their ability to launch, dock with the International Space Station (ISS), and return to Earth in 2017 and there are only about 4 months between each of these demonstrations. The companies will need to successfully complete these demonstrations and the certification process before they can fly post-certification missions. NASA extended its contract with the Russian Federal Space Agency to procure additional seats on the Soyuz vehicle through 2018 to ensure that it has access to ISS if delays occur.

Design

The Commercial Crew Program is monitoring several design-related issues that could delay final CTS certification, including the maturity of Boeing and SpaceX's current designs and the ability of the companies to meet NASA requirements and standards. Both Boeing and SpaceX held critical design reviews in 2015, but will not complete design activities until later than planned. Boeing held a critical design review in March 2015 for its CTS, which includes the Starliner crew vehicle, Atlas V launch vehicle, and ground systems, and a follow-on review in May 2015 that focused on the design of the launch vehicle and launch site. SpaceX held the first part of a multi-part critical design review in October 2015, which focused on the design of its launch vehicle—an upgraded version of the Falcon 9—and uncrewed ground systems, and the second part in December 2015, which focused on the Crew Dragon capsule and mission operations. An additional critical design review is planned to be completed by August 2016 for any remaining Dragon component or subsystem designs, including an updated seat design, and the crewed ground systems.

The program is tracking risks related to the design maturity of both companies' crew vehicles because they have several key subsystem designs that are not yet mature.

Commercial Crew Program

For example, Boeing does not plan to complete the final lower-level component design reviews for crew life support systems until May 2016 and SpaceX does not plan to completely mature its Dragon seat designs until spring 2016. Our best practice work shows that having a stable design prior to hardware fabrication can reduce the risk of rework efforts that could result in cost increases and schedule delays. For the parts of the CTS designs that are mature, the program is using a design change control process to assess the potential effects of proposed design changes on safety, and to approve or disapprove the companies' proposed changes.

Both companies have requested variances, or permission from the program to deviate from certain NASA requirements and design standards. If the program does not approve some of these variances, it could force the companies to make design changes, which could have cost and schedule implications for the companies. For example, Boeing requested variances for aspects of both the Starliner and Atlas V designs that do not meet fault tolerance requirements, which are requirements related to the ability of a system to continue operating should a component error or failure occur. SpaceX has requested a variance to use commercial-off-the-shelf parts in certain applications rather than parts that have gone through special testing to be considered "space-rated." SpaceX officials said that they have used this approach and proven that it is reliable for multiple short-duration cargo missions. Overall, the program is taking several steps to mitigate these types of issues, including accommodating the companies' specific ways of doing business, limiting changes to requirements that might lead to design changes, and actively engaging with the companies on requested variances.

The Commercial Crew Program is also concerned that it may fall short of meeting the program's loss of crew requirement based on the current CTS designs. The program's loss of crew requirement is 1 in 270, which is a measure of how likely there will be loss of crew on a given mission. This is an increase in the requirement from the end of the Space Shuttle program, which was about 1 in 90. Boeing and SpaceX are responsible for meeting a loss of crew requirement of 1 in 200, and the program is responsible for closing the gap between that requirement and the one for the program. The program conducted assessments of each company's designs in order to meet the overall requirement and determined that it would be challenging without additional spacecraft modifications to protect against micrometeoroid and orbital debris. The companies would need to make these design changes soon, as they are both moving into manufacturing their systems. The program has established a team to develop a plan to close the requirements gap.

Launch

The Commercial Crew Program is working to address a number of launch vehicle issues that will need to be resolved prior to certifying that the vehicles are safe to transport crew.

- Boeing's selected launch vehicle, the Atlas V, is being modified by adding a new emergency detection system and a second engine to its upper stage, so that it can be certified for human space flight and meet fault tolerance requirements. The Commercial Crew Program is working through the variances the launch vehicle provider has submitted for the new upper stage and plans to complete mitigation plans by April 2016 to resolve any remaining risk of certifying the modified Atlas V for human space flight.
- SpaceX's launch vehicle, the Falcon 9, has been upgraded to improve its performance by increasing engine thrust and using densified propellants. Among the risks associated with the upgraded vehicle is SpaceX's planned concept of operations for launching using densified propellants. SpaceX plans to load crew into the Dragon and then fuel the rocket to keep the densified propellants chilled. The program has reported that loading the crew prior to the propellant is a potential safety risk. SpaceX stated that its approach will improve safety by minimizing personnel exposure to a fueled rocket. It has also identified safety and hazard controls to mitigate any risks associated with this approach. In December 2015, SpaceX launched the upgraded Falcon 9 for the first time and successfully landed its first stage on land.

Commercial Crew Program

Funding

One of the Commercial Crew Program's top risks during 2015 was funding uncertainty, but this appears to have been alleviated with the passage of the Consolidated Appropriations Act, 2016. In the Act, the program received funding in the amount requested by NASA. According to NASA, one of the reasons for the funding uncertainty was confusion over the way NASA is financing the contracts. The design, development, test, and evaluation activities in the contract that culminate in certification are fixed-price. The program uses performance-based payments, also referred to as milestone payments, to finance Boeing and SpaceX, and they are only paid after the successful completion of a milestone. The program designated five mandatory milestones, such as the certification review, and the companies developed a set of interim milestones. Under a fixed-price contract with performance-based financing payments, the contractors' incurred costs are irrelevant, and the milestone payments help finance the contract through development to completion. For example, the companies might use milestone payments received for completing the critical design review milestones to purchase hardware for test articles. Moving forward, if the program receives inadequate funding to finance planned contract work, it could be required to renegotiate the contract, which may result in price increases and schedule delays.

Project Office Comments

In commenting on a draft of this assessment, Commercial Crew Program officials stated that having at least two companies developing different crew transportation systems provides benefits in redundancy, innovation, and cost effectiveness. They also stated that the program was not funded at the levels requested in the President's Budget request during fiscal years 2011-2015, which were critical years of design and development. They emphasized that adequate and timely funding and maintaining competition between the two companies are essential to ensuring program performance. Commercial Crew Program, Boeing, and SpaceX officials provided technical comments, which were incorporated as appropriate.

Europa

Project Challenges
- Funding
- Design
- Launch
- Technology

PROJECT ESSENTIALS

NASA Center Lead:
Jet Propulsion Laboratory

Partner: **TBD**

Launch Location: **TBD**
Launch Vehicle: **TBD**

Mission Duration: **3 year science mission**

Requirement derived from: **2010 Decadal Survey**

NASA 2014 Strategic Plan Alignment: **Strategic Objective 1.5 Understand the solar system**

CONTRACT INFORMATION

Current highest value contract

Contractor: **TBD**

Contractor Activity: **TBD**

Type of Contract: **TBD**
Date of Award: **TBD**
Initial Value of Contract: **TBD**
Current Value: **TBD**

PROJECT PERFORMANCE

Then year dollars

Preliminary Estimate of Project Life Cycle Cost[a]

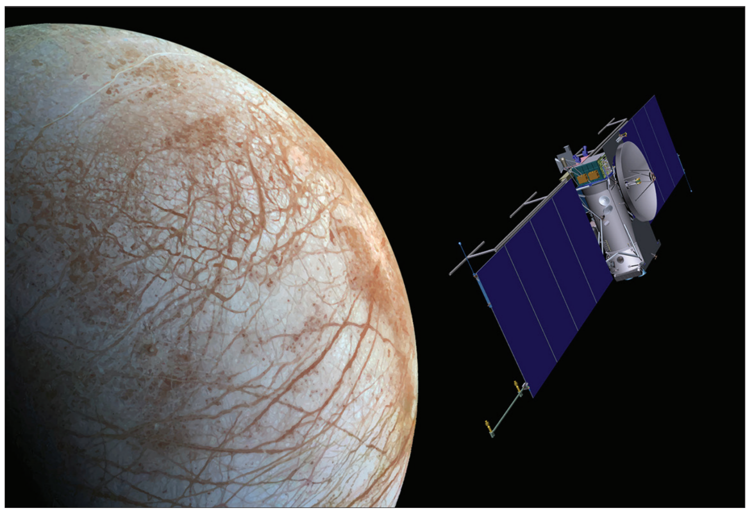
Latest: **February 2016** **$3 – $4 BILLION**

[a] *This estimate is preliminary, as the project is in formulation and there is uncertainty regarding the costs associated with the design options being explored. NASA uses these estimates for planning purposes.*

Launch Schedule[b]: **July 2022**

[b] *The launch schedule is for planning purposes and could change as the project explores design options, such as incorporating a lander.*

The Europa mission aims to investigate whether the Jupiter moon could harbor conditions suitable for life. The project plans to launch the spacecraft in the 2020s, put it in orbit around Jupiter, and conduct a series of 45 investigatory flybys of Europa. The mission currently has four planned science objectives: (1) characterize Europa's ice shell and any subsurface water, (2) understand the habitability of Europa's ocean by analyzing its composition and chemistry, (3) understand the formation of surface features, and (4) characterize scientifically compelling sites for a potential future landed mission.



Source: Europa Project Personnel, California Institute of Technology, Jet Propulsion Laboratory.
GAO-16-309SP

PROJECT SUMMARY

The Europa project has developed its mission profile and selected its science instruments, but it is still evaluating possible launch dates, launch vehicles, and additional payloads, all of which can have an effect on the project's cost, schedule, and risk. The project is working to a July 2022 launch readiness date that is contingent upon the project continuing to be appropriated more funding than requested by NASA, as it has for the past 4 years. However, the project is currently reassessing its plans after the Consolidated Appropriations Act, 2016 required it to incorporate a Europa lander, which would require significant design changes and increase the project's costs and development schedule. The Act also requires the Europa project to use the Space Launch System (SLS), which could have cost, schedule, and risk implications. SLS offers a shorter travel time to Jupiter than other launch vehicles, but it poses other risks because it may still be in development at Europa's preliminary design review—the point when projects prefer to select a launch vehicle.

Implementation

07/22 Projected launch readiness date

07/20 System integration review

05/19 Critical design review

Formulation

05/18 Project confirmation

03/18 Preliminary design review

06/16 System requirements/ mission definition review

12/15 GAO review

06/15 Formulation start

Europa

Cost and Schedule Status

The Europa project entered the concept and technology development phase in June 2015. It plans to enter the preliminary design and technology completion phase in July 2016, at which point it will establish a range of the expected cost and schedule for the project. The project developed its current plan before the Consolidated Appropriations Act, 2016 required Europa to fly an orbiter with a lander.

Funding

The Europa project is currently working to a July 2022 launch readiness date that is contingent upon the project receiving a higher level of funding than requested by NASA. The project was appropriated more funding than the agency requested for the past 4 years. For instance, in fiscal year 2016, the project was appropriated $175 million, which was $145 million more than NASA requested. However, even with this level of funding, it is unclear whether the 2022 launch date is still feasible given the direction to include a lander as part of the project.

Design

NASA may have to make significant changes to its planned design concept. The Consolidated Appropriations Act, 2016 requires Europa to fly an orbiter with a lander. The project is currently assessing how it will incorporate this into its current mission concept. Project officials previously stated that a lander would require significant design changes and increase the project's costs and development schedule. The project has set aside 250 kilograms of mass for payload options, such as a potential life detection instrument or a free-flying component to investigate plumes emitted from Europa's surface. Project officials have stated that a lander cannot be accommodated within this 250 kilogram limit.

Launch

The choice of launch vehicle could have cost, schedule, and risk implications for the Europa project. The project was maintaining compatibility with both evolved expendable launch vehicle variants, such as the Delta IV, Atlas V, and Falcon Heavy, and NASA's SLS; however, the recently enacted Consolidated Appropriations Act, 2016 requires the Europa project to launch on an SLS. Project officials said they view SLS as the best option because it offers a shorter travel time to Jupiter. However, it involves other risks. SLS will likely still be in development when the Europa project holds its planned preliminary design review in March 2018. The preliminary design review is the point when projects usually prefer to select a launch vehicle because it can affect the design of the spacecraft. Project officials previously said they would be willing to delay launch vehicle selection and maintain spacecraft compatibility with both launch vehicle options for 8 months until the SLS's committed launch readiness date of November 2018.

Technology

According to project officials, the Europa project's nine planned science instruments have been used in prior versions on other missions, but additional development will be required to ensure that they are adequately protected from Jupiter's harsh radiation environment. The damaging effect of Jupiter's harsh radiation environment on flight systems is the project's top risk. To mitigate this risk, the project is testing parts, modeling the spacecraft exterior, and reviewing radiation survivability approaches.

Project Office Comments

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

Exploration Ground Systems

Project Challenges
- Design
- Schedule

PROJECT ESSENTIALS

NASA Center Lead:
Kennedy Space Center

Partners: **Ames Research Center, Johnson Space Center, Langley Research Center, Marshall Space Flight Center**

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

NASA 2014 Strategic Plan Alignment: **Strategic Objective 1.1 Develop evolving exploration systems and capabilities**

CONTRACT INFORMATION

Current highest value contract

Contractor: **Hensel Phelps Construction**

Contractor Activity: **Install work platforms for Space Launch System in Vehicle Assembly Building High Bay 3**

Type of Contract: **Firm-Fixed-Price**
Date of Award: **March 2014**
Initial Value of Contract: **$99.6 million**
Current Value: **$124.7 million**

The Exploration Ground Systems (EGS) program is modernizing and upgrading infrastructure at the Kennedy Space Center and developing software needed to integrate, process, and launch the Space Launch System (SLS) and the Orion Multi-Purpose Crew Vehicle (Orion). The EGS program includes several major construction and facilities projects involving the Mobile Launcher, Crawler Transporter, Vehicle Assembly Building (VAB), and launch pad, all of which need to be complete before the first uncrewed exploration mission (EM-1) using the SLS and Orion vehicles.

Source: NASA. | GAO-16-309SP

11/18 Committed launch readiness date

02/17 System integration review

12/15 GAO review

12/15 Critical design review

Implementation

05/14 Project confirmation

03/14 Preliminary design review

08/12 Mission/system definition review

02/12 Formulation start

Formulation

PROJECT PERFORMANCE

Then year dollars in millions

Total Project Cost
$2,812.9
$2,812.9
0.0% CHANGE

Formulation Cost
$969.4
$965.8
-0.4% CHANGE

Development Cost
$1,843.5
$1,847.1
0.2% CHANGE

Operations Cost
N/A
N/A
0% CHANGE

Launch Schedule
11 2018
11 2018
0 months CHANGE

Baseline FY 2014
Latest Est. Feb 2016

PROJECT SUMMARY

The EGS program held its critical design review in December 2015, but several technical issues are putting pressure on the program's overall schedule. In an assessment prior to that review, NASA indicated that all EGS systems were mature with the exception of two software development efforts. The program is tracking these software development efforts as well as modifications to the building where SLS is assembled as top program risks. The EGS program is also tracking multiple risks related to the interdependencies between the Orion, SLS, and EGS programs. For example, EGS is working with SLS to resolve a problem identified with the connections between EGS support infrastructure and the SLS upper stage. Those issues, if not addressed, could affect EGS's ability to meet its November 2018 launch readiness date.

Exploration Ground Systems

Cost and Schedule Status

The EGS program held its critical design review in December 2015. Technical issues with the Vehicle Assembly Building (VAB), Mobile Launcher, verification and validation testing, the Ground Flight Application Software (GFAS), and the Spaceport Command and Control System (SCCS) have increased schedule risk.

Design and Schedule

Prior to the EGS program's critical design review, NASA indicated that all major EGS sub-systems were mature, with the exception of two software systems known as SCCS and GFAS, which have experienced development delays. The EGS program is concerned that delays in SCCS software development could affect the launch date for the first uncrewed exploration mission. The program is developing two software systems concurrently—the SCCS to operate and monitor ground equipment needed to launch and communicate with the integrated SLS and Orion vehicles, and GFAS to interface with flight systems and ground crews. SCCS development is behind its planned software release schedule. Program officials attributed the delays to workforce constraints and requirements maturing late. According to officials, the program has hired additional staff for SCCS and will be adding staff to GFAS in 2016 to help resolve this issue. In addition, the program is tracking a risk that development of GFAS could be delayed and costs could increase because it is dependent in part on SCCS development progress. GFAS must function within an operating structure defined by SCCS. Program officials expect the added workforce and, for GFAS, a schedule replan, to reduce the risk to both software programs.

Construction and safety issues associated with modifications to the VAB—the Apollo-era building where all parts of SLS will be assembled together—are also a top program risk. For example, according to EGS officials, the program has experienced challenges with the construction of new platforms in the VAB to accommodate SLS because the design of the platforms had to be modified to resolve issues discovered during hardware testing. Further, parts of the VAB do not meet national fire safety standards. Program officials said they are addressing the compliance issues in accordance with agency policy and procedures. The program estimates that if the platform design challenges continue, they may delay the completion of the VAB and result in a cost increase.

Other Issues to Be Monitored

The EGS program is also tracking multiple risks related to the interdependencies between the Orion, SLS, and EGS programs. NASA is developing the three programs separately, but plans for them to function together in order to launch SLS and Orion. While the program has made progress on the major equipment and facilities modernization initiatives, EGS officials said ongoing issues may affect the design and installation of systems that interact directly with the Orion and SLS vehicles. For example, recent modeling showed that the connection that supplies power, fuel, and cooling connectivity between the SLS upper stage and the mobile launcher may apply more force than anticipated while moving away from the upper stage during launch. As a result, the EGS program is redesigning the connection. The mobile launcher is currently driving the project's overall schedule, so any issues it encounters have the potential to affect the program's ability to meet its November 2018 launch readiness date.

Project Office Comments

In commenting on a draft of this assessment, EGS program officials emphasized that the program is holding sufficient schedule reserve to cover potential GFAS and VAB delays. They also stated that multiple integrated technical task teams and programmatic working groups exist to facilitate integration among SLS, Orion, EGS, and the enterprise. The program officials also provided technical comments, which were incorporated as appropriate.

Gravity Recovery and Climate Experiment Follow-On

Project Challenges
- Development partner

PROJECT ESSENTIALS

NASA Center Lead:
Jet Propulsion Laboratory

Partner: **German Research Centre for Geosciences (Germany)**

Launch Location: **Yasny, Russia**
Launch Vehicle: **Dnepr**

Mission Duration: **5 years**

Requirement derived from:
NASA 2010 Climate Plan

NASA 2014 Strategic Plan Alignment: **Strategic Objective 2.2 Understand our home planet**

CONTRACT INFORMATION

Current highest value contract

Contractor: **Airbus Defence and Space**

Contractor Activity: **Satellite buses**

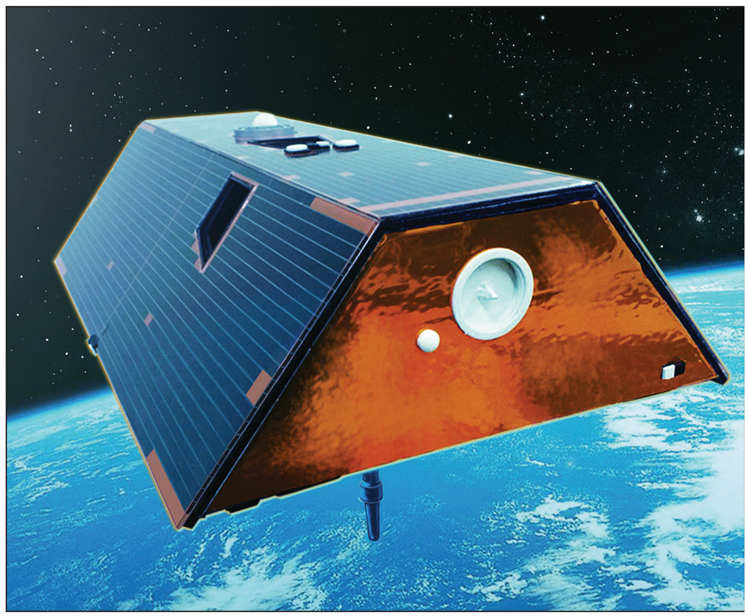
Type of Contract: **Firm-Fixed-Price**
Date of Award: **January 2012**
Initial Value of Contract: **$118.4 million**
Current Value: **$124.3 million**

PROJECT PERFORMANCE

Then year dollars in millions

	Baseline FY 2014	Latest Est. Feb 2016	Change
Total Project Cost	$431.9	$431.9	0.0%
Formulation Cost	$107.4	$107.4	0.0%
Development Cost	$264.0	$263.4	-0.2%
Operations Cost	$60.5	$61.1	1.0%
Launch Schedule	02 2018	02 2018	0 months

The Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) will continue and expand upon the 2002 GRACE mission, which remains in operation. It will provide high-resolution models of Earth's gravity field and insight into water movement on and beneath the Earth's surface over a 5-year period. These models will provide rates of ground water depletion and polar ice melt and enable improved planning for droughts and floods. The system operates as an observatory with instruments working concurrently within its two spacecraft. GRACE-FO is a collaborative effort with the German Research Centre for Geosciences (GFZ).



Source: NASA/JPL Caltech. | GAO-16-309SP

PROJECT SUMMARY

The GRACE-FO project successfully completed its critical design review and system integration review in 2015 and remains on track to launch 6 months early in August 2017. The project completed its critical design review with a mature design, which was largely based on heritage technology used in GRACE. The project continues to track risks related to its Russian launch vehicle and launch site. It is working with GFZ to develop alternative launch service options in the event that political or other risks affect the availability of the Dnepr launch vehicle. The project is also tracking a health risk for staff at its new launch site in Yasny, Russia, which is near an asbestos mine. The launch site changed from its original site in Kazakhstan to Yasny for technical reasons. The project will have to manage potential staffing challenges, since some personnel are not willing to travel to the new site.

02/18 Committed launch readiness date

08/17 Manifested launch readiness date

12/15 GAO review

Implementation

07/15 System Integration review

02/15 Critical design review

02/14 Project confirmation

Formulation

01/14 Preliminary design review

07/12 Mission/ system definition review

01/12 Formulation start

Gravity Recovery and Climate Experiment Follow-On

Cost and Schedule Status

The GRACE-FO project successfully completed its critical design review and system integration review in 2015. The project began assembly, test, and launch operations in August 2015, and remains on track to launch 6 months early in August 2017. The project continues to hold cost and schedule reserves consistent with the amount required by NASA center and Jet Propulsion Laboratory policy.

Technology and Design

The GRACE-FO project completed its critical design review in February 2015 with a mature design, which can help reduce risk in subsequent phases of a project. The design of GRACE-FO is largely based on the original GRACE spacecraft and uses updated heritage technology. Utilizing heritage technologies and designs on projects can help to reduce risk and control costs when they are used for similar purposes in similar environments. The project does not have any new critical technologies, but it will include a Laser Ranging Interferometer instrument, which is expected to measure the range between the two spacecraft with more precision than the heritage technology, as a technology demonstration. The flight models of this instrument were delivered in September 2015 for test and integration in Germany.

Development Partner

The GRACE-FO project continues to track risks related to its Russian launch vehicle and launch site. The project office is working with GFZ to mitigate potential risks associated with its launch vehicle, Dnepr, which is contributed by GFZ. NASA and GFZ are developing alternative launch service options in the event that political or other risks affect the availability of the launch vehicle. The launch vehicle is manufactured by Kosmotras, a Russian firm, in conjunction with the Ukrainian firm Yuzhnoye. According to the project office, the firms' working relationship has not been affected by the unrest between the two countries.

The GRACE-FO project office is also tracking potential health risks and staffing challenges associated with its new launch site in Yasny, Russia. The Yasny launch site is a few miles from an active, open-air asbestos mine. GRACE-FO was originally supposed to launch from the Baikonur Cosmodrome in Kazakhstan. However, due to technical reasons, the project's launch site was changed to Yasny in February 2015. Although staff exposure to asbestos at the site is expected to be minimal, the project plans to test asbestos levels at the site and limit staff exposure time in the lead up to launch. The project will also have to manage potential staffing challenges, since some personnel are not willing to travel to the new site.

Delays in receiving clearances from the Russian Ministry of Defense for the project to access the Yasny launch site are affecting the project's schedule for several launch-related milestones, including asbestos testing and the launch vehicle's critical design review, which was originally planned for June 2015. The project did not receive the clearances in October 2015 as expected and these milestones will be completed at least 7 months later than planned.

Project Office Comments

In commenting on a draft of this assessment, GRACE-FO project officials noted that the project continues to have excellent coordination among participants with a focus on risk mitigation and is working to resolve issues related to the delays in obtaining launch site clearances. The project continues to have a close partnership with GFZ for the launch service, mission, and ground operations planning activities, and the development of the German elements of the Laser Ranging Interferometer. Project officials also stated that the spacecraft and instruments are proceeding well with minimal risk. All NASA instrument components have been delivered to Germany in preparation for spacecraft integration and the remaining flight instrument components are expected to be delivered in January 2016. Project officials also provided technical comments, which were incorporated as appropriate.

Ice, Cloud, and Land Elevation Satellite-2

Project Challenges
- Technology
- Schedule

Previously Reported Challenges
- Parts
- Design
- Funding
- Launch
- Workforce

PROJECT ESSENTIALS

NASA Center Lead:
Goddard Space Flight Center

Partner: **None**

Launch Location: **Vandenberg AFB, CA**
Launch Vehicle: **Delta II**

Mission Duration: **3 years**

Requirement derived from:
2007 Earth Science Decadal Survey

NASA 2014 Strategic Plan Alignment:
Strategic Objective 2.2 Understand our home planet

CONTRACT INFORMATION

Current highest value contract

Contractor: **Orbital Sciences Corp.**

Contractor Activity: **Spacecraft development**

Type of Contract: **Firm-Fixed-Price**
Date of Award: **September 2011**
Initial Value of Contract: **$135.1 million**
Current Value: **$177.1 million**

PROJECT PERFORMANCE

Then year dollars in millions

Total Project Cost
$860.3
$1,063.6
23.6% CHANGE

Formulation Cost
$248.8
$249.1
0.1% CHANGE

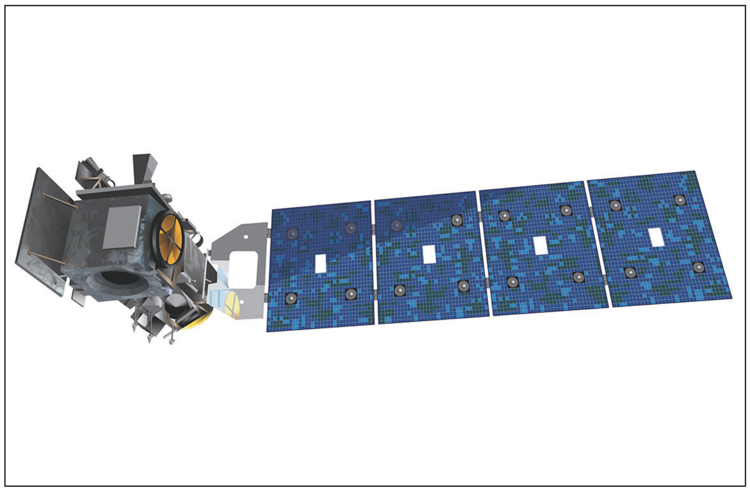
Development Cost
$558.9
$763.7
36.6% CHANGE

Operations Cost
$52.6
$50.8
-3.4% CHANGE

Launch Schedule
05 2017 — 06 2018
13 months CHANGE

Baseline FY 2013 | Latest Est. Feb 2016

NASA's Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2) is a follow-on mission to ICESat designed to measure changes in polar ice-sheet mass and elevation. These measurements will provide a better understanding of the mechanisms that drive these changes and their associated effect on global sea level. ICESat-2 will use a pulsing multi-beam laser instrument to take measurements. The instrument will also have a high-pulse repetition rate, which allows the satellite to make more frequent measurements and provide better elevation estimates than ICESat over high slope and rough areas.



Source: Orbital Sciences Corporation. | GAO-16-309SP

PROJECT SUMMARY

The ICESat-2 project plans to begin system-level integration and testing in November 2016, but continues to face schedule risks related to its only instrument, the Advanced Topographic Laser Altimeter System (ATLAS). Since its May 2014 rebaseline, the project has used 5 of its 10 months of schedule reserve to address ATLAS technical challenges and late component deliveries. The project is tracking several risks that could result in the use of additional reserves. For example, an ATLAS flight laser and mirrors in the telescope alignment monitoring system might need to be replaced with spares, which could result in additional ATLAS schedule delays. The ICESat-2 project completed its spacecraft segment in February 2015 and is conducting risk reduction activities while it waits to be integrated with ATLAS.

Implementation
- **06/18** Committed launch readiness date
- **10/17** Manifested launch readiness date
- **10/16** System integration review
- **12/15** GAO review
- **05/14** Project rebaseline
- **02/14** Critical design review

Formulation
- **12/12** Project confirmation
- **10/12** Preliminary design review
- **05/11** Mission/system definition review
- **12/09** Formulation start

Ice, Cloud, and Land Elevation Satellite-2

Cost and Schedule Status

The ICESat-2 project plans to begin system-level integration and testing in November 2016, but continues to face schedule risks related to its only instrument, ATLAS. The project was re-baselined in May 2014. Since the rebaseline, the project used 5 of its 10 months of schedule reserve to address ATLAS technical challenges and late component deliveries. The project's rate of using schedule reserves decreased in 2015 and it continues to hold cost and schedule reserves consistent with the amount required by NASA center policy.

Technology and Schedule

The ICESat-2 project achieved several important milestones with the ATLAS instrument in 2015, but continuing technical issues pose a schedule risk for the project. In July 2015, the project integrated and aligned the instrument's two lasers and test fired them for the first time. Project officials said integrating the lasers was especially difficult because they have to perfectly align with the receiver to collect science data. All of the major ATLAS subsystems were also delivered for integration and testing, which is underway and scheduled to end in July 2016.

The ICESat-2 project has used 5 of the 8 months of schedule reserve specifically held for ATLAS and is tracking risks that could consume the rest. If those risks materialize, system-level integration and testing could be delayed. In the last year, the project used 1 month of schedule reserve to address ATLAS technical issues during integration and test. Our prior work shows that it is during integration and test where problems are commonly found and schedules tend to slip. The project is tracking multiple risks that could result in the use of additional schedule reserves. For example, there is a risk that a crystal in the each of ATLAS's two lasers may become de-bonded from its mount, which would result in loss of laser function. If the project determines that the flight lasers are unacceptable to fly, it plans to replace one of them with a spare laser, which is currently being built. ICESat-2 only needs one laser for mission success. Replacing one of the lasers could result in a 2-month delay to ATLAS delivery. The project may also have to replace mirrors in the telescope alignment monitoring system because their coatings failed a damage resistance test. Replacing these mirrors with spares that have passed this test could result in a 1-month delay in the ATLAS integration and test schedule. In addition to those risks, the project is concerned that it may experience additional schedule delays if it identifies problems during its 5.5-month long ATLAS environmental testing. This testing is scheduled to begin in February 2016 and must be successfully completed before the instrument's delivery for system-level integration and testing in November 2016. According to project officials, this environmental testing is sequential in nature and cannot be compressed. Consequently, the project will not be able to address problems by adjusting interim milestones in this test period.

The project has worked ahead in other areas to reduce its overall schedule risk. After the spacecraft segment was completed in February 2015, the project began conducting risk reduction activities with it while it waits to be integrated with ATLAS. For example, the project addressed an interference problem found in the spacecraft's solar array. The project also began conducting mission operations risk reduction testing using the spacecraft in October 2015.

Project Office Comments

In commenting on a draft of this assessment, ICESat-2 project officials noted the major ATLAS schedule risks identified in the assessment continue to be mitigated by the ATLAS team. The project plans to make a decision on whether it will replace one of the flight lasers due to crystal de-bonding risk in spring 2016. Project officials also reported that they plan to use up to 1 month of schedule reserves to replace mirrors in the telescope alignment monitoring system in January 2016, which will delay the start of ATLAS environmental testing. They said the project continues to work with the contractor responsible for system-level integration and testing to identify opportunities to recover schedule if ATLAS is delivered later than planned. Project officials also provided technical comments, which were incorporated as appropriate.

Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport

Project Challenges
- Technology
- Development partner (new)
- Funding

PROJECT ESSENTIALS

NASA Center Lead:
Jet Propulsion Laboratory

Partners: **Centre National d'Etudes Spatiales (France) and German Aerospace Center (Germany)**

Launch Location: **Vandenberg AFB, CA**
Launch Vehicle: **Atlas V**

Mission Duration: **29 months**

Requirement derived from:
2010 Decadal Survey

NASA 2014 Strategic Plan Alignment:
Strategic Objective 1.5 Understand the solar system

CONTRACT INFORMATION

Current highest value contract

Contractor: **Lockheed Martin Corporation**

Contractor Activity: **Spacecraft development**

Type of Contract: **Cost-Plus-Fixed-Fee/ Award-Fee**
Date of Award: **October 2012**
Initial Value of Contract: **$199.2 million**
Current Value: **$226.2 million**

PROJECT PERFORMANCE

Then year dollars in millions

Total Project Cost
$675.1
~~$675.1~~
~~0.0%~~ CHANGE

Formulation Cost
$98.9
~~$98.9~~
~~0.0%~~ CHANGE

Development Cost
$541.8
~~$541.8~~
~~0.0%~~ CHANGE

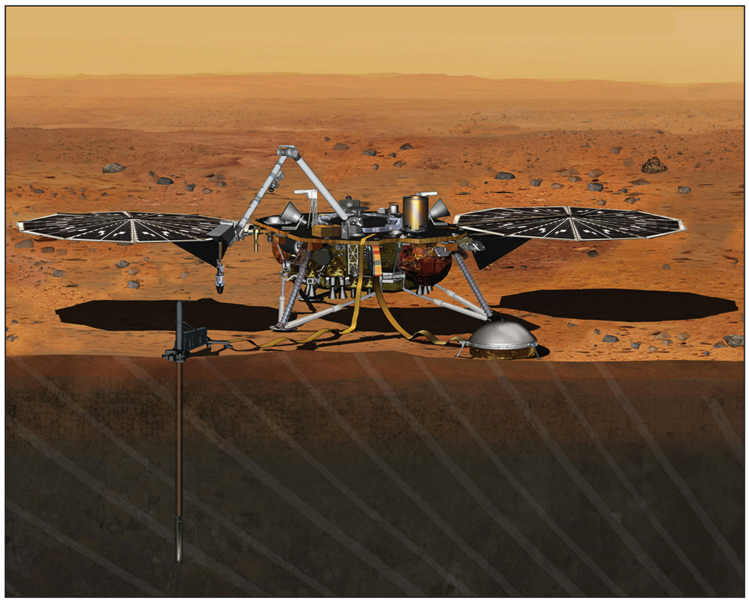
Operations Cost
$34.4
~~$34.4~~
~~0.0%~~ CHANGE

Launch Schedule[a]
03 2016 ~~03 2016~~
~~0 months~~ CHANGE

Baseline FY 2014
Latest Est.[a] Feb 2016

[a]*The project is being reviewed, and final cost and schedule information is not available.*

The Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport (InSight) is a Mars lander with two primary objectives. It is intended to further understanding of the formation and evolution of terrestrial planets by determining Mars's size, its composition, and the physical state of the core; the thickness of the crust; and the composition and structure of the mantle, as well as the thermal state of the interior. It will also determine the present level of tectonic activity and the meteorite impact rate on Mars. InSight is based on the Phoenix lander design. Phoenix successfully landed on Mars in 2008.



Source: © California Institute of Technology. | GAO-16-309SP

PROJECT SUMMARY

The InSight project will not launch in March 2016 as planned due to technical issues with the Seismic Experiment for Interior Structure (SEIS) instrument, which is critical to achieving the project's science objectives. The project will not meet its committed launch date and must wait 26 months before another planetary launch opportunity is available. The instrument, which was already 11 months behind schedule and was rapidly consuming the project's remaining schedule margin, experienced numerous vacuum seal leaks in its sphere enclosure during instrument-level testing and efforts to repair it were unsuccessful. In December 2015, NASA managers decided to suspend the March 2016 launch, citing insufficient time to resolve the leak and complete testing required to ensure a successful mission. NASA is currently assessing the effects of the launch delay and the project's options going forward.

03/16 Launch readiness date (under review)
03/16 Committed launch readiness date
12/15 GAO review
02/15 System integration review
Implementation
05/14 Critical design review
03/14 Project confirmation
10/13 Preliminary design review
Formulation
07/12 Formulation start

Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport

Cost and Schedule Status

NASA will not launch InSight in March 2016 as planned due to technical issues with the Seismic Experiment for Interior Structure (SEIS) instrument. The project will not meet its committed launch date and must wait 26 months before another launch opportunity is available. NASA is currently assessing the effect of the SEIS issues and launch delays and whether or not to continue the project. If the project is not terminated, the launch delay will likely result in an increase in project costs.

Technology and Development Partner

In December 2015, NASA canceled its planned March 2016 InSight launch because of recurring problems with the SEIS, its primary payload science instrument. SEIS, a seismometer contributed by the French Space Agency, the Centre National d'Etudes Spatiales (CNES), is critical for meeting three of the project's six top level mission requirements, and contributes to the other three. SEIS experienced numerous vacuum seal leaks in its sphere enclosure during instrument-level testing. The instrument, which was already 11 months behind schedule and was rapidly consuming the project's remaining schedule margin, requires a vacuum seal around its three main sensors in order to make accurate seismic measurements on Mars. In December 2015, the project made a targeted repair to the sphere, but in subsequent testing in extreme cold temperatures designed to replicate the Martian environment, SEIS again failed to hold a vacuum. NASA managers decided to suspend the March 2016 launch, citing insufficient time to resolve the leak and complete testing required to ensure a successful mission. The next available launch window is 26 months from the original planned launch date. A CNES official stated that CNES is working to address SEIS sphere problems. The InSight spacecraft, which was delivered to the launch site in mid-December 2015, will be returned to the contractor for storage while NASA decides the future of the project.

Funding

Prior to the launch delay, InSight project's cost estimates for the operations phase had increased and the project will need to use cost reserves to cover the associated costs. NASA officials stated that estimated operations cost have grown as the project has gained a better understanding of what it will take to safely deploy InSight's instruments on the ground with less risk. Project officials stated that they lacked a good understanding of the post-launch resources needed for deployment earlier in the project's life cycle. The project expects to use a combination of NASA headquarters-held cost reserves and the remaining project-held cost reserves to cover these additional costs.

Project Office Comments

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

Ionospheric Connection

Project Challenges
- Technology
- Contractor

PROJECT ESSENTIALS

NASA Center Lead:
Goddard Space Flight Center

Partner: **University of California, Berkeley**

Launch Location:
Kwajalein (Marshall Islands)
Launch Vehicle: **Pegasus**

Mission Duration: **2 years**

Requirement derived from:
2013-2022 Decadal Survey; Heliophysics Division 2009 Roadmap

NASA 2014 Strategic Plan Alignment:
Strategic Objective 1.4 Understand the Sun

CONTRACT INFORMATION

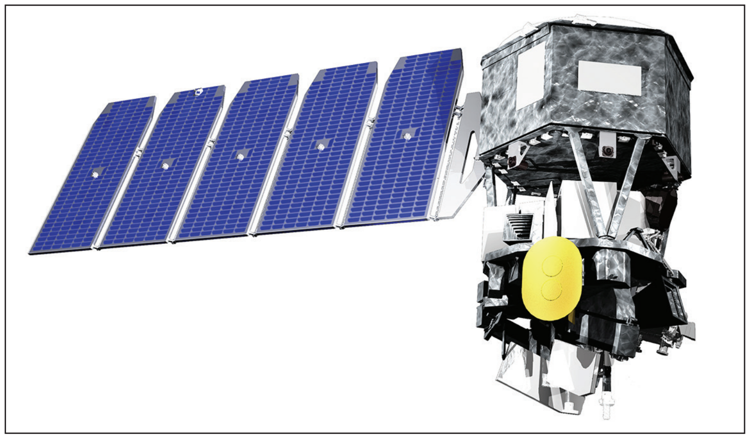
Current highest value contract

Contractor: **University of California, Berkeley**

Contractor Activity: **Project management, mission systems engineering, and mission operations**

Type of Contract: **Cost-No-Fee**
Date of Award: **January 2012**
Initial Value of Contract: **$138.5 million**
Current Value: **$139.1 million**

The Ionospheric Connection (ICON) observatory will orbit Earth to explore its ionosphere—the boundary region between Earth and space where ionized plasma and neutral gas collide and react. Its four instruments will provide a combination of direct measurements and remote sensing to further understanding of Earth's upper atmosphere, the Earth-Sun connection, and the ways in which Earth weather drives space weather.



Source: © University of California, Berkeley. | GAO-16-309SP

- **10/17** Committed launch readiness date
- **06/17** Targeted launch readiness date
- **06/16** System integration review
- **12/15 GAO review**
- **04/15** Critical design review
- Implementation
- **10/14** Project confirmation
- **07/14** Preliminary design review
- **01/14** Mission/system definition review
- Formulation
- **09/11** Formulation start

PROJECT PERFORMANCE

Then year dollars in millions

Total Project Cost
$252.7
$252.7
0.0% CHANGE

Formulation Cost
$42.4
$42.4
0.0% CHANGE

Development Cost
$196.0
$195.8
-0.1% CHANGE

Operations Cost
$14.3
$14.5
1.4% CHANGE

Launch Schedule
10 2017 10 2017
0 months CHANGE

Baseline FY 2015 | Latest Est. Feb 2016

PROJECT SUMMARY

The ICON project held a successful critical design review in April 2015 with a mature design, and project data indicates it has performed well against its cost and schedule baselines. The project expects a number of schedule delays related to the production and delivery of three of its four payload instruments, but these delays are not expected to negatively affect the project's overall schedule. All four instruments are scheduled to be delivered by February 2016 for payload integration and testing.

Ionospheric Connection

Cost and Schedule Status

The ICON project held a successful critical design review in April 2015 with a mature design and the project plans to complete payload and spacecraft integration and testing by its planned systems integration review in June 2016. The project is currently holding cost and schedule reserves at the amount required by NASA center policy. During ICON's confirmation review in October 2014, the project's targeted launch readiness date was set for June 2017—4 months later than previously anticipated. The new launch readiness date was set, in part, to allow the project to add instrument hardware to improve the reliability of scientific measurements, and to increase the overlap with other similar NASA missions to optimize data collection. Project officials stated that the added 4 months will also provide more time to address technical risks.

Technology

The ICON project has experienced several technical issues that could delay spacecraft and payload integration and testing, but have not negatively affected the project's overall schedule. For example, one of ICON's contractors reported component failures and production problems that delayed testing of the integration master avionics unit, which is the spacecraft's electronics control system. The unit was delivered for integration with the spacecraft in November 2015. Additionally, technical problems with the Far Ultraviolet (FUV) instrument have delayed its delivery to payload integration and testing by 2 months to February 2016. As a result, the FUV is now driving the project's schedule. The project lost 3 weeks of schedule margin due to problems with the equipment that supports FUV calibration. The FUV flight detector, which is part of the instrument's flight cameras, also experienced a high voltage discharge during testing which is expected to further contribute to delays. The project plans to change the sequence of tasks performed during payload integration and testing to minimize the use of schedule reserve due to the late FUV delivery.

Contractor

The ICON project experienced a schedule delay in 2015 with what project officials described as its most complex instrument, the Michelson Interferometer for Global High-Resolution Thermospheric Imaging (MIGHTI). The delay was due to a change in the subcontractor providing engineering support to the Naval Research Laboratory, which is responsible for developing MIGHTI. After the change, it took 2 to 3 weeks to transition key MIGHTI support personnel to the new subcontract. Project officials stated that they are working to recover lost schedule reserves by developing a fully integrated MIGHTI test model that will go through qualification testing. Project officials anticipate that this testing will help them discover problems early and reduce risk later in development. MIGHTI is scheduled to be delivered to payload integration and testing by late January 2016.

Project Office Comments

In commenting on a draft of this assessment, ICON project officials said the project continues to progress toward system integration. All instruments are in the final stages of environmental testing and on schedule to be delivered in February 2016; spacecraft hardware is on schedule to be delivered after completion of component level environmental testing; and ground segment equipment needed to test the spacecraft has been delivered and integrated at the contractor's facility. Project officials also reported that there are no known technical risks at this time for the spacecraft, payload, or ground segment components and that it has sufficient margins to achieve its planned launch date. Project officials also provided technical comments, which were incorporated as appropriate.

James Webb Space Telescope

Project Challenges

- Schedule
- Design
- Manufacturing
- Contractor (new)

Previously Reported Challenges

- Technology
- Test and integration
- Funding

PROJECT ESSENTIALS

NASA Center Lead:
Goddard Space Flight Center

Partners: **European Space Agency, Canadian Space Agency (Canada)**

Launch Location: **Kourou, French Guiana**
Launch Vehicle: **Ariane 5**

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

Requirement derived from:
2001 Astrophysics Decadal Survey

NASA 2014 Strategic Plan Alignment:
Strategic Objective 1.6 Search for life and understand the universe

CONTRACT INFORMATION

Current highest value contract

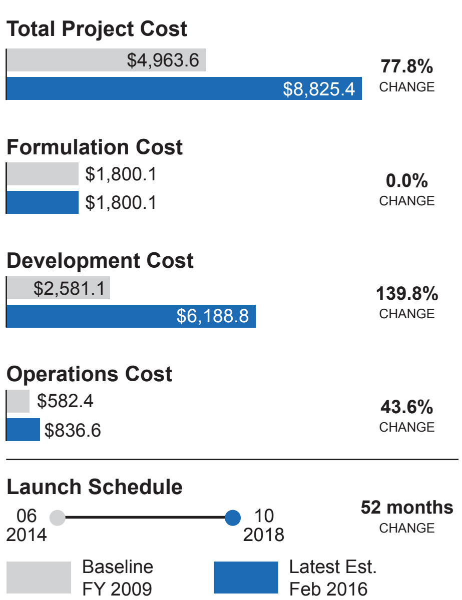
Contractor: **Northrop Grumman Aerospace Systems**

Contractor Activity: **Spacecraft development and other components**

Type of Contract: **Cost-Plus-Award-Fee/Incentive-Fee**
Date of Award: **2002**
Initial Value of Contract: **$824.6 million**
Current Value: **$3,598.0 million**

PROJECT PERFORMANCE

Then year dollars in millions



The James Webb Space Telescope (JWST) is a large, infrared-optimized space telescope designed to help understand the origin and destiny of the universe, the creation and evolution of the first stars and galaxies, and the formation of stars and planetary systems. It will also help further the search for Earth-like planets. JWST will have a large primary mirror composed of 18 smaller mirrors and a sunshield the size of a tennis court. Both the mirror and sunshield are folded for launch and open once JWST is in space. JWST will reside in an orbit about 1 million miles from the Earth.

Source: NASA. | GAO-16-309SP

PROJECT SUMMARY

The JWST project continues to meet its cost and schedule commitments, but technical challenges have reduced overall project schedule reserves. The project is still holding schedule reserves above the project's plan and NASA center requirements, but it must complete five major integration and test events, three of which have not yet begun. Integration and test is when problems are often identified and schedules tend to slip. In addition, all JWST elements and major subsystems remain within weeks of driving the project's overall schedule. As a result, the use of additional reserve on any element or major subsystem may further reduce the overall project schedule reserve and require the project to prioritize mitigating some issues over others. The cryocooler—a driver of cost and schedule issues for the project—was delivered by the responsible subcontractor in July 2015—approximately 18 months later than planned. It remains a schedule risk as it begins testing.

James Webb Space Telescope

Cost and Schedule Status

The JWST project continues to operate within its 2011 cost and schedule baseline. As of December 2015, the project held almost 9 months of schedule reserve, which is above the project's plan and NASA center requirements.

Schedule

The JWST project is currently on schedule, but in December 2015, we found that the project continues to face schedule risks.[a] Before launch, the project must complete five major integration and test events, three of which have not yet begun. Integration and test is when problems are often identified and schedules tend to slip. In addition, all JWST elements and major subsystems remain within weeks of becoming the critical path, which drives the project's overall schedule. As a result, the use of additional reserve on any element or major subsystem may reduce the overall project schedule reserve and require the project to prioritize mitigating some issues over others.

Design and Manufacturing

The project consumed about 2 months of schedule reserve in 2015 addressing design and manufacturing issues. For example, the instrument suite's heat straps—flexible straps that conduct energy and heat away from the instruments—did not perform as expected in testing and had to be redesigned and reinstalled. In addition, the majority of the 76 cryogenic harnesses that connect to mirrors on the Optical Telescope Element were damaged because the supplier used inappropriate tooling and required repairs or replacement. The sunshield also experienced various manufacturing problems, such as damage to a section of the multi-segmented mid-boom assembly, and the project will need to use additional schedule reserves to remanufacture the damaged piece. Finally, the cryocooler experienced technical challenges that used schedule reserve and delayed its delivery. The cryocooler was delivered by the responsible subcontractor in July 2015—approximately 18 months later than planned—and it remains a schedule risk as it begins testing.

Contractor

In December 2015, we reported that the primary threat to JWST meeting its long-term cost commitment was the prime contractor. For the past 20 months, Northrop Grumman's actual workforce exceeded its projections. The prime contractor needed a larger workforce than planned due to unexpected technical issues—primarily related to the spacecraft and sunshield development—and additional work requested by NASA.

Other Issues to Be Monitored

The JWST project continues to meet its cost commitments, but unreliable contractor performance data may pose a risk to project management. To help manage the project and account for new risks, project officials conducted a cost risk analysis of the prime contractor in 2014. A cost risk analysis uses information about cost drivers, technical risks, and schedule to determine the reliability of a program's cost estimate. In December 2015, we found the analysis substantially met best practices, but officials do not plan to periodically update it. Instead, the project is using a risk-adjusted analysis to update and inform its cost position, but this analysis is based on contractor-provided performance data that contained anomalies that render the data unreliable. NASA agreed with our recommendation to improve the reliability of this data by requiring contractors to identify, explain, and document all anomalies.

Project Office Comments

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

[a]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).

Mars 2020

Project Challenges
- Technology maturity (new)
- Design

Previously Reported Challenges
- Funding

PROJECT ESSENTIALS

NASA Center Lead:
Jet Propulsion Laboratory

Partners: **NASA Human Exploration and Operations Mission Directorate, NASA Space Technology Mission Directorate, U.S. Department of Energy, Centre National d'Etudes Spatiales (France), Centro de Astrobiología (Spain), Norwegian Defence Research Establishment (Norway)**

Launch Location: **Eastern Range, FL**
Launch Vehicle: **TBD**

Mission Duration: **2 years**

Requirement derived from:
2011 National Research Council Decadal Survey and Mars Program

NASA 2014 Strategic Plan Alignment:
Strategic Objective 1.5 Understand the solar system

CONTRACT INFORMATION

Current highest value contract

Contractor: **Aerojet Rocketdyne**

Contractor Activity: **Mars Lander Engines**

Type of Contract: **Cost-Plus-Fixed-Fee**
Date of Award: **October 2013**
Initial Value of Contract: **$7.5 million**
Current Value: **$7.7 million**

PROJECT PERFORMANCE

Then year dollars

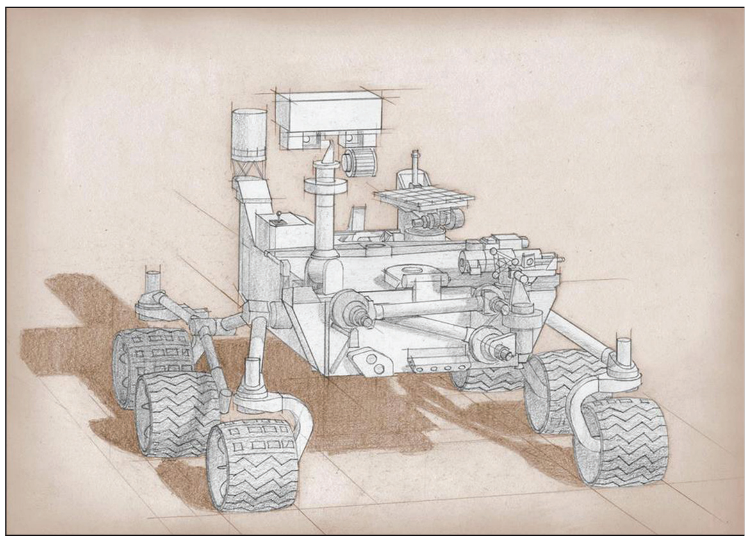
Preliminary Estimate of Project Life Cycle Cost*:

Latest: **February 2016** **$2.168 – $2.351 BILLION**

**This estimate is preliminary, as the project is in formulation and there is uncertainty regarding the costs associated with the design options being explored. NASA uses these estimates for planning purposes.*

Launch Schedule: **July 2020**

Mars 2020 is part of the Mars Exploration program, which seeks to further understand whether Mars was, is, or can be a habitable planet. Its rover and science instruments will systematically explore Mars by conducting geological assessments, searching for signs of ancient life, determining potential environmental habitability, and preparing well-documented soil or rock samples for potential future return to Earth. The rover may also include a technology demonstration instrument designed to convert carbon dioxide into oxygen. Mars 2020 will be based heavily on architecture of the Mars Science Laboratory (MSL), or Curiosity, which landed on Mars in 2012 and remains in operation.



Source: NASA/JPL Caltech. | GAO-16-309SP

PROJECT SUMMARY

The Mars 2020 project delayed its preliminary design review by 2 months to February 2016 to allow the project more time to develop some of its new instruments. The project's confirmation review, or Key Decision Point C, was also delayed. In preparation for the preliminary design review, the project continued to mature its seven critical technologies, but at the time of our review, several had not yet reached the level of maturity recommended by best practices for preliminary design. The project has also identified several design and mass-related issues that pose cost and schedule risks for the project. For example, the overall mass of the rover could exceed the MSL design, rover wheel redesigns to improve performance could add mass, and design changes to the spacecraft might be needed to integrate terrain relative navigation (TRN) technology, which could help ensure a successful landing near science targets.

Implementation
- **07/20** Projected launch readiness date
- **11/17** System integration review
- **11/16** Critical design review
- **03/16** Project confirmation
- **02/16** Preliminary design review
- **12/15** GAO review

Formulation
- **10/14** System requirements/ mission definition review
- **11/13** Formulation start

Mars 2020

Cost and Schedule Status

The Mars 2020 project delayed its preliminary design review by 2 months to February 2016, in part to allow for more time to develop of some of its new instruments. The project also delayed its project confirmation, or Key Decision Point C, by 3 months to March 2016, at which point it will establish its cost and schedule baselines. Schedule is a key driver for Mars 2020. If the project misses its 2020 launch window, it must wait 26 months before another launch opportunity is available.

Technology Maturity

The Mars 2020 project is continuing to mature its seven critical technologies, but several have not yet reached the level of maturity—technology readiness level 6—recommended for preliminary design. Maturing critical technologies to this level is a best practice, which helps minimize risks for space systems entering product development. Of the project's seven critical technologies, the least mature is part of a technology demonstration instrument that is designed to convert carbon dioxide to oxygen. If the instrument does not work as intended, it can be removed from the project because it is not needed to achieve any of the primary science objectives.

Design

The Mars 2020 project has identified several design and mass-related issues that pose cost and schedule risks for the project. The project is tracking a risk that increases to the combined mass of the rover, payload, and sampling system could exceed the project's mass allocations and loads capability. A project official said the project has partly mitigated the risk by determining that it could increase its landing mass and permit up to 70 kilograms beyond the MSL rover's 980 kilogram mass. However, new risks continue to emerge. For example, the project is monitoring the mass and volume of the turret for the rover's robotic arm. The design of the turret is important because it affects the functionality of two instruments and parts of the sampling and caching system that will take samples of the Martian surface. Due to the turret's location, it also affects the balance and mobility of the rover. Mass growth in any of the turret's components has the potential to impact the robotic arm design and increase overall rover mass, necessitating further redesign. In addition, the project is tracking a risk that the rover's sampling and caching system may be late to assembly and testing. For example, the project noted that increases in the mass or volume of subcomponents could lead to hardware redesigns and development delays. The project plans to continue tracking this risk until after its critical design review, planned for November 2016.

The project is also considering design changes that could result in mass increases. For example, the project is considering a redesign of the Mars 2020 rover wheels to prevent similar damage to MSL's wheels caused by sharp rocks on the Martian terrain. We reported in 2015 that because the project is based heavily on the MSL design, any changes to the existing design could affect the project's ability to control cost and schedule. The wheel redesign would also likely introduce additional mass and complicate the project's overall rover mass concerns.

Further, the project might need to make design changes to the spacecraft to integrate terrain relative navigation (TRN) technology, which would better ensure a successful landing near science targets. The project held a landing site workshop in August 2015, and subsequently announced that access to most of the top eight sites requires TRN. Project officials estimated that it will cost $30 million to $50 million to integrate TRN technology into Mars 2020. The project anticipates making a final decision on TRN prior to project confirmation.

Project Office Comments

In commenting on a draft of this assessment, Mars 2020 project officials noted that the project plans to mature all of its critical technologies prior to the preliminary design review in February 2016. The project also continues to proceed with heritage builds, which have gone well to date, and reports that the wheel redesign should not negatively affect mass. The Mars Program has identified funding for TRN that would eliminate any need for additional project development funds should it be added to the mission. Project officials also provided technical comments, which were incorporated as appropriate.

NASA ISRO – Synthetic Aperture Radar

Project Challenges
- Technology maturity
- Design (new)
- Development partner

PROJECT ESSENTIALS

NASA Center Lead:
Jet Propulsion Laboratory

Partner: **Indian Space Research Organisation (India)**

Launch Location: **Satish Dhawan Space Centre, India**
Launch Vehicle: **Geosynchronous Satellite Launch Vehicle Mark II**

Mission Duration: **3 years**

Requirement derived from:
National Research Council Decadal Survey

NASA 2014 Strategic Plan Alignment: **Strategic Objective 2.2 Understand our home planet**

CONTRACT INFORMATION

Current highest value contract

Contractor: **Northrop Grumman Aerospace Systems**

Contractor Activity: **Radar antenna reflector development**

Type of Contract: **Cost-Plus-Fixed-Fee and Cost-Plus-Incentive-Fee**
Date of Award: **October 2015**
Initial Value of Contract: **$28.3 million**
Current Value: **$28.3 million**

PROJECT PERFORMANCE

Then year dollars

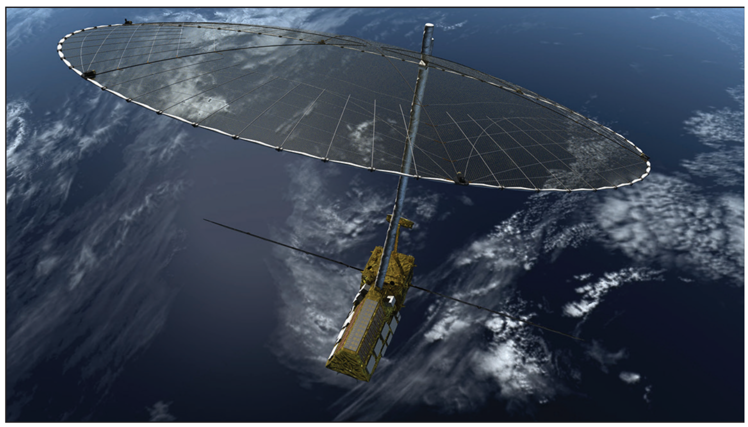
Preliminary Estimate of Project Life Cycle Cost*:

Latest: **February 2016** **$718 – $808** MILLION

This estimate is preliminary, as the project is in formulation and there is uncertainty regarding the costs associated with the design options being explored. NASA uses these estimates for planning purposes.

Launch Schedule: **December 2020**

The NASA Indian Space Research Organisation (ISRO) - Synthetic Aperture Radar (NISAR) is being designed to study the solid Earth, ice masses, and ecosystems and address questions such as what drives changes in ice masses and how this relates to Earth's climate, how the Earth's carbon cycle and ecosystem are changing and the implications of these changes, and how to mitigate the impact of natural hazards such as earthquakes and volcanoes. The project will include the world's first dual frequency synthetic aperture radar instrument, which will use advanced radar imaging to construct large-scale data sets of the earth's movements. NISAR represents the first major aerospace science partnership between NASA and ISRO.



Source: © 2014 California Institute of Technology/Jet Propulsion Laboratory. | GAO-16-309SP

PROJECT SUMMARY

The NISAR project continues to mature its critical technologies and expects to demonstrate they are at the level of maturity recommended by best practices by its preliminary design review, scheduled for June 2016. Maturing technologies to this level helps reduce risk for projects entering development. The project is currently not meeting its mass margin requirements, but expects to have a better mass estimate after it finalizes the selection of key hardware vendors. The project is also tracking risks related to its radar development, the differences in NASA and ISRO project management processes, and the viability of the ISRO-contributed launch vehicle. The project plans to hold its confirmation review, or Key Decision Point C, in September 2016—at which point the project will establish its cost and schedule baselines.

Implementation

- **12/20** Projected launch readiness date
- **02/19** System integration review
- **01/18** Critical design review
- **09/16** Project confirmation
- **06/16** Preliminary design review
- **12/15** GAO review

Formulation

- **12/14** Mission definition/ system requirements review
- **03/14** Formulation start

NASA ISRO – Synthetic Aperture Radar

Cost and Schedule Status

The NISAR project plans to hold its preliminary design review early in late June 2016 and its confirmation review, or Key Decision Point C, on schedule in September 2016—at which point the project will establish its cost and schedule baselines.

Technology Maturity

The NISAR project is continuing to mature its three critical technologies and, according to a project official, expects them to reach technology readiness level 6 by its planned June 2016 preliminary design review. Maturing critical technologies to this level is a best practice, which helps minimize risks for space systems entering product development. We reported in 2015 that the project spent several years and approximately $63 million prior to beginning the concept and technology development phase in order to mature the technology associated with the synthetic aperture radar and reduce associated risks.

One of the critical technologies currently being matured is the reflector boom. The boom assembly will be used to deploy a 12-meter radar reflector as part of the instrument antenna that will be used to transmit and receive radar signals from the L- and S-band radars. The reflector boom will be built in-house at the Jet Propulsion Laboratory based on lessons learned from the recently launched Soil Moisture Active and Passive (SMAP) project. SMAP encountered several design issues with its reflector boom assembly, which was built by a contractor. Project officials stated that the boom assembly will be developed concurrently with the Surface Water and Ocean Topography (SWOT) project to achieve cost savings. The requirements for the boom will be based on SWOT requirements since those are more stringent.

Design

The NISAR project does not meet NASA's mass margin requirements for its current phase of development, but expects to be in compliance by the preliminary design review. Officials stated that they expect to have a better mass estimate after the selection of key hardware vendors. The project also plans to complete instrument structure mass optimization efforts in December 2015. If needed, the project has contingencies available to reduce mass, such as eliminating system redundancies.

Development Partner

Because the NISAR project is the first major partnership between NASA and ISRO, the project is tracking a risk that differences in NASA and ISRO project management processes could negatively affect cost and schedule. The project is managing this risk by working with ISRO to understand process differences and expectations for deliverables. The project expects this issue to remain a cost and schedule risk until the system integration review in February 2019.

In addition, the project continues to monitor a risk regarding the reliability of the ISRO-contributed Geosynchronous Satellite Launch Vehicle (GSLV) Mark II because it has not yet met NASA-ISRO agreed-upon criteria for its use on NISAR. For example, the GSLV Mark II must have three successful launches prior to NISAR's planned launch date in 2020. According to project officials, the first GSLV Mark II launch was unsuccessful. However, as of September 2015, it has had two consecutive successful launches, with its most recent launch in August 2015 a success. If ISRO cannot achieve the agreed-upon criteria, the project could be delayed by 2 years and costs could grow by approximately $20 million to $30 million.

Project Office Comments

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

Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer

Project Challenges
- Technology (new)
- Development partner

PROJECT ESSENTIALS

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

Partner: **Canadian Space Agency (Canada)**

Launch Location: **Cape Canaveral AFS, FL**
Launch Vehicle: **Atlas V**

Mission Duration: **7 years**

Requirement derived from: **Vision and Voyages for Planetary Science in the Decade 2013-2022**

NASA 2014 Strategic Plan Alignment: **Strategic Objective 1.5 Understand the solar system**

CONTRACT INFORMATION

Current highest value contract

Contractor: **Lockheed Martin Space Systems Company**

Contractor Activity: **Spacecraft development**

Type of Contract: **Cost-Plus-Award-Fee**
Date of Award: **January 2012**
Initial Value of Contract: **$315.9 million**
Current Value: **$342.4 million**

PROJECT PERFORMANCE

Then year dollars in millions

Total Project Cost
$1,121.4
$1,057.2
-5.7% CHANGE

Formulation Cost
$144.3
$144.3
0.0% CHANGE

Development Cost
$778.6
$700.4
-10.0% CHANGE

Operations Cost
$198.5
$212.5
7.1% CHANGE

Launch Schedule
10 2016 10 2016
0 months CHANGE

Baseline FY 2013 | Latest Est. Feb 2016

The Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer (OSIRIS-REx) spacecraft will travel to a near-Earth asteroid and use a robotic arm to retrieve samples that could help explain our solar system's formation and how life began. The OSIRIS-REx mission has five science objectives: (1) return and analyze a sample from an asteroid, (2) document the sample site, (3) create maps of the asteroid, (4) measure forces on the asteroid's orbit that make it an impact threat to the Earth, and (5) compare the asteroid's characteristics with ground-based telescopic data of the entire asteroid population. If successful, OSIRIS-REx will be the first U.S. mission to return samples from an asteroid to Earth.

Source: NASA. | GAO-16-309SP

PROJECT SUMMARY

The OSIRIS-REx project expects to be ready to launch on schedule in September 2016 and complete development under its committed cost. As of December 2015, all of the project's payload instruments have been delivered for integration and testing, but technical challenges have delayed the delivery of a flight navigation system until April 2016. The project plans to ship the fully integrated and tested spacecraft to the launch site in May 2016. Because OSIRIS-REx has a 39-day planetary launch window that begins September 3, 2016, maintaining the project's schedule is especially important to meeting the planned launch date. The project has the required level of schedule margin for this stage of the project.

10/16 Committed launch readiness date
12/15 GAO review
02/15 System integration review
04/14 Critical design review
Implementation
05/13 Project confirmation
03/13 Preliminary design review
05/12 Mission/ system design review
Formulation
05/11 Formulation start

Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer

Cost and Schedule Status

The OSIRIS-REx project expects to be ready to launch on schedule in September 2016 and complete development under its committed cost. As of December 2015, all OSIRIS-REx payload instruments have been delivered for integration and testing. The project plans to ship the fully integrated and tested spacecraft to the Cape Canaveral launch site in May 2016. According to project officials, maintaining the project's schedule is important because OSIRIS-REx has a 39-day planetary launch window, which begins on September 3, 2016. If the project misses this window, it will have to wait a year for another launch opportunity. The project currently meets the required level of schedule margin for this stage of the project.

Technology

The OSIRIS-REx project has experienced technical challenges that have delayed the delivery of flight hardware and navigation systems, but it has been able use schedule reserves to prevent these delays from affecting the launch schedule. The project expects the spacecraft's guidance, navigation, and control light detection and ranging (GN&C LIDAR) instrument, which is critical to navigating the spacecraft around the target asteroid, to be delivered to integration and testing 14 months later than planned, due to a number of technical issues. For example, during system-level testing, the GN&C flight units experienced a leak in their laser enclosures, which led the project to implement an alternate design with a new vendor. The project expects the resealed GN&C LIDAR units to be delivered in April 2016. To avoid delaying spacecraft integration and testing, the project is using a mass model and a GN&C flight model without the repaired enclosure for spacecraft environmental testing. Project officials have determined the minimum level of GN&C LIDAR testing required in the event the test period must be shortened due to the late delivery. Project officials stated that the GN&C LIDAR will remain a source of technical and schedule risk even after it has been delivered to integration and testing. They said that GN&C LIDAR issues could increase project costs by as much as $1.8 million, but the project has cost reserves to address the issues, if needed. The project has developed a separate redundant system, called Natural Feature Tracking, to serve as a backup capability if the GN&C LIDAR does not successfully complete testing or fails during flight.

Development Partner

The OSIRIS-REx laser altimeter (OLA) instrument, a non-essential contribution from the Canadian Space Agency, was delivered 4 months behind schedule in late November 2015 and missed critical system-level testing, including mechanical testing. The project used a mass model for mechanical testing in order to reduce testing risks. OLA is a ranging instrument that will help create a high-resolution 3-dimensional model of the asteroid.

Other Issues to Be Monitored

The Science Processing and Operations Center (SPOC), which is responsible for processing data from OSIRIS-REx, has experienced schedule delays due to multiple issues, including design problems and poorly written software code. SPOC must be completed before launch. To maintain the project's schedule, it de-scoped initial SPOC software requirements and plans to deliver the first of four complete SPOC builds by December 2015, with subsequent software builds scheduled for delivery in the spring and summer of 2016. The project conducted three ground readiness tests in fall 2015 and plans to complete its final ground readiness tests by July 2016 to support launch.

Project Office Comments

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

Orion Multi-Purpose Crew Vehicle

Project Challenges
- Funding
- Design
- Development partner (new)

Previously Reported Challenges
- Schedule

PROJECT ESSENTIALS

NASA Center Lead: **Johnson Space Center**

Partner: **European Space Agency**

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

Mission Duration:
Up to 21 day active mission duration capability with four crew

Requirement derived from:
NASA Authorization Act of 2010

NASA 2014 Strategic Plan Alignment:
Strategic Objective 1.1 Develop evolving exploration systems and capabilities

CONTRACT INFORMATION

Current highest value contract

Contractor: **Lockheed Martin**

Contractor Activity: **Spacecraft development**

Type of Contract: **Cost-Plus-Award-Fee**
Date of Award: **September 2006**
Initial Value of Contract*: **$3.89 billion**
Current Value: **$12.10 billion**

**The initial value of the contract was established under the Constellation program in 2006. In February 2014, the contract was modified to extend the period of performance until 2020.*

PROJECT PERFORMANCE

Then year dollars in millions

Total Project Cost
$11,283.5
$11,283.5
0.0% CHANGE

Formulation Cost
$4,515.1
$4,671.5
3.5% CHANGE

Development Cost
$6,768.4
$6,612.0
-2.3% CHANGE

Operations Cost
N/A
N/A
0.0% CHANGE

Launch Schedule
- First non-crewed launch readiness date: **Sept 2018**
- First crewed launch readiness date: **no later than April 2023**

Baseline FY 2015 | Latest Est. Feb 2016

The Orion Multi-Purpose Crew Vehicle (Orion) is being developed to conduct crewed in-space operations beyond low-Earth orbit, including traveling to Mars or an asteroid. The Orion program is continuing to advance development of the human safety features, designs, and systems started under the Constellation program, which was canceled in 2010. Orion is planned to launch atop NASA's Space Launch System (SLS). The current design of Orion consists of a crew module, service module, and launch abort system.

Source: NASA/Kennedy. | GAO-16-309SP

PROJECT SUMMARY

In September 2015, NASA established its cost and schedule baselines for the Orion program's first crewed mission with a life-cycle cost estimate of $11.3 billion and a launch readiness date of no later than April 2023. The program continues to work toward an internal launch readiness date of August 2021. NASA will not commit to an actual launch date for the first crewed mission until after the first uncrewed mission is complete. The baseline does not include a date for the first uncrewed mission, although the program is working to a launch readiness date of September 2018. The Orion program continues to make progress on development of the vehicle and in October 2015 held the critical design review associated with the first uncrewed mission; however, the program does not plan to close out the critical design review until a follow-on review is held in May 2016.

Implementation
- **04/23** First crewed launch readiness date
- **09/18** First non-crewed launch readiness date
- **12/15** GAO review
- **10/15** Critical design review
- **09/15** Project confirmation

Formulation
- **12/14** First exploration test flight
- **08/14** Orion preliminary design review
- **02/12** Orion formulation start
- **02/10** Orion cancelled under Constellation Program
- **07/06** Formulation start under Constellation program

Orion Multi-Purpose Crew Vehicle

Cost and Schedule Status

In September 2015, NASA established cost and schedule baselines for the Orion program's first crewed Exploration Mission (EM-2) with a life-cycle cost of $11.3 billion and a launch readiness date of no later than April 2023. This life-cycle cost estimate does not include production, operations, or sustainment of additional crew vehicles, despite NASA's plans to use and possibly enhance the vehicle after 2023. The baseline does not include a date for the first uncrewed Exploration Mission (EM-1), which is planned to demonstrate the spacecraft's system performance prior to EM-2. The program is working to a launch readiness date of September 2018 for EM-1. NASA has not yet determined actual launch dates for EM-1 or EM-2. It plans to establish an integrated launch date target for EM-1 after all three associated programs—Orion, SLS, and Exploration Ground Systems—reach a sufficient level of design maturity. NASA plans to identify a launch date target for EM-2 after EM-1 is complete.

Funding

The Orion program is working to an earlier internal launch readiness date of August 2021 for EM-2 that depends on the program being appropriated more funding than NASA requested in fiscal year 2016 and plans to request in fiscal years 2017 through 2021. While Congress has provided the program with more funding than NASA requested in fiscal years 2013 through 2016, it may be unrealistic for NASA to expect additional funding each year given the constrained fiscal environment.

Design

The Orion program continues to make progress on development of its vehicle, having completed the critical design review for EM-1 in October 2015. However, the program did not fully review the design for the European Service Module (ESM), which has its system-level critical design review scheduled for April 2016; the heat shield, which is being redesigned; key crew life support systems, which were deferred from EM-1 to EM-2; or the program's cost and schedule estimates to ensure they are credible and adequate resources exist to complete development. The Orion program plans to close out the EM-1 critical design review during a follow-on review in May 2016. The program will not assess the key crew life support systems and other unique crew capabilities that will first fly on EM-2 until the EM-2 critical design review currently planned for 2017.

The Orion program is redesigning its heat shield. During the first exploration test flight in December 2014, the vehicle flew with a monolithic heat shield design. However, NASA has determined that not all aspects of the monolithic design will meet the more stringent requirements for EM-1 and EM-2 when the vehicle will be exposed to a greater temperature variance and longer durations. The program has decided to use a block heatshield design for EM-1, where it will adhere approximately 300 blocks to the support structure and apply filler material to the gaps between blocks. However, this design also has some risk because of uncertainty about the ability to adhere the blocks to the support structure. To mitigate this risk, the program will continue to develop the monolithic design as well.

Development Partner

The European Space Agency has experienced design challenges with the ESM. Under a barter agreement signed in December 2012, the European Space Agency is to contribute portions of the Orion service module for EM-1. After delivery, NASA's prime contractor for Orion will be responsible for integrating the ESM with the remaining service module components. As a result of design challenges, several ESM subsystem preliminary design reviews were completed as much as 6 months later than planned, with the last completed in June 2015. Similarly, individual subsystem critical design reviews have been delayed by up to 5 months in 2015.

Project Office Comments

In commenting on a draft of this assessment, Orion program officials noted that NASA continues to direct the program to execute to the August 2021 launch readiness date, which the agency acknowledges is aggressive and carries risk including the uncertainty of annual funding. They added that NASA has quantified this risk through the establishment of the Agency Baseline Commitment that places the first crewed flight no later than April 2023. Program officials also provided technical comments, which were incorporated as appropriate.

Solar Probe Plus

Project Challenges
- Design
- Manufacturing (new)

Previously Reported Challenges
- Funding
- Parts
- Test and integration
- Launch
- Technology

PROJECT ESSENTIALS

NASA Center Lead:
Goddard Space Flight Center

Partner: **None**

Launch Location: **Kennedy Space Center, FL**
Launch Vehicle: **Delta IV-heavy class with NASA-provided upper stage**

Mission Duration: **7 years**

Requirement derived from:
2013-2022 Solar and Space Physics Decadal Survey
NASA 2014 Strategic Plan Alignment:
Strategic Objective 1.4 Understand the Sun

CONTRACT INFORMATION

Current highest value contract

Contractor: **Johns Hopkins University Applied Physics Laboratory**

Contractor Activity: **Aerospace research development and engineering support**

Type of Contract: **Cost-Plus-Fixed-Fee**
Date of Award: **May 2010**
Initial Value of Contract: **$676.9 million**
Current Value: **$729.1 million**

PROJECT PERFORMANCE

Then year dollars in millions

Total Project Cost
$1,553.4
$1,553.4
0.0% CHANGE

Formulation Cost
$247.1
$247.1
0.0% CHANGE

Development Cost
$1,055.7
$1,050.3
-0.5% CHANGE

Operations Cost
$250.6
$256.0
2.2% CHANGE

Launch Schedule
08 2018 08 2018
0 months CHANGE

Baseline FY 2014 | Latest Est. Feb 2016

Solar Probe Plus (SPP) will be the first NASA mission to visit a star. Using the gravity of Venus, the spacecraft will orbit the Sun 24 times and gather information to increase knowledge about the solar wind, including its origin, acceleration, and how it is heated. SPP instruments will observe the generation and flow of solar winds from very close range and sample and take measurements of the Sun's outer atmosphere, or solar corona, where solar particles are energized. To achieve its mission, parts of the spacecraft must be able to withstand temperatures exceeding 2,500 degrees Fahrenheit as well as endure blasts of extreme radiation.

Source: Johns Hopkins University/Applied Physics Lab (artist depiction). | GAO-16-309SP

PROJECT SUMMARY

The SPP project has encountered a series of design and manufacturing challenges, but it currently has adequate cost and schedule reserves to address them. The project held its critical design review in March 2015 with 34 percent of design drawings released, which is lower than recommended by best practices, to allow the project to begin the 2-year process of building the flight cooling system and maintain its planetary launch window. At the review, the project released 100 percent of the drawings for the cooling system. The project has had to use cost and schedule reserves to address design and manufacturing issues. The project redesigned an instrument within its Solar Wind Electrons Alphas and Protons (SWEAP) instrument suite—which is key to meeting the project's science objectives. Further, the start of integration and test was put at risk because some of the spacecraft's panels were made too large, due to a design error.

Implementation
- **08/18** Committed launch readiness date
- **05/16** System integration review
- **12/15** GAO review
- **03/15** Critical design review

Formulation
- **03/14** Project confirmation
- **01/14** Preliminary design review
- **11/11** Mission/ system definition review
- **11/09** Formulation start

Solar Probe Plus

Cost and Schedule Status

The SPP project held its critical design review in March 2015, as planned, but the start of system integration and test could be delayed due to design and manufacturing issues. The project plans to begin spacecraft integration and testing in June 2016 and system-level testing in March 2017. The project has used cost and schedule reserves to address design and manufacturing issues, but continues to hold reserves consistent with the amount required by NASA center policy.

Design and Manufacturing

The SPP project has encountered a series of design and manufacturing challenges, but it currently has adequate cost and schedule reserves to address them. The project held its critical design review in March 2015 with only 34 percent of its design drawings released. According to best practices, releasing at least 90 percent of drawings by this review lowers the risk of subsequent cost growth and schedule delays. Project officials explained that they held the critical design review with a relatively low level of releasable drawings to allow the project to begin the 2-year process of building the flight cooling system and preserve its launch window. At the critical design review, the project released 100 percent of the drawings for this system. Maintaining the project's 2018 planetary launch window is important because the window only opens every 10 months and subsequent launch windows have longer mission durations and require more fuel. An SPP project official said the project expects to release the majority of the drawings by its May 2016 system integration review when the project must demonstrate that all system components are ready for integration.

The SPP project also had to address design issues with key instruments. First, part of the SWEAP payload, which is required to meet the project's top science objectives, had to be redesigned to better accommodate its launch environment. The SWEAP payload also experienced delays as a result of poor management by the responsible subcontractor. As a result of these issues, the project took over management of part of SWEAP and provided additional cost and schedule reserves to the SWEAP effort. The project also made changes to its antenna design following its critical design review to mitigate potential damage to the Fields instrument antenna and spacecraft during launch. Antenna damage could impede SPP's ability to meet its science objectives. The project is testing an updated design that provides a more effective way to secure the antennas to the spacecraft. The project expects to resolve this issue in July 2016, after its system integration review.

Design-related manufacturing issues have put the start of system integration and testing at risk. The project was unable to assemble the spacecraft structure on schedule because four of the eight spacecraft structural panels were too large and needed to be resized. The project completed the spacecraft structure in December 2015, but had to use schedule reserves to cover the 5-week period needed to fix the panels.

Issue Update

We previously reported that the SPP project changed its launch vehicle and as a result carried a design risk into critical design review. NASA has since awarded contracts for the launch vehicle and upper stage, which has enabled the project to begin to understand and address launch environment risks. For example, the project is working with the launch provider to mitigate the risk of increased vibration to the spacecraft when the spacecraft and the upper stage separate during launch. The project has benefitted from a decrease of more than $1 million in its expected launch vehicle costs. The exact amount will not be fully known until the project launches in 2018.

Project Office Comments

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

Space Launch System

Project Challenges
- Cost (new)
- Schedule
- Design (new)
- Contractor (new)

Previously Reported Challenges
- Funding
- Integration of Existing Hardware

PROJECT ESSENTIALS

NASA Center Lead:
Marshall Space Flight Center

Partner: **None**

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

Mission Duration:
Varied based on destination

Requirement derived from:
NASA Authorization Act of 2010

NASA 2014 Strategic Plan Alignment:
Strategic Objective 1.1 Develop evolving exploration systems and capabilities

CONTRACT INFORMATION

Current highest value contract

Contractor: **Boeing**

Contractor Activity: **SLS core stage**

Type of Contract: **Cost-Plus-Award-Fee**
Date of Award: **August 2007***
Initial Value of Contract: **$4.389 billion**
Current Value: **$4.193 billion**

**This contract was originally awarded under the Constellation program with a different cost and scope of work.*

PROJECT PERFORMANCE

Then year dollars in millions

Total Project Cost
$9,695.4
$9,695.4
0.0% CHANGE

Formulation Cost
$2,674.0
$2,674.0
0.0% CHANGE

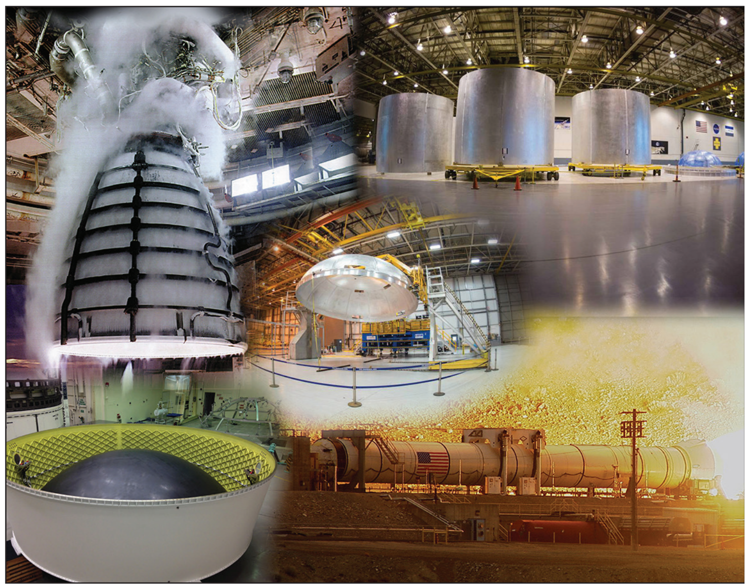
Development Cost
$7,021.4
$7,021.4
0.0% CHANGE

Operations Cost
N/A
N/A
0.0% CHANGE

Launch Schedule
11 2018 11 2018
0 months CHANGE

Baseline FY 2014 | Latest Est. Feb 2016

The Space Launch System (SLS) is intended to be the nation's first human-rated heavy-lift launch vehicle since the Saturn V was developed for the Apollo program. SLS is planned to launch NASA's Orion spacecraft and other systems on missions to an asteroid and eventually to Mars. SLS is being designed to provide an initial lift capacity of 70 metric tons to low-Earth orbit and be evolvable to 130 metric tons, enabling deep space missions. The initial 70-metric ton capability will include a core stage, powered by four RS-25 engines and two five-segment boosters. The 130-metric ton capability will use a new upper stage and advanced boosters.



Source: NASA. | GAO-16-309SP

PROJECT SUMMARY

The SLS program completed its critical design review for the 70-metric ton launch vehicle's uncrewed first exploration mission (EM-1) in July 2015, but it is at risk of design changes due to problems and delays with a major subsystem—the interim cryogenic propulsion stage (ICPS). The SLS program plans to complete its assessment of the ICPS design at a design review planned for spring 2016. If new development issues arise, the program has limited cost and schedule reserves remaining to address them. A critical period also lies ahead as NASA responds to congressional direction to not use funds to human-rate ICPS for carrying crew as originally planned for the second SLS exploration mission (EM-2) scheduled for 2021.

11/18 Committed launch readiness date

12/15 GAO review

07/15 Critical design review

Implementation

08/14 Project confirmation

07/13-09/13 Preliminary design review

05/12 Mission/ system design review

11/11 Formulation start

Formulation

Space Launch System

Cost and Schedule Status

The SLS program's limited cost and schedule reserves place it at increased risk of exceeding its committed cost and schedule baseline.[a] At its confirmation in August 2014, the program established its cost and schedule baseline for EM-1 at approximately $7 billon for development, with a launch readiness date of November 2018. The program's baseline cost includes reserves of less than 4 percent per year. Similarly, the SLS program has limited schedule reserves. The program has already allocated 7 of 11 months of schedule reserve to mitigate delays with the development of the core stage, the SLS's fuel tank and structural backbone. A major contributing factor in this delay was the need to repair incorrectly installed structural components within the core stage assembly facility. The program is tracking other threats to its schedule, including a risk regarding excessive hydrogen accumulating around the base of the vehicle during launch.

Design

Prior to the July 2015 critical design review for the SLS 70-metric ton vehicle, the SLS program had released nearly 90 percent of design drawings—a best practice—but it is at risk of design changes due to problems and delays with a major subsystem. The interim cryogenic propulsion stage (ICPS), which provides in-space propulsion for the SLS, did not have a stable design at the time of the SLS program's critical design review, due in part to immature safety and reliability analysis and the discovery of potential ICPS vibration issues. The program also purposefully deferred portions of the ICPS critical design review until spring 2016, which is when the second phase of the spacecraft and payload integration and evolution critical design review is scheduled, because designs for new avionics and secondary payloads were not yet ready for review.

Contractor

The SLS program is renegotiating the core stage contract with Boeing. According to NASA officials, the contract is being modified, in part, to resolve differences between the program and contractor regarding the level of funding available to begin work on the exploration upper stage. Program officials anticipate the renegotiated contract will be finalized in early 2016, at which point the effect on the program's overall cost and schedule should be known.

Other Issues to Be Monitored

The Joint Explanatory Report to the Consolidated Appropriations Act, 2016, while not law, prohibited the use of NASA funds to human-rate the ICPS. The SLS program had originally planned to use ICPS as the second stage propulsion system for both the EM-1 uncrewed and EM-2 crewed missions and then develop a new exploration upper stage for future missions. As part of the fiscal year 2016 NASA Exploration appropriation, Congress appropriated no less than $2 billion for SLS, of which no less than $85 million is to be for the development of a new upper stage.

Project Office Comments

In commenting on a draft of this assessment, SLS program officials stated that they had developed a solution to prevent excessive hydrogen from accumulating around the base of the launch vehicle by repositioning the hydrogen burn-off ignitors. They also stated that solutions have been identified for ICPS vibration issues. The program plans to complete its design review of the ICPS avionics and secondary payloads in spring 2016. Program officials also provided technical comments, which were incorporated as appropriate.

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

Space Network Ground Segment Sustainment

Project Challenges
- Contractor

Previously Reported Challenges
- Funding
- Technology

PROJECT ESSENTIALS

NASA Center Lead:
Goddard Space Flight Center

Partner: **None**

Mission Duration: **25 years with periodic, required upgrades to hardware and software**

Requirement derived from:
March 2008 Space Network modernization concept study

NASA 2014 Strategic Plan Alignment: **Strategic Objective 3.2 Ensure sustainable technical capabilities for NASA's future missions**

CONTRACT INFORMATION

Current highest value contract

Contractor: **General Dynamics C4 Systems**

Contractor Activity: **Modernizing the ground system and network**

Type of Contract: **Cost-Plus-Award-Fee**
Date of Award: **June 2010**
Initial Value of Contract: **$626.0 million**
Current Value: **$952.6 million**

PROJECT PERFORMANCE

Then year dollars in millions

Total Project Cost
$862.6
~~$1207.9~~
~~40.0%~~ CHANGE

NASA's Portion of Project Cost
$493.9
~~$842.2~~
~~70.5%~~ CHANGE

NASA's Formulation Cost
$125.8
~~$165.4~~
~~31.5%~~ CHANGE

NASA's Development Cost
$368.1
~~$676.8~~
~~83.9%~~ CHANGE

Contribution from Other Users[a]
$368.7
~~$365.7~~
~~-0.8%~~ CHANGE

Completion schedule
06 2017 — ~~09 2019~~
~~27 months~~ CHANGE

Baseline FY 2013 | Latest Est.[b] Feb 2016

[a]*At its 2013 confirmation, SGSS expected approximately $368.7 million from other Space Network users. As of 2015, the actual amount received was $365.7 million.*

[b]*The project's latest cost and schedule estimates are currently under review.*

The Space Network Ground Segment Sustainment (SGSS) project plans to develop and deliver a new ground system for three Space Network sites—which provides essential communication and tracking services to NASA, other government agencies, and commercial users. Existing ground systems, based on 1980s technology and software, are becoming increasingly obsolete and unsustainable. Updated systems, software, and equipment will allow the Space Network to continue to provide critical communications services to customer missions for the next several decades, while reducing operations and maintenance costs.

Source: NASA. | GAO-16-309SP

PROJECT SUMMARY

The SGSS project continues to experience contractor performance problems that could result in further cost and schedule increases. NASA approved a new baseline for the project in June 2015, which increased its estimated cost by $345 million and delayed its estimated completion by 27 months. The SGSS project has completed three of its five software increments. The SGSS contractor has fallen behind schedule on the fourth increment due to lower than expected levels of software development productivity. The fifth increment is also at risk. If the contractor continues to perform poorly, the Space Communications and Navigation (SCaN) program will consider reducing the scope of the project after the contractor delivers an initial capability in 2018 and trains NASA personnel how to install, operate, and maintain the system.

Implementation
- **09/19** Final acceptance review
- **09/18** First operational readiness review
- **08/17** System integration review
- **12/15** GAO review
- 06/15 Project rebaseline
- 06/13 Critical design review

Formulation
- 04/13 Project confirmation
- 09/12 Preliminary design review
- 11/11 Mission/system definition review
- 09/10 Formulation start

Space Network Ground Segment Sustainment

Cost and Schedule Status

NASA approved a new SGSS cost and schedule baseline in June 2015, but the contractor is falling behind its new schedule. The cost overruns that led to the new baseline were caused, in part, by overly optimistic contractor staffing estimates. NASA managers had noted concerns with contractor plans and staffing estimates in 2013 during project confirmation. The new baseline provides the SGSS project with over $65 million in cost reserves and 8 months of schedule margin. The project plans to complete software integration and testing by December 2016, but this schedule is at risk.

Contractor

The SGSS project continues to experience contractor performance problems that could result in further cost increases and schedule delays in its software development effort. The SGSS project is comprised of five software increments, with each successive increment building upon the prior increments. The first three increments are complete, and the final two, which contain the project's management and control software, are in development. At the project's June 2015 rebaseline review, the standing review board warned that the contractor's estimates for the new baseline underrepresented the complexity of the final two increments and the aggressiveness of the schedule. As of December 2015, the completion of the fourth increment was at least 5.5 weeks behind the contractor's schedule, and the project is concerned that additional delays may occur. The project also estimated that costs could increase by as much as $6.6 million over several fiscal years due to the schedule delays. The project expects to use project-held cost and schedule reserves to address the schedule delays and cost increases. The schedule and cost of the fifth software increment is also a project risk because the contractor might need more staff and time than estimated to complete it due to lower than expected levels of software development productivity. The backlog of defects to be addressed by the fifth increment also continues to increase.

SCaN has recently taken several steps to improve contractor oversight in response to standing review board recommendations. For example, the project developed metrics to help track contractor performance in software development. We have reported that metrics, such as measuring changes in the expected amount of software code that needs to be developed, provide useful insight to software development activities and progress, and identify areas for improvement.

If the contractor continues to perform poorly, SCaN may reduce the scope of the project. SCaN is considering terminating the project after an initial capability is delivered and the project holds its operational readiness review in September 2018. SCaN would terminate the project at this point because the contractor would have delivered the hardware, antenna modifications, and software needed to enable the full range of SGSS capabilities and Space Network staff would have been trained on how to take over installation, operations, and maintenance of the system. NASA would still have to finish installation work across the three Space Network sites and complete the transition to SGSS. According to NASA officials, this transition would occur incrementally as funding became available. The SGSS project is to complete a detailed transition plan before entering the system integration, test, and deployment phase in 2017.

Project Office Comments

In commenting on a draft of this assessment, SGSS project and SCaN officials reported that the project has sufficient project- and headquarters-held cost and schedule reserves to cover contractor schedule and cost expansion. They noted that the project has partially mitigated the effect of contractor performance problems, including by simplifying the design and automating testing. In addition, the officials stated that the project is working to deliver full scope of capabilities at all three sites by September 2019. Project officials also provided technical comments, which were incorporated as appropriate.

Surface Water and Ocean Topography

Project Challenges
- Technology maturity (new)
- Development partner
- Design (new)

PROJECT ESSENTIALS

NASA Center Lead:
Jet Propulsion Laboratory

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

Launch Location: **Vandenberg AFB, CA**
Launch Vehicle: **TBD**

Mission Duration: **3 years**

Requirement derived from:
2007 Decadal Survey

NASA 2014 Strategic Plan Alignment: **Strategic Objective 2.2 Understand our home planet**

CONTRACT INFORMATION

Current highest value contract

Contractor: **Airbus Defence and Space**

Contractor Activity: **Gyroscope development**

Type of Contract: **Firm-Fixed-Price**
Date of Award: **November 2015**
Initial Value of Contract: **$3.7 million**
Current Value: **$3.7 million**

PROJECT PERFORMANCE

Then year dollars

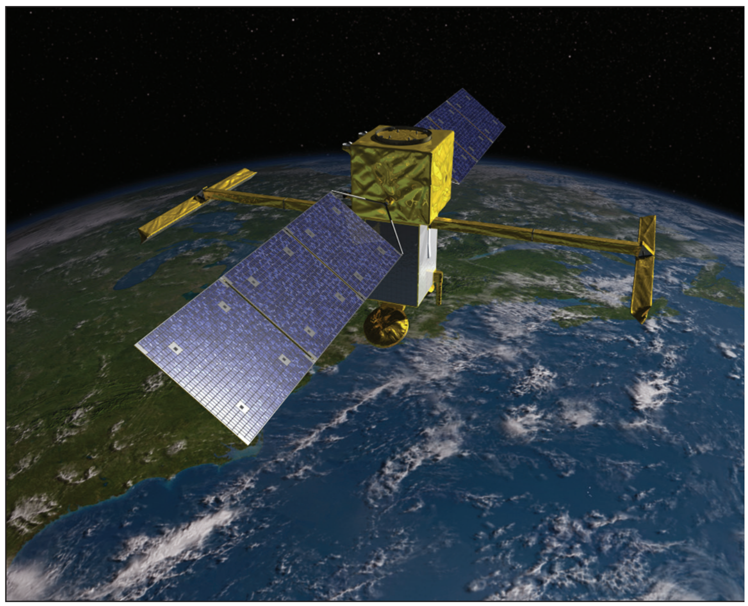
Preliminary Estimate of Project Life Cycle Cost*

Latest: **February 2016** **$647 – $757** MILLION

**This estimate is preliminary, as the project is in formulation and there is uncertainty regarding the costs associated with the design options being explored. NASA uses these estimates for planning purposes.*

Launch Schedule: **October 2020**

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



Source: NASA/JPL – Caltech (artist depiction). | GAO-16-309SP

PROJECT SUMMARY

The SWOT preliminary design review has been delayed by several months to March or April 2016 to allow the project time to study ways to enhance reliability after another NASA mission with a radar instrument experienced a failure after launch. The project's confirmation review, or Key Decision Point C, has also been delayed. In preparation for the preliminary design review, the project matured three of its four critical technologies to the level of maturity recommended by best practices and is in the process of confirming the maturity of the fourth technology, which is contributed by CNES. The SWOT project is also addressing potential payload mass issues in the lead-up to the design review. Project officials stated that potential changes to the payload design to reduce mass could require the project to use some of its cost reserves.

Implementation

10/20 Projected launch readiness date

01/19 System integration review

06/17 Critical design review

05/16 Project confirmation

04/16 Preliminary design review

12/15 GAO review

Formulation

05/14 Mission/system definition review

11/12 Formulation start

Surface Water and Ocean Topography

Cost and Schedule Status

The SWOT preliminary design review has been delayed by several months to late March or early April 2016. The project delayed the design review so that it could study ways to enhance the reliability of the mission after the Soil Moisture Active and Passive (SMAP) mission's radar failed after launch. The project also delayed its confirmation review, or Key Decision Point C, to May 2016, at which point it will establish its cost and schedule baselines.

Technology Maturity and Development Partner

The SWOT project expects to mature all four critical of its technologies to a technology readiness level 6 in preparation for its preliminary design review. Maturing critical technologies to this level is a best practice, which helps minimize risks for space systems entering product development. The project has matured three out of its four critical technologies to a technology readiness level 6. These technologies are components of Ka-band Radar Interferometer (KaRIn) instrument, which is the project's most complicated and challenging development. According to the project, the fourth KaRIn component, the CNES-contributed radio frequency unit (RFU), was reported as technology readiness level 6 prior to the KaRIn instrument-level preliminary design review. The project plans to formally recognize the RFU as technology readiness level 6 after it receives additional test documentation from CNES. The project is also tracking a variety of KaRIn RFU-related risks including its aggressive schedule and limitations on its performance.

Design

The SWOT project is addressing potential mass issues in the lead-up to its preliminary design review. The project is tracking a risk that its payload mass could exceed its spacecraft allocation. If the payload mass exceeds its allocation, the spacecraft design would have to change or the payload mass would need to be reduced, which could have cost, schedule, or performance implications. The project's mass margin decreased to a level below NASA requirements after design updates to KaRIn in May and June 2015, but the margin has since improved. The project is currently conducting a mass scrub exercise, which gets triggered when margins become tight. Project officials stated that changes to the design to reduce payload mass could require the project to use some of its cost reserves.

Other Issues to Be Monitored

The project is concerned that an outage that occurred in July 2015 on the recently launched SMAP mission could affect the development of SWOT's radar components and is taking steps to proactively address the issues. SMAP's radar experienced an anomaly that originated in the radar's high power amplifier, which boosts the power level of the radar's pulse to ensure accurate measurements. NASA made a final, unsuccessful attempt to power up the radar unit in August 2015, and decided to end attempts to recover SMAP's radar operations after exhausting options to recover the high power amplifier. The project is proactively monitoring and researching the SMAP anomaly because its findings may affect the SWOT design and implementation plans. The project has not yet identified any areas of commonality between SMAP and SWOT related to the anomaly that are a concern; however, the SMAP failure has caused the project to re-examine its own risk of experiencing a single point failure that could threaten the mission. As a result, the project is delaying its preliminary design review, so that it and CNES can study ways to enhance SWOT reliability without affecting cost, schedule, or partnership commitments.

Project Office Comments

In commenting on a draft of this assessment, SWOT project officials noted that the project continues to track mass and other key performance parameters in close coordination with CNES. Project officials stated that they employ a combination of techniques, such as redesigns and reassessing requirements, to maintain the appropriate technical margins at key milestones. They also reported that the enhanced reliability study is progressing well and expect to complete it in early February 2016. Project officials provided technical comments, which were incorporated as appropriate.

Transiting Exoplanet Survey Satellite

Project Challenges
- Schedule
- Contractor (new)
- Launch (new)

Previously Reported Challenges
- Design

PROJECT ESSENTIALS

NASA Center Lead:
Goddard Space Flight Center

Partner: **Massachusetts Institute of Technology, Principal Investigator**

Launch Location: **Cape Canaveral AFS, FL**
Launch Vehicle: **Upgraded Falcon 9**

Mission Duration: **2 years**

Requirement derived from:
2010 Decadal Survey

NASA 2014 Strategic Plan Alignment: **Strategic Objective 1.6 Search for life and understand the universe**

CONTRACT INFORMATION

Current highest value contract

Contractor: **Orbital ATK, Inc.**

Contractor Activity: **Spacecraft development**

Type of Contract: **Cost-Plus-Fixed-Fee**
Date of Award: **May 2014**
Initial Value of Contract: **$64.3 million**
Current Value: **$73.0 million**

PROJECT PERFORMANCE

Then year dollars in millions

	Baseline FY 2015	Latest Est. Feb 2016	Change
Total Project Cost	$378.4	$351.7	-7.1%
Formulation Cost	$27.1	$27.1	0.0%
Development Cost	$323.2	$296.4	-8.3%
Operations Cost	$28.1	$28.2	0.4%
Launch Schedule	06 2018	06 2018	0 months

The Transiting Exoplanet Survey Satellite (TESS) will use four identical, wide field-of-view cameras to conduct the first extensive survey of the sky from space. The mission's goal is to discover exoplanets—or planets in other solar systems—during transit, the time when the planet's orbit carries it in front of its star as viewed from Earth. TESS aims to discover Earth-sized, rocky, and potentially habitable exoplanets, of which few are known. The mission plans to characterize the most favorable targets for detailed investigations by other missions, including the James Webb Space Telescope.

Source: NASA. | GAO-16-309SP

PROJECT SUMMARY

The TESS project continues to pursue an aggressive schedule, and as a result it has increased its risk of cost growth and schedule delays. The project is working toward an August 2017 launch date, which is 10 months before its committed launch date and 4 months before NASA's planned date. This schedule-driven approach has been evident in project execution. For example, the project held its critical design review in August 2015 before its instrument design was stable. Development delays and technical issues with the data handling unit (DHU), a primary component of the TESS instrument, pose a threat to the project schedule and have led the project to pursue a dual path for DHU development, which will increase project costs. The project is also tracking several launch-related risks stemming from a June 2015 Falcon 9 launch failure and unknowns related to the upgraded Falcon 9 that will be used for TESS.

Implementation
- **06/18** Committed launch readiness date
- **12/17** NASA internal launch readiness date
- **08/17** Project launch readiness date
- **10/16** System integration review
- **12/15** GAO review
- **08/15** Critical design review

Formulation
- **10/14** Project confirmation
- **09/14** Preliminary design review
- **02/14** Mission/system definition review
- **04/13** Formulation start

Transiting Exoplanet Survey Satellite

Cost and Schedule Status

The TESS project held its critical design review in August 2015, but did not successfully complete it because its instrument design was not stable. The project addressed the outstanding issues with its instrument design, including the cameras and data handling unit (DHU), at a separate technical review in December 2015. The start of system integration and test—planned for October 2016—could be delayed. The TESS project has used cost and schedule reserves to address DHU issues, but is currently holding reserves consistent with the amount required by NASA center policy.

Schedule and Contractor

The TESS project continues to pursue an aggressive development schedule, and as a result has increased its risk of cost growth and schedule delays. The project is working toward an August 2017 launch, which is 10 months before its committed launch date and 4 months before NASA's planned launch date. To stay on schedule, the project held its critical design review before its instrument design was stable. The project released less than 90 percent of its design drawings by the review, which best practices show can increase the project's risk of cost growth and schedule delays.

Development delays with the DHU are threatening the project's schedule. The DHU provides power to TESS's cameras and serves as the instrument data storage and processing computer. The development of the DHU is behind schedule due to a series of technical issues related to its complex and compact design and contractor performance issues. As a result, the project has depleted the schedule margin for its instrument and could delay its system–level integration and test. The project has taken several steps to mitigate DHU-related risks. First, to maintain the August 2017 launch date, the project plans to begin system-level testing with the DHU's design model instead of the final flight unit. In addition, the project increased management and oversight of the DHU contractor. Finally, the project plans to award a contract for an alternative DHU. The project plans to pursue both DHU paths in the near-term, which will increase project costs by at least several million dollars.

Further delays to the TESS development are possible. The project is tracking a risk that it will not reach the level of maturity required to complete its systems integration review, planned for October 2016, which is required to begin the assembly, integration and test phase. Because the project did not complete its critical design review on schedule, the time between that milestone and the systems integration review has been compressed.

Launch

The TESS project is tracking several launch related risks. Subsequent to the project's selection of the Falcon 9 as its launch vehicle, SpaceX decided to phase out its existing Falcon 9 for an upgraded version that had yet to be flown. NASA will have to certify the upgraded Falcon 9, but it has not yet done so. A project official told us that if the certification process is delayed, it could result in a TESS launch delay. Further, the project is concerned that it does not know what effect the launch environment for this vehicle may have on its delicate science instrument. Project officials said that after its March 2016 launch vehicle preliminary design review, the project will better understand the upgraded Falcon 9 and will consider options, such as purchasing a "soft ride" to mitigate potential frequency and vibration during launch. The project also continues to monitor the accident investigation and corrective actions taken by SpaceX as a result of a June 2015 Falcon 9 launch failure, which involved the prior design, not the planned upgrade.

Project Office Comments

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

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.

In its comments, NASA noted that it has undertaken efforts in recent years to improve program and project management capabilities through the use of tools, such as earned value management (EVM), and changes to how it operates. For EVM, the agency stated that it had closed all of the recommendations from our 2012 report on EVM implementation at NASA.[33] However, as we point out in this report, NASA did not fully implement one recommendation that would have required projects to implement formal EVM surveillance programs due to resource constraints. We continue to find issues with the quality of EVM data on projects, such as the James Webb Space Telescope, which suggests NASA needs to remain focused on improving its practices in this area. In its comments, NASA also noted that it has undertaken a multi-year effort to assess the agency's core capabilities, which include technical, programmatic, and business services capacity, while concurrently implementing changes to improve how it operates. In the report, we highlighted one of those changes—NASA's plans to dissolve its independent program assessment office to help bolster its workforce in key areas—and stated it could impact project oversight. In its comments, NASA stated that is aware that there are risks associated with its strategy and that it is addressing them through the implementation strategy it is currently developing.

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.

[33] GAO-13-22.

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 C. Shelby
Chairman
The Honorable Barbara A. Mikulski
Ranking Member
Subcommittee on Commerce, Justice, Science, and Related Agencies
Committee on Appropriations
United States Senate

The Honorable Ted Cruz
Chairman
The Honorable Gary C. Peters
Ranking Member
Subcommittee on Space, Science, and Competitiveness
Committee on Commerce, Science, and Transportation
United States Senate

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

The Honorable Brian Babin
Chairman
The Honorable Donna F. Edwards
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 and oversight. We also assessed the status and challenges faced by NASA's 18 major projects, each with life-cycle costs more than $250 million.

To respond to these objectives, we developed a standard data collection instrument (DCI) which was completed by each project office. Through the DCI, we gathered data on each project's technology and design maturity, parts issues, and development partners. We developed other DCIs that were completed by NASA's Office of the Chief Financial Officer and Office of Procurement that gathered data on each project's cost performance, current and projected development activities, including the project's schedule and launch readiness dates, and contracts information.[1] We also analyzed data from prior reviews.

To assess the cost and schedule performance of NASA's portfolio of major projects, we compared the current cost and schedule data reported by NASA for the 12 projects in the implementation phase during our review to previously established project cost and schedule baselines. The Commercial Crew Program has a tailored project life cycle and project management requirements, so it was excluded from this analysis. While we completed our audit work, the Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport project was not able to meet its March 2016 launch date and the agency decided to review the Space Network Ground Segment Sustainment project. Updated cost and schedule information for these projects was not available and therefore not included in our analyses. In addition, we assessed development cost and schedule performance for NASA's portfolios of major projects for 2009 to 2016 to examine longer term 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

[1]For the fixed-price contracts discussed in this report, the initial contract values plus contract modifications issued to equitably adjust the contract costs equal the current contract values. For the cost-reimbursement contracts, the current contract value can be greater than the initial contract estimate when the government is required to reimburse the contractor for increased costs associated with performance.

across the portfolio. We then compared that historical trend to the portfolio's cost and schedule performance to determine if there was a relationship. Finally, we assessed how often, since 2009, NASA projects have exhibited cost growth to trigger a rebaseline.[2] We identified previously reviewed projects that had also been rebaselined and analyzed their schedules to identify when the rebaseline occurred. We also analyzed the development cost growth on those projects. For Stratospheric Observatory for Infrared Astronomy, National Polar-orbiting Operational Environmental Satellite System Preparatory Project, Glory, and Mars Science Laboratory projects, we used estimated baseline values, which were identified by NASA in 2010, to measure development cost growth. All cost information is presented in nominal then-year dollars for consistency with budget data.[3] 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 provide 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—and 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

[2]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.

[3]Because of changes in NASA's accounting structure, its historical cost data are relatively inconsistent. As such, we used then-year dollars to report data consistent with the data NASA reported to us. Then year dollars include the effects of inflation and escalation.

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; whether the project encountered any problems in modifying the technology; and whether the project considered the heritage technology as a risk to the project. For the development projects in the Science Mission Directorate, we examined the relationship between the number of critical technologies developed by a project and whether it was a directed or competed. We met with NASA officials from the Office of the Chief Technologist to discuss the agency's technology development efforts and analyzed relevant agency documents, such as the Journey to Mars strategic document.

To assess design stability, we asked project officials to provide the number of engineering drawings completed or projected for release by the preliminary and critical design reviews and as of our current assessment.[4] We did not verify or validate project office supplied data on the number of released and expected engineering drawings. However, we collected the project offices' rationale for cases where it appeared that only a small percentage of the expected drawings were completed by the

[4]In our calculation for the percentage of total number of drawings projected for release, we used the number of drawings released at the critical design review as a fraction of the total number of drawings projected, including where a growth in drawings occurred. So, 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.

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 releasable 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. 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 from project documents and compared it against NASA requirements.[5] We omitted the Exploration Ground Systems, Space Network Ground Segment Sustainment, and Space Launch System as those projects that do not contain spacecraft. We excluded the Orion program because it does not have applicable metrics.

To assess NASA's progress in reducing acquisition management risk, we analyzed ongoing NASA initiatives and any associated challenges. To assess NASA's implementation of the joint cost and schedule confidence level process, we interviewed officials and reviewed NASA's Cost Estimating Handbook and GAO's Cost Estimating Guide.[6] To assess NASA's implementation of earned value management among NASA's centers and projects, we reviewed collected information about NASA's ongoing implementation efforts from relevant agency offices, including the Office of the Chief Engineer, Cost Analysis Division and Independent Program Assessment Office. To examine the changes to NASA's independent assessment function, we reviewed NASA policies and documentation, such as the Standing Review Board Handbook, and met with agency officials. To assess the accuracy of prime operation cost baselines, we collected data on 19 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

[5]Our assessment this year was limited to projects operating out of the Jet Propulsion Laboratory and the Goddard Space Flight Center. Jet Propulsion Laboratory projects' technical margin requirements are set by Jet Propulsion Laboratory Design Principles. Goddard Space Flight Center technical margin requirements are set by the Goddard Open Learning Design Rules.

[6]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).

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 operation 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 established prime operation cost baseline established at the project confirmation review. We also spoke with agency officials to gather information about how projects estimate operations costs for the confirmation review.

Our work was performed primarily at NASA headquarters in Washington, D.C. In addition, we 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 18 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, major contractor, or other partner involved in the project, the project's cost and schedule performance, a schedule timeline identifying key project dates, and a brief narrative describing the current status of the project. We also provided a detailed discussion of project challenges for selected projects as applicable. For the four-page assessment for the Commercial Crew program, we included discussions of the two funded companies' current status and timelines.

Project cost and schedule performance is outlined according to cost and schedule changes in the various stages of the project life cycle. 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.

The project's timeline is based on acquisition cycle time, which is defined as the number of months between the project's start, or formulation start, and the projected or actual launch date. Formulation start generally refers to the initiation of a project; NASA refers to a project's start as key decision point (KDP)-A, or the beginning of the formulation phase. The preliminary design review typically occurs toward the end of the formulation phase, followed by a review at KDP-C, known as project confirmation, which allows the project to move into the implementation phase. The critical design review is generally held during the latter half of the final design and fabrication phase of implementation and demonstrates that the maturity of the design is appropriate to support continuing with the final design and fabrication phase. The manifested launch date is the launch date which the project is working toward, and when a launch vehicle is available to launch the project. This date is only a goal launch date for the project, not a commitment that they will launch on this date. The committed launch readiness date is determined through a launch readiness review that verifies that the launch system, spacecraft, and payloads are ready for launch. The implementation phase includes the operations of the mission and concludes with project disposal.

Project Challenges Discussion on Each Individual Project Assessment

To assess the project 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, project contractors with related contract values and award fees, and project partnerships. For the Commercial Crew program, we requested similar information from the two companies funded under the current phase of the program. 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. A challenge was identified for a project if performance had been or could be affected by the issue. The challenges we identified were primarily apparent in the projects that had entered the implementation phase; however, there were instances where these challenges were identified in projects in the formulation phase. For this year's report, we identified the following challenges across the projects we reviewed: launch, contractor, development partner, funding, design, technology, schedule, and manufacturing. These challenges do not represent an exhaustive or exclusive list. They are subject to change and evolution as we continue this annual assessment in future years. The challenges 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

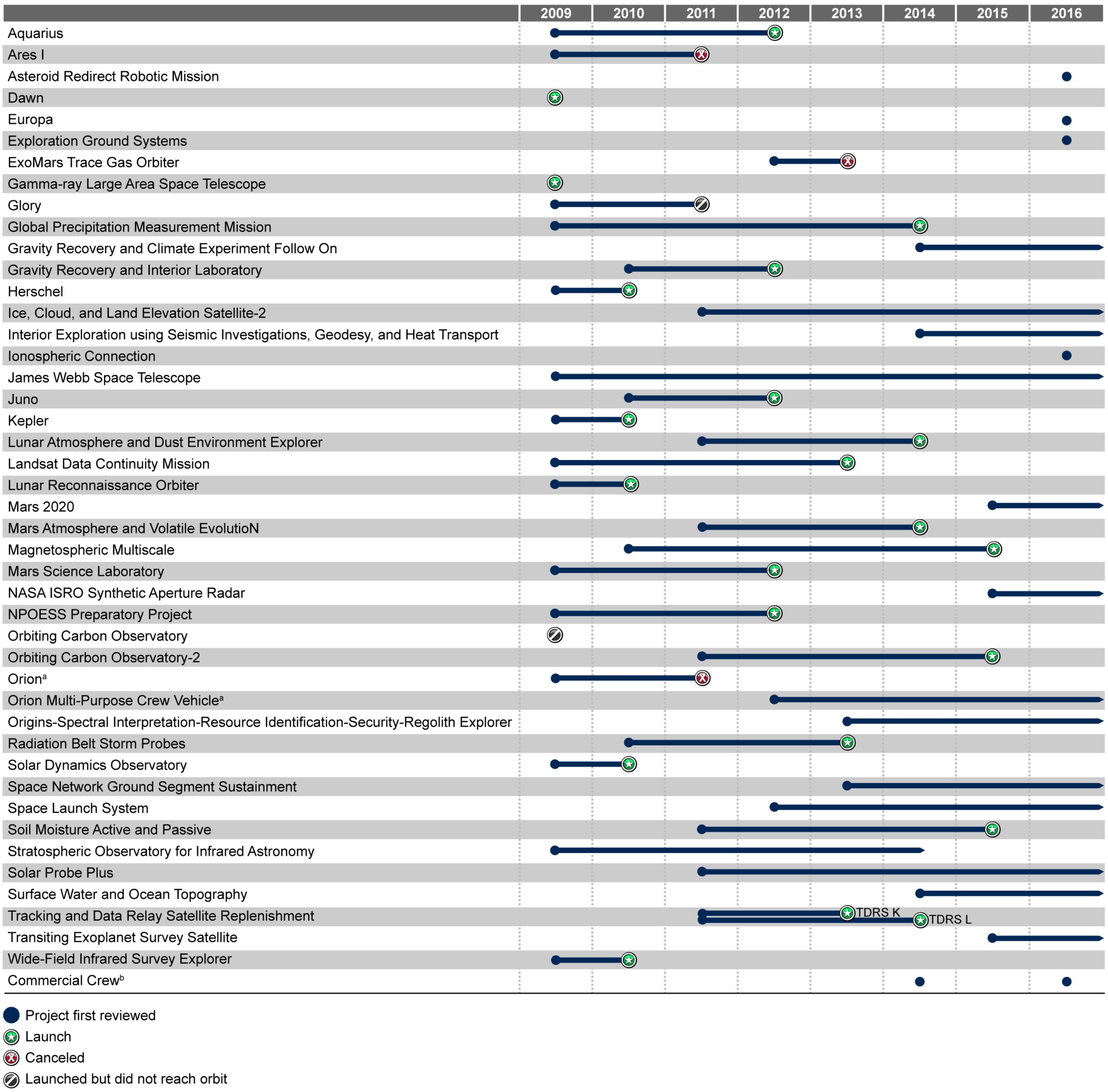
NASA provided preliminary estimated life-cycle cost ranges and associated schedules for the five projects that had not yet entered implementation, which are generally established at KDP-B. NASA formally establishes cost and schedule baselines, committing itself to cost and schedule targets for a project with a specific and aligned set of planned mission objectives, at KDP-C, which follows a preliminary design 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 2015 to March 2016 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 45 major National Aeronautics and Space Administration (NASA) projects or programs since our initial review in 2009. See figure 13 below for a list of projects included in our assessments from 2009 to 2016.

Figure 13: Major NASA Projects Reviewed in GAO's Annual Assessments



Source: GAO analysis of NASA data. | GAO-16-309SP

[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 cancelled in June 2011 when the Constellation program was cancelled 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

Technology readiness level	Description	Hardware	Demonstration environment
1. Basic principles observed and reported.	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties.	None (paper studies and analysis).	None.
2. Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be invented. The application is speculative and there is no proof or detailed analysis to support the assumption. Examples are still limited to paper studies.	None (paper studies and analysis).	None.
3. Analytical and experimental critical function and/or characteristic proof of concept.	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.	Analytic studies and demonstration of nonscale individual components (pieces of subsystem).	Lab.
4. Component and/or breadboard. Validation in laboratory environment.	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low-fidelity" compared to the eventual system. Examples include integration of ad-hoc hardware in a laboratory.	Low-fidelity breadboard. Integration of nonscale components to show pieces will work together. Not fully functional or form or fit but representative of technically feasible approach suitable for flight articles.	Lab.
5. Component and/or breadboard validation in relevant environment.	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so that the technology can be tested in a simulated environment. Examples include high-fidelity laboratory integration of components.	High-fidelity breadboard. Functionally equivalent but not necessarily form and/or fit (size, weight, materials, etc.). Should be approaching appropriate scale. May include integration of several components with reasonably realistic support elements/subsystems to demonstrate functionality.	Lab demonstrating functionality but not form and fit. May include flight demonstrating breadboard in surrogate aircraft. Technology ready for detailed design studies.

Technology readiness level		Description	Hardware	Demonstration environment
6.	System/subsystem model or prototype demonstration in a relevant environment.	Representative model or prototype system, which is well beyond the breadboard tested for technology readiness level 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in simulated realistic environment.	Prototype. Should be very close to form, fit, and function. Probably includes the integration of many new components and realistic supporting elements/subsystems if needed to demonstrate full functionality of the subsystem.	High-fidelity lab demonstration or limited/restricted flight demonstration for a relevant environment. Integration of technology is well defined.
7.	System prototype demonstration in a realistic environment.	Prototype near or at planned operational system. Represents a major step up from technology readiness level 6, requiring the demonstration of an actual system prototype in a realistic environment, such as in an aircraft, vehicle, or space. Examples include testing the prototype in a test bed aircraft.	Prototype. Should be form, fit, and function integrated with other key supporting elements/subsystems to demonstrate full functionality of subsystem.	Flight demonstration in representative realistic environment such as flying test bed or demonstrator aircraft. Technology is well substantiated with test data.
8.	Actual system completed and "flight qualified" through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this technology readiness level represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.	Flight qualified hardware.	Developmental Test and Evaluation in the actual system application.
9.	Actual system "flight - proven" through successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last "bug fixing" aspects of true system development. Examples include using the system under operational mission conditions.	Actual system in final form.	Technology assessed as fully mature. Operational Test and Evaluation in operational mission conditions.

Source: GAO analysis of NASA data. | GAO-16-309SP

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 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

[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).

- 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 NASA

National Aeronautics and Space Administration

Office of the Administrator
Washington, DC 20546-0001

March 17, 2016

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

Dear Ms. Chaplain:

The National Aeronautics and Space Administration (NASA) appreciates the opportunity to comment on the Government Accountability Office (GAO) draft report entitled "NASA: Assessments of Selected Large-Scale Projects" (GAO-16-309SP). The GAO's Congressionally mandated annual assessment is a good opportunity for NASA to receive an independent perspective on its performance in acquisition of major programs and projects. We appreciate the GAO's insights and the opportunity for open dialogue. NASA values the continued constructive communications between NASA and the GAO on this effort and appreciates the on-going work by the GAO assessment team.

As noted in the draft report, this year has been one of transition for NASA in terms of how we approach program and project management. NASA has undertaken a multi-year effort to assess the Agency's core capabilities, which include technical, programmatic, and business services capacity, while concurrently implementing changes to improve how we operate. Specifically with respect to the Agency's Programmatic Capability — consisting of program management, resource analysis, scheduling, cost estimation, and independent assessment activities — NASA has concluded that a more efficient operating model will result in the following programmatic emphases: (a) holding program/project managers more responsible for mission success; (b) using the NASA technical authorities for advice; and, (c) shifting engineering talent from dedicated oversight functions to hands-on work.

Maintaining a strong independent evaluation function is essential to NASA's long-term success. Independent reviews are critical to ensuring that the most accurate and informed program/project risk, cost and schedule assessments, and performance projections are presented to decision makers at Key Decision Points. Under the changes we have proposed, many tenets of the existing process will continue. For example, Mission Directors will establish standing review boards (SRBs) for programs and projects in line with existing guidelines, as agreed to with the Associate Administrator, and will use Center resources independent of a program or project to provide assessment into program/project performance. Mission Directorates, in coordination with the Centers, will be responsible for selecting the review board chairs with approval of the Decision Authority. SRB chairs will select the members of the SRB by working with the NASA Headquarters-based Office of the Chief Financial Officer and the Office of the Chief Engineer to identify the relevant

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programmatic and technical experts, respectively. The Associate Administrator remains the Decision Authority for Life Cycle reviews for programs and major projects.

NASA is aware that there are risks associated with this strategy, and we are addressing them through the strategy that is currently in implementation. We look forward to discussing this further with the GAO during the next assessment period.

The GAO's draft report also highlights additional efforts NASA has undertaken in recent years to improve program and project management capabilities through the use of earned value management (EVM) and design stability metrics. With regard to EVM, NASA is pleased that in September 2015 the GAO agreed to close all remaining open actions from the 2012 report, "NASA: Earned Value Management Implementation across Major Spaceflight Projects is Uneven" (GAO-13-22).

NASA is also pleased that the GAO has observed improved cost and schedule performance across our portfolio of spaceflight programs and projects. NASA agrees with the GAO's assessment that there are several large, complex projects comprising the majority of the available budget over the next several years and that these projects have all entered, or will soon enter, the development phase. As we have previously discussed with the GAO, NASA has learned from the issues associated with the James Webb Space Telescope, and the project is continuing to make excellent progress against its new baseline and continues to meet its annually established milestones. Similarly, the Space Launch System, Orion, and Exploration Ground System are on track toward Exploration Mission-1.

While NASA had hoped to launch the Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport (InSight) mission to Mars this year, technical issues with a partner-provided science instrument forced us to make the decision to forego the 2016 launch opportunity. While a disappointment, NASA believes that this was the most prudent course of action to ensure mission success. The Science Mission Directorate is currently reviewing the requirements for the next launch opportunity, which occurs in 2018, before NASA commits to a new baseline.

NASA is committed to working with the GAO jointly to address any questions and appreciates the ongoing dialog with the GAO on this critical subject. If you have any questions or require additional information, please contact Ellen Gertsen at (202) 358-0812.

Sincerely,

Robert Lightfoot
Associate Administrator

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; Lorraine Ettaro; Lisa L. Fisher; Laura Greifner; Kurt Gurka; Kristine R. Hassinger; Katherine Lenane; Jonathan Mulcare; Adrian Pavia; Erin Preston; Roxanna T. Sun; and Kristin Van Wychen made significant contributions to this report.

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