

March 2009

NASA

Assessments of
Selected Large-Scale
Projects



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Highlights

Highlights of [GAO-09-306SP](#), a report to congressional committees

Why GAO Did This Study

The National Aeronautics and Space Administration (NASA) plans to invest billions in the coming years in science and exploration space flight initiatives. The scientific and technical complexities inherent in NASA's mission create great challenges in managing its projects and controlling costs. In the past, NASA has had difficulty meeting cost, schedule, and performance objectives for some of its projects. The need to effectively manage projects will gain even more importance as NASA seeks to manage its wide-ranging portfolio in an increasingly constrained fiscal environment.

Per congressional direction, this report provides an independent assessment of selected NASA projects. In conducting this work, GAO compared projects against best practice criteria for system development including attainment of knowledge on technologies and design as well as various aspects of program management. The projects assessed are considered major acquisitions by NASA—each with a life-cycle cost of over \$250 million. No recommendations are provided.

To view the full product, including the scope and methodology, click on [GAO-09-306SP](#). For more information, contact Cristina Chaplain at (202) 512-4841 or chaplainc@gao.

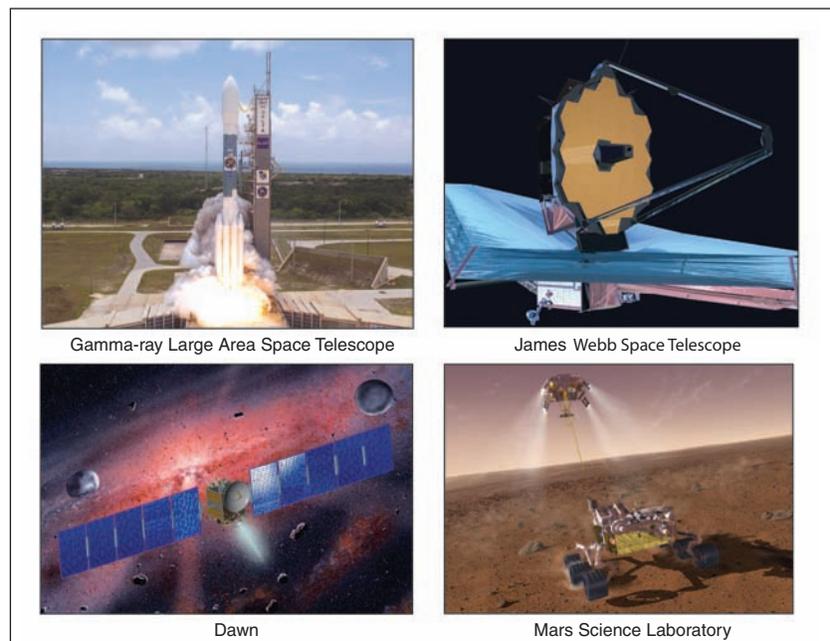
NASA

Assessments of Selected Large-Scale Projects

What GAO Found

GAO assessed 18 NASA projects with a combined life-cycle cost of more than \$50 billion. Of those, 10 out of 13 projects that had entered the implementation phase experienced significant cost and/or schedule growth. For these 10 projects, development costs increased by an average of 13 percent from baseline cost estimates that were established just 2 or 3 years ago and they had an average launch delay of 11-months. In some cases, cost growth was considerably higher than what is reported because it had occurred prior to the most recent baseline. Many of the projects we reviewed experienced challenges in developing new technologies or retrofitting older technologies as well as in managing their contractors, and more generally, understanding the risks and challenges they were up against when they started their efforts.

GAO's previous work has consistently shown that reducing the kinds of problems this assessment identifies in acquisition programs hinges on developing a sound business case for a project. In essence, this means establishing firm requirements, maturing technologies, and assuring other vital resources, such as time and funding, are sufficient before making long-term commitments to acquisitions. NASA has acted to adopt practices that would ensure programs proceed based on a sound business case and undertaken an array of initiatives aimed at improving program management, cost estimating, and contractor oversight. Continued attention to these efforts should help maximize NASA's acquisition investments.



Source: Kennedy Space Center, Cape Canaveral. JWST Project Office; NASA/JPL/McREL; Background: William K. Hartmann, UCLA; Mars Science Laboratory.

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Abbreviations

AFB	Air Force Base
AFS	Air Force Station
AIA	Atmospheric Imaging Assembly
APS	aerosol polarimetry sensor
ASI	Argenzia Spaciale Italiana (Italian Space Agency)
CCD	charged-coupled device
CDR	critical design review
CERES	Clouds and Earth's Radiant Energy System
CEV	Crew Exploration Vehicle
CONAE	Comision Nacional de Actividades Espaciales (Space Agency of Argentina)
CrIS	Cross-track Infrared Sounder
CSA	Canadian Space Agency
DCI	data collection instrument
DLR	German Aerospace Center
DPR	dual-frequency precipitation radar
EO-1	Earth Observatory Satellite
ESA	European Space Agency
EVE	Extreme Ultraviolet Variability Experiment
GBM	gamma-ray burst monitor
GLAST	Gamma-ray Large Area Space Telescope
GMI	GPM microwave imager

GPM	Global Precipitation Measurement (mission)
HIFI	Heterodyne Instrument for the Far Infrared
HMI	Helioseismic and Magnetic Imager
IPO	Integrated Program Office
JAXA	Japan Aerospace Exploration Agency
JPL	Jet Propulsion Laboratory
KDP	key decision point
LAT	large area telescope
LCROSS	Lunar Crater Observation and Sensing Satellite
LDCM	Landsat Data Continuity Mission
LRO	Lunar Reconnaissance Orbiter
MEP	Mars Exploration Program
MSL	Mars Science Laboratory
NAR	nonadvocate review
NASA	National Aeronautics and Space Administration
NIR	near infrared (bands)
NPR	NASA Procedural Requirements
NPOESS	National Polar-Orbiting Operational Environmental Satellite System
NPP	NPOESS Preparatory Project
OCO	Orbiting Carbon Observatory
OLI	Operational Land Imager
PA&E	Office of Program Analysis and Evaluation (NASA)
PDR	preliminary design review
PICA	phenolic impregnated carbon ablator
SDO	Solar Dynamics Observatory
SDR	system definition review
SOFIA	Stratospheric Observatory for Infrared Astronomy
SSS	sea surface salinity
TIM	total irradiance monitor
TIRS	Thermal Infrared Sensor
TRL	technology readiness level
TSIS	Total Solar Irradiance Sensor
USGS	U.S. Geological Service
VIIRS	Visible Infrared Imaging Radiometer Suite

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United States Government Accountability Office
Washington, DC 20548

March 2, 2009

Congressional Committees

In response to congressional direction, this report provides our assessment of large-scale NASA projects. NASA is at a critical juncture. The agency is in the midst of phasing out the Space Shuttle program and beginning another major undertaking, the Constellation program—which will create the next generation of spacecraft for human spaceflight and is expected to cost upward of \$230 billion. This massive effort, unparalleled since the transition from the Apollo program to the Shuttle program, presents the agency with myriad complex and interdependent challenges.

NASA is taking on this endeavor against a backdrop of growing national government fiscal imbalance and budget deficits that continue to strain all federal agencies' resources. While NASA's budget represents less than 2 percent of the federal government's fiscal discretionary budget, the agency is increasingly being asked to expand its portfolio to support important scientific missions including the study of climate change. Therefore, it is exceedingly important that these resources be managed as effectively and efficiently as possible.

In the past, this has not always been the case. NASA has had difficulty meeting cost, schedule, and performance objectives for some of its projects, and in fact, it had to cancel prior attempts to replace the Space Shuttle, after billions had already been spent, in the face of cost overruns and program management problems. However, to its credit, NASA has developed a comprehensive plan to address systemic acquisition management weaknesses and is in the initial stages of implementing the plan. Moreover, as we have urged it to do, NASA recently incorporated best practice criteria for system development in its acquisition policy, though our review shows more needs to be done to ensure the policy is followed. To maximize NASA's ability to invest in science and space exploration, senior

leaders should focus attention to adopting best practices and demonstrate a willingness to fix and/or terminate projects that are not performing well. This assessment should support such efforts.

A handwritten signature in black ink that reads "Gene L. Dodaro". The signature is written in a cursive style with a large, prominent initial "D".

Gene L. Dodaro
Acting Comptroller General
of the United States



United States Government Accountability Office
Washington, DC 20548

March 2, 2009

Congressional Committees

The National Aeronautics and Space Administration's (NASA) extensive portfolio of missions ranges from sending robotic vehicles to Mars, to scientific study of Earth from space, to assembling and supplying the International Space Station. Some of these missions, such as the Hubble Space Telescope and NASA's earth science efforts, have literally changed the way we view our planet and the universe. The technology that NASA developed has resulted in numerous spin-off products that are used across a wide range of technical and commercial fields.

However, NASA has also had its share of challenges. For example, the X-33 and X-34 programs, which were meant to demonstrate technology for future reusable launch vehicles, were cancelled due to technical difficulties and cost overruns after NASA spent more than \$1 billion on them. More recently, the Mars Science Laboratory, which was already over budget, announced a two-year launch delay. Current estimates suggest the price of this delay may be \$400 million—which drives the current project life-cycle cost estimate to \$2.3 billion, up from its initial confirmation estimate of \$1.6 billion. GAO and others have also reported on overruns on many other NASA programs over the past decade. What is common among these and other programs is that whether they succeed or fail, they cost more to build and take longer to launch than planned. As a result, NASA is able to accomplish less than it plans with the money it is allocated, and it is forced to make unplanned trade-offs among its projects—shorting one to pay for the mistakes of another.

Congress has expressed concern about NASA's performance and has identified the need to standardize the reporting of cost, schedule, and content for NASA research and development projects. In 2005, Congress required NASA to report cost and schedule baselines—benchmarks against which changes can be measured—for all NASA programs and projects with estimated life-cycle costs of at least \$250 million that have been approved to proceed to implementation.¹ It also required that NASA report to Congress when development cost is likely to exceed the baseline estimate by 15 percent or more, or when a milestone is likely to be delayed by six

¹ National Aeronautics and Space Administration Authorization Act of 2005, Pub. L. No. 109-161, §103; 42 U.S.C. § 16613(b)(f)(4).

months or more.² In response, NASA began establishing cost and schedule baselines in 2006 and has been using them as the basis for annual project performance reports for Congress provided in its annual budget submission each year.

The explanatory statement of the House Committee on Appropriations accompanying the Consolidated Appropriations Act of 2008 directed GAO to prepare project status reports on selected large-scale NASA programs, projects, or activities. This report responds to that mandate by assessing 18 NASA projects, each with a life-cycle cost over \$250 million. The combined life-cycle cost for these 18 projects exceeds \$50 billion. Each assessment is presented in a two-page summary that analyzes the project's cost and schedule status and project challenges. We also provide general observations about the performance of NASA's major projects and the agency's management of those projects during development.

NASA provided updated cost and schedule data as of December 2008 for 13 of the 18 projects.³ We reviewed and compared that data to previously established baselines for each of those 13 projects. We took appropriate steps to address data reliability.

Our approach included an examination of the phase of a project's development and how each project was advancing within this framework. Each project we reviewed was in either the formulation phase or the implementation phase of the project life-cycle. In the formulation phase, the project develops and defines the project requirements—what the project should be able to do—establishes a schedule, estimates costs and produces a plan for implementation. In the implementation phase, the project carries out these plans, performing final design and fabrication as well as testing components and system assembly, integrating these components and testing how they work together, and launching the project. This phase also includes the period from project launch through mission completion. We assessed each project's cost and schedule and characterized growth in either as significant if it was greater than the thresholds established for Congressional reporting.

² 42 U.S.C. § 16613(d).

³ NASA also provided preliminary estimates in the form of cost ranges for three projects in the formulation phase. Since the values provided were ranges, rather than specific values, we did not include these projects in our analysis. Further, the agency did not provide schedule baselines for these projects so we could not determine any schedule changes they experienced.

Based on discussion with project officials and drawing on GAO's established criteria for knowledge-based acquisitions and on other GAO work on space and weapon system acquisitions, we identified five challenges that can contribute to cost and schedule growth in these projects: technology maturity, design stability, complexity of heritage technology, contractor performance and development partner performance. To assess technology maturity, we examined the projects' reported critical technology readiness levels—a measure that NASA devised and that is now used at other agencies as well. We looked at the technology readiness level at the time of the project's preliminary design review, which occurs just before it enters the implementation phase, and compared that against the level of maturity that best practices call for at that stage to minimize risks. To assess design stability, we examined the percentage of engineering drawings completed or projected to be completed by the critical design review—which is usually held about mid-way through the project's development. We asked project officials to provide this information and we compared it against GAO's best practices' metric of 90 percent of drawings released by the critical design review. Finally, based in part on our discussions with officials for the individual projects, we identified the extent to which project cost and schedule were negatively impacted by challenges integrating heritage—or pre-existing—technology into their projects. We also discussed the extent to which contractors' and development partners' challenges in developing and delivering project hardware impacted overall project cost and schedule. In this review, these challenges were largely apparent in the projects that had entered the implementation phase.

This list of challenges is not exhaustive; we believe these challenges will evolve and change as we continue this work into the future. Our objectives are to expand on the importance of developing a knowledge-based acquisition strategy and to provide decision-makers with an independent, knowledge-based assessment of individual systems that identifies potential risks and allows them to take actions to put projects that are early in the development cycle in a better position to succeed. This report and the challenges we discuss in it are a starting point for our future work in this area. The individual project offices were given an opportunity to comment on and provide technical clarifications on our assessments prior to their inclusion in the final product.

We conducted this performance audit from February 2008 to March 2009 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 III contains detailed information on our scope and methodology. We do not provide recommendations in this report.

A Sound Business Case Underpins Successful Acquisition Outcomes

The major projects that NASA undertakes range from highly complex and sophisticated space transportation vehicles, to robotic probes, to satellites equipped with advanced sensors to study the earth. In many cases, NASA's projects are expected to incorporate new and sophisticated technologies while operating in harsh, distant environments. Many of its projects are also one time articles, meaning there is little opportunity to apply knowledge gained to the production of a second, third, or future increments of spacecraft. Moreover, NASA often partners with other space-faring countries, including several European nations, Japan, and Argentina. These partnerships go a long way to foster international cooperation in space, but they also put NASA projects in a vulnerable position when partners do not meet their obligations or run into technical obstacles they cannot easily overcome. While space development programs are complex and difficult by nature, and most are one-time efforts, we are convinced that NASA would benefit from a more disciplined approach to its acquisitions. The nature of its work should not preclude NASA from achieving what it promises when requesting and receiving funds.

The development and execution of a knowledge-based business case for these 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 studies of best practice organizations show the risks inherent in NASA's work can be mitigated by developing a solid, executable business case before committing resources to a new product development.⁴ In its simplest form, this is evidence that (1) the customer's needs are valid and can best be met with the chosen concept, and (2) the chosen concept can be developed and produced within existing resources—that is, proven technologies, design knowledge, adequate funding, and adequate time to deliver the product when needed. A program should not go forward into product development unless a sound business case can be made. If the business case measures up, the organization

⁴ 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); *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).

commits to the development of the product, including making the financial investment. Our best practice work has shown that developing business cases based on matching requirements to resources before program start leads to more predictable program outcomes—that is, programs are more likely to be successfully completed within cost and schedule estimates and deliver anticipated system performance.⁵

At the heart of a business case is a knowledge-based approach to product development that is a best practice among leading commercial firms. Those firms have created an environment and adopted practices that put their program managers in a good position to succeed in meeting these expectations. For a program to deliver a successful product within available resources, managers should demonstrate high levels of knowledge before significant commitments are made. In essence, knowledge supplants risk over time. This building of knowledge can be described over the course of a program, as follows:

- 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 needed 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 appropriate form, fit, and function to address the customer's needs within available resources.
- Then, about midway through the product's development, its design should be stable and demonstrate it is capable of meeting performance requirements. The critical design review takes place at that point in time because it generally signifies when the program is ready to start building production-representative prototypes. If design stability is not achieved, but a product development continues, costly re-designs 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.

⁵ [GAO-05-242](#).

Our best practice work has identified numerous other actions that can be taken to increase the likelihood that a program can be successfully executed once that business case is established. These include ensuring cost estimates are complete, accurate and updated regularly; holding suppliers accountable to deliver high-quality parts for their product through such activities as regular supplier audits and performance evaluations of quality and delivery; and holding program managers accountable for their choices. Moreover, we have recommended using metrics and controls throughout the life-cycle to gauge when the requisite level of knowledge has been attained and direct decision makers to consider criteria before advancing a program to the next level and making additional investments.

The consequence of proceeding with system development without establishing and adhering to a sound business case is substantial. GAO and others have reported that NASA has experienced cost and schedule growth in several of its projects over the past decade, resulting from problems that include failing to adequately identify requirements and underestimating complexity and technology maturity. For example, the X-33 and X-34 programs both were terminated because of significant cost increases caused by problems developing the necessary technologies and flight demonstration vehicles. Neither program fully assessed the costs associated with developing new, unproven technologies. Additionally, in 2005, GAO reported on the lack of an established sound business case for NASA's Prometheus I—a project that faced challenges in identifying preliminary requirements, establishing firm cost estimates and maturing critical technologies. After concurring with GAO's recommendation that NASA establish a firm business case for the project, NASA identified more realistic requirements for Prometheus I and reduced the project's requested funding by nearly \$2.4 billion through 2010.

NASA Has Made Efforts to Improve Its Acquisitions

In 2005, we reported that NASA's acquisition policies did not conform to best practices for product development because they lacked major decision reviews at several key points in the project life-cycle, which would allow decision makers to make informed decisions about whether a project should be authorized to proceed in the development life-cycle. Based, in part, on our recommendations, NASA issued a revised policy in March 2007⁶ that institutes several key decision points (KDP) in the development life-cycle for space flight programs and projects. At each KDP, a decision authority is responsible for authorizing the transition to the next life-cycle

⁶ National Aeronautics and Space Administration Procedural Requirements 7120.5D, *NASA Spaceflight Program and Project Management Requirements* (Mar. 6, 2007). (Hereinafter cited as NPR 7120.5D (Mar. 6, 2007)).

phase for the project.⁷ In addition, NASA acquisition policies also require that new technologies be sufficiently mature at the preliminary design review, the design is appropriate to support proceeding with full-scale fabrication, assembly, assembly, integrating and test at the critical design review, and the system can be fabricated within cost, schedule and performance specifications. These changes brought the policy more in line with best practices for product development. A more detailed discussion of NASA's acquisition policy and how it relates to best practices is provided in appendix II of this report.

Further, in response to GAO's designation of NASA acquisition management as a "high risk" area,⁸ NASA developed a corrective action plan to improve the effectiveness of NASA program/project management.⁹ The approach focuses on how best to ensure the mitigation of potential issues in acquisition decisions and better monitor contractor performance. The plan identifies five areas for improvement—program/project management, cost reporting process, cost estimating and analysis, standard business processes, and management of financial management systems—each of which contain targets and goals to measure improvement. As part of this initiative, NASA has taken a positive step in improving management oversight of project cost, schedule, and technical performance with the establishment of a baseline performance review with NASA's senior management. Through monthly reviews, NASA intends to highlight projects that are predicted to exceed internal NASA cost and/or schedule baselines, which are set lower than cost and schedule baselines submitted to Congress, so the agency can take pre-emptive actions to minimize the projects' potential cost overruns or schedule delays.

While these efforts are positive steps towards achieving successful project outcomes and ensuring that decision makers are appropriately investing the agency's resources, they will be limited if project officials are not held accountable for demonstrating that elements of a knowledge-based business case are demonstrated at key junctures in development. It is critical that project officials not only have a high level of knowledge about a project at key junctures, but also that this information is used by decision makers to make decisions on whether to invest additional resources and allow a project to proceed through the development life cycle.

⁷ NPR 7120.5D, paragraph 2.4.5 (Mar. 6, 2007).

⁸ GAO, *High-Risk Series: An Update*, [GAO-07-310](#) (Washington, D.C.: Jan. 2007).

⁹ NASA, *Plan for Improvement in the GAO High-Risk Area of Contract Management* (Oct. 31, 2007).

Project Assessments

We found several factors that occurred throughout the various projects we reviewed that can contribute to project cost and schedule growth. These factors—characterized as project challenges—were mostly present in the projects that had reached the implementation phase of the project life-cycle. They, along with a profile of each project we reviewed, are described in a two-page assessment for each project. The project profile presents a general description of the mission objectives for each of the projects; a picture of the spacecraft or aircraft; a schedule timeline identifying key dates for the project; a table identifying programmatic and launch information; and the baseline year cost and schedule estimates and December 2008 cost and schedule data.

The remainder of the assessment analyzes the project challenges and the extent to which each project faces cost, schedule, or performance risk due to these challenges. They are based on past GAO work on elements of a successful acquisition business case—technology maturity, heritage technology complexity, and design stability. Additionally, through our review, we identified two more challenges—contractor performance and development partner performance—that had an impact on cost and schedule performance of the NASA projects. Contractor performance impacts NASA's ability to deliver a project within cost and schedule baselines because the agency depends on the expertise of the contractor to deliver what it promises. Similarly, NASA sometimes relies on other domestic and international organizations to provide key instruments, the spacecraft, and/or launch services for collaborative projects; the performance of these partners can impact NASA's performance for a project. When a development partner cannot deliver an instrument or integrate it on schedule, the impact is felt by NASA. Specifically, since often there is no exchange of money between partners, the cost of any delays to the project must be assumed by each partner.

For each individual project assessment, we provide a table showing the challenges relevant to the project and a project status narrative. This is followed by a narrative of the project challenges we identified relevant to each project.

NASA project offices were provided an opportunity to review drafts of the individual two-page assessments prior to their inclusion in the final product. The projects provided both technical corrections and more general comments. We integrated the technical corrections as appropriate and characterized the general comments on the second page of each two-page assessment.

Our Observations

NASA provided cost and schedule data for 13 projects in the implementation phase of the project life-cycle.¹⁰ Ten of those 13 projects experienced significant cost and/or schedule growth from their project baselines.¹¹ Based on our analysis, development costs for projects in our review increased by an average of almost 13 percent from their baseline cost estimates—all in just two or three years—including one project's cost that increased by over 50 percent. It should be noted that a number of these projects had experienced considerably more cost growth before they were baselined in response to the statutory reporting requirement.¹² Our analysis also shows that projects in our review had an average delay of 11 months to their launch dates. The lack of knowledge at key junctures during project development, as well as the complexity of using heritage hardware—systems with characteristics similar to the one being developed—and working relationships with contractors and development partners contributed to the cost and schedule growth. Table 1 depicts the 13 projects we reviewed that had entered the implementation phase, the challenges they faced or are currently facing, and the cost and schedule changes they experienced.

¹⁰ We also reviewed the James Webb Space Telescope, but NASA did not provide cost or schedule data for that project even though it is in implementation.

¹¹ For purposes of our analysis, significant cost and schedule growth occurs when a project's cost and/or its schedule growth exceeds the thresholds established for Congressional reporting.

¹² 42 U.S.C. § 16613(b).

Table 1: Assessment of Challenges for NASA Projects in the Implementation Phase

NASA Projects	Technology Maturity	Design Stability	Complexity of Heritage Technology	Contractor Performance	Development Partner Performance	Development Cost Change	Launch Delay (months)
Aquarius		•			•	6%	10
Dawn			•	•		-2%	0
Gamma-ray Large Area Space Telescope		•	•	•	•	5%	9
Glory	•	•	•	•		53%	6
Herschel	•	•			•	13%	20
Kepler			•	•		25%	9
Lunar Reconnaissance Orbiter			•			0%	6 ^a
Mars Science Laboratory	•	•	•			26%	25
NPOESS Preparatory Project	•	•	•		•	19%	26
Orbiting Carbon Observatory		•		•		18%	5
Solar Dynamics Observatory		•		•	•	1%	17
Stratospheric Observatory for Infrared Astronomy			•	•		3%	9
Wide-field Infrared Survey Explorer		•				-1%	0

Source: GAO analysis of NASA project data.

Note: Shading indicates project exceeded cost and/or schedule baseline. A blank cell indicates the challenge does not apply to that particular project or the project did not supply data or make a projection of the data.

^aThe Lunar Reconnaissance Orbiter exceeded its schedule threshold by 5 months and 25 days, but the table shows 6 months due to rounding.

We did not specifically correlate individual project challenges with specific cost and/or schedule changes in each project. The degree to which specific challenges contributed to cost and schedule growth varied across the projects in this review. Nonetheless, since previous GAO work has demonstrated the impact of these challenges on cost and schedule growth and our discussions with NASA project officials identified the additional challenges we discuss as contributing to cost and schedule growth, we are

confident in our characterization of them for the purpose of this specific review.

Technology Maturity

Four of the thirteen projects in our assessment for which we received data and that had entered the implementation phase did so without first maturing all critical technologies.¹³ Further, three of those four projects had also not matured their critical technologies before continuing to assembly, integration, and testing. This means that needed knowledge about these technologies remained unknown well into development thereby adding potential cost and schedule risk to the projects. For example, five of the eight critical technologies for one instrument and three of the five critical technologies for another instrument identified by the Herschel project office were immature when the project moved into implementation. Almost two years later at the critical design reviews, four of the thirteen critical technologies for these two instruments were still immature, yet the project proceeded. When complex development programs proceed without understanding whether technologies can work as intended, they end up facing unanticipated technical problems that have costly, reverberating effects on other aspects of the program.

Design Stability

The majority of the projects in our assessment that held a critical design review did so without first achieving a stable design. GAO best practices recommend completion of at least 90 percent of engineering drawings at the critical design review to provide evidence that the design is stable. Though NASA's acquisition policy does not specify how the project should achieve design stability by the critical design review, NASA's system engineering handbook adheres to GAO's metric. Of the projects we were able to assess that had reached that point in their life-cycle, none had achieved design stability by the time they proceeded into assembly, integration, and testing.

All of the projects in our assessment that had reached their critical design review and that provided data on engineering drawings experienced some growth in the total number of design drawings after their critical design review. Growth ranged from 8 percent to, in the case of two projects, well over 100 percent. Some of this increase can be attributed to change in system design after the critical design review. For some projects, design changes after the critical design review were necessary due to problems in maturing technologies or issues found during testing. For example, the Mars Science Laboratory required several design changes to address various issues, including redesign of the plumbing for the propulsion system, which

¹³ Appendix IV provides a description of the metrics used to assess technology maturity in this review.

increased the drawing count by 67 percent from the critical design review to the time of our review.

Complexity of Heritage Technology

More than half the projects in the implementation phase—8 of them—encountered challenges in integrating or modifying heritage technologies. Additionally, two projects in formulation—Ares I and Orion—also encountered this challenge. We found that the projects that relied on heritage technologies underestimated the effort required to modify them to the necessary form, fit, or function. According to NASA officials, heritage technologies are not the same as critical technologies because, in their opinion, critical technologies are not based on existing—or heritage—technology. Generally, the project officials said that the technology they were using was not considered “new” if it had been demonstrated in a test environment or used on a prior mission, even if there needed to be a change or customization in configuration or design. Yet, these projects all failed to build in the necessary resources for technology modification. For example, the Kepler project office did not identify any critical technologies since all had flown on earlier missions, but viewed their modification as a design challenge for the Kepler mission. However, the project underestimated the effort required to modify the photometry array and, as a result, this challenge contributed to a 25 percent—or \$78 million—cost overrun and Kepler’s launch schedule being delayed by nine months.

Contractor Performance

Six of the seven projects that cited contractor performance as a challenge also experienced significant cost and/or schedule growth. Through our discussions with the project offices, we were informed that contractors encountered technical and design problems with hardware which disrupted development progress. Additionally, contractors lacked the experience in space systems that was required for the projects, which may be the underlying reason for these development challenges. For example, the Dawn contractor had no experience in deep space missions. Officials from the company acknowledged they had difficulty developing the spacecraft wiring. They also encountered problems developing the ion propulsion system for the spacecraft.

Contractors also faced workforce or corporate issues, such as closing facilities, lack of resources, and management inefficiencies. For example, the Glory project manager cited management inefficiencies with the instrument contractor. According to Glory project officials at NASA, among the drivers of these management inefficiencies were senior leadership changes, a loss of core competencies due to plant closure, and a lack of proper decision authority. The contractor agreed that the plant closure and the need to re-staff were major project challenges. In this case, as with

others in our review, the contractors forfeited their contract fees or spent the fee they had received from NASA to cover project costs.

Development Partner Performance

Five of the thirteen projects we reviewed encountered challenges with a development partner. In these cases, the development partner could not meet their commitments to the project within planned timeframes. This may have been a result of issues within the specific development partner organization or as a result of issues faced by a contractor to that development partner. For example, NASA is collaborating with the European Space Agency (ESA) on the Herschel space observatory. While NASA has delivered its two instruments to ESA, ESA has encountered difficulties developing its instruments and has delayed Herschel's launch by 14 months. Because of this delay, NASA has incurred about \$39 million in cost growth due to the need to fund component developers for a longer period of time than originally planned.

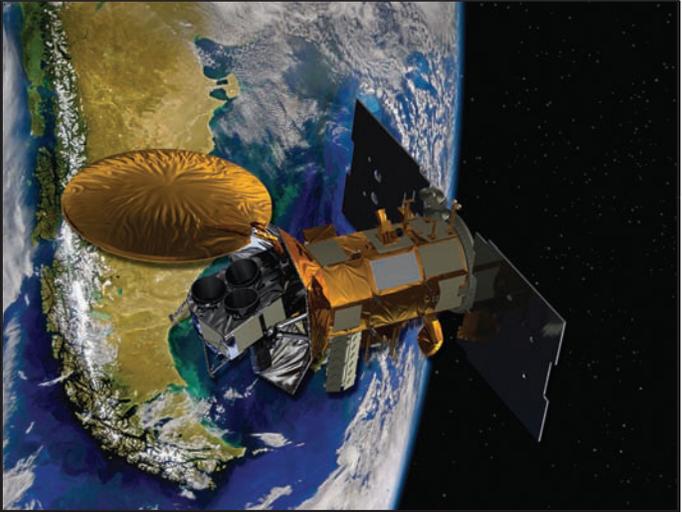
Assessments of Individual Projects

Our assessments of all 18 individual projects follow.

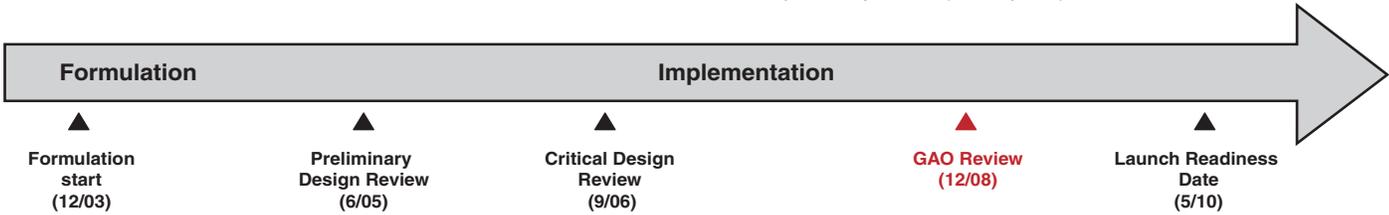
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Aquarius

Aquarius is a satellite mission developed by NASA and the Space Agency of Argentina (Comisión Nacional de Actividades Espaciales, CONAE) to investigate the links between the global water cycle, ocean circulation, and the climate. It will measure global sea surface salinity. The Aquarius science goals are to observe and model the processes that relate salinity variations to climatic changes in the global cycling of water and to understand how these variations influence the general ocean circulation. By measuring salinity globally for 3 years, Aquarius will provide an unprecedented new view of the ocean's role in climate.



Source: Aquarius Project Office (artist depiction).



Project Essentials

NASA Center Lead: Jet Propulsion Laboratory
International Partner: Argentina's National Committee of Space Activities (CONAE)

Major Contractors: in-house development

Projected Launch Date: May 23, 2010
Launch Location: Vandenberg AFB, Calif.
Launch Vehicle: Delta II

Mission Duration: 3 years for Aquarius mission
 5 years for SAC-D (CONAE) mission

Project Performance

(then year dollars in millions)

	Baseline Est. (FY 2008)	Latest (Dec. 2008)	Change
Total Project Cost	\$241.8	\$253.1	4.7%
Formulation Cost	\$35.5	\$35.6	0.3%
Development Cost	\$192.7	\$204.5	6.1%
Operations Cost	\$13.6	\$13.0	-4.4%

Launch Schedule	7/2009	5/2010	10 months
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- ### Project Challenges
- Design Stability
 - Development Partner Performance

Project Status

The launch for Aquarius has been delayed 10 months, from July 2009 to May 2010 because of delays in CONAE's spacecraft development activities. The launch delay prompted NASA to report to the Congress that the Aquarius project exceeded its development schedule threshold and caused NASA to experience a \$10.7 million cost increase. Based on the cost-sharing arrangements with CONAE, NASA will also bear its own costs associated with future delays. NASA has continued its development of the Aquarius instrument, which is currently scheduled for completion in March 2009 and shipment to CONAE in June 2009 for integration with the Argentine-developed spacecraft.

Aquarius

Detailed Project Discussion

The only critical technology the project office identified was the Aquarius instrument itself, which includes the scatterometer and the radiometer components. The project deemed the instrument mature at the preliminary design review because the instrument uses heritage technologies, even though those technologies were brought together in a different form, fit, and function for use on Aquarius. The instrument design, however, was not stable at the critical design review (CDR) as the Aquarius project had released only 16 percent of the engineering drawings. Project officials told us that some detailed parts were either not accounted for or not very mature at CDR, and they needed a follow-on review to clear up the issue. For example, details in the design of a connector arm of a reflector to the instrument were lagging. In addition, project officials said that the Aquarius instrument design was far ahead of development of CONAE's spacecraft, so the project could not finalize and release all the instrument drawings until CONAE finished the spacecraft design. To help minimize project risk in the interim, project officials said NASA provided CONAE with an engineering model to work with as the Argentines developed the spacecraft. All engineering drawings have now been released.

Aquarius' schedule slipped 10 months, prompting NASA to report to the Congress that the Aquarius program has exceeded its development schedule threshold. According to project officials and budget documents, a delay in development of the spacecraft bus by CONAE is the primary reason for the schedule slip. Project officials said that CONAE is using some newer and unfamiliar technologies on the spacecraft, such as lithium-ion batteries for power storage. NASA's review of CONAE's proposed schedule indicated that CONAE had made several high-risk decisions in order to meet a planned launch date of September 2009. For example, CONAE decided to begin flight model fabrication before completing adequate testing of the engineering models. Subsequent discussions between NASA and CONAE led to a decision to set a new launch date of May 2010. The spacecraft will also house several instruments for CONAE science missions. According to project officials, those instruments all appear to be on schedule, but officials added that none of those instruments are needed for NASA's Aquarius mission and that the mission would launch without the CONAE instruments if any were delayed.

NASA expects the Aquarius instrument to be completed in March 2009 and held until June 2009 when it will ship to Argentina to be integrated with the spacecraft. Since no funds are exchanged between the U.S. and Argentina for this project, NASA bears its own costs associated with any further delays for its portion that could occur. Project officials indicated that the schedule slip increased NASA's cost by \$10.7 million. They also noted that this cost increase does not include increased launch vehicle costs because of the delay or Delta-II launch site maintenance costs at Vandenberg Air Force Base.

Project Office Comments

The Aquarius project provided technical comments to a draft of this assessment, which were incorporated as appropriate. Project officials also commented that Aquarius had changes to its baseline due to slips by its development partner, the CONAE, and that they believe the NASA contribution to this mission is on schedule for completion in March 2009. They added that the benefit of the international partnership, plus the groundbreaking information about the Earth's climate, outweigh the additional costs, which NASA has chosen to absorb within its budget. Project officials said that NASA will continue to closely monitor progress and work with its development partner to minimize impacts.

Ares I Crew Launch Vehicle (CLV)

NASA's Ares I Crew Launch Vehicle, as part of the Constellation Program, is the next generation human spacecraft that will carry the Orion Crew Exploration Vehicle into low Earth orbit. The mission of the Ares I project is to deliver a safe, reliable, and affordable launch system for space exploration. Ares I will feature a 24.5-metric ton lift capability to carry crew to the Moon or deliver crew and cargo to the International Space Station.



Source: Ares Project Office (artist depiction).



Project Essentials

NASA Center Lead: Marshall Space Flight Center
International Partner: None

Major Contractors: Alliant Techsystems, Pratt and Whitney, Rocketdyne, Boeing

Projected Launch Date: March 2015
Launch Location: Kennedy Space Center, Fla.
Launch Vehicle: Ares I

Mission Duration: N/A

Project Performance (then year dollars in millions)

**Latest
(Jan. 2009)**

Preliminary Estimate of Project Life Cycle Cost*	\$17,000 to \$20,000
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**This estimate is preliminary, as the project is in formulation and there is still uncertainty in the value as design options are explored. NASA uses these estimates for planning purposes. This estimate is for the Ares I vehicle only.*

Launch Schedule	3/2015
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Project Challenges

- > Complexity of Heritage Technology

Project Status

Contract costs for the development the Ares I increased by \$304 million since initial award and the first manned launch has slipped from fiscal year 2014 to fiscal year 2015. The Ares I had planned to begin developmental flight testing in April 2009. However, delays to the planned Hubble Space Telescope servicing mission have impacted the project's ability to modify the launch pad needed to support planned testing, resulting in at least a 3-month delay to the first Ares I developmental flight test.

Ares I Crew Launch Vehicle (CLV)

Detailed Project Discussion

Because of the use of heritage systems and technology in system designs, Ares I project officials said they did not identify any critical technologies. However, we found that all three major elements of the Ares I system—the first stage, upper stage, and upper stage engine—face significant development challenges. The first stage draws heavily from existing Space Shuttle systems, but requires modifications such as incorporating a fifth segment that is likely to affect flight characteristics. In addition, modeling indicates that thrust oscillation within the first stage could cause unacceptable structural vibrations throughout the Ares I and Orion vehicles which could adversely affect crew safety if left unmitigated. NASA is considering solutions including incorporating tuned vibration absorbers into the Ares I first stage or adding a composite structure between the first and second stages. Thrust oscillation was again identified as a risk during the September 2008 preliminary design review, and the project has scheduled another review in the fall of 2009 to fully incorporate design solutions. The upper stage design includes a shared bulkhead between the hydrogen and oxygen fuel tanks, even though experience from the Apollo program shows that common bulkheads are complex and difficult to manufacture. The J-2X upper stage engine represents a new engine development effort that is likely to encounter problems during development; NASA estimates that J-2X will require 29 rework cycles to address problems, which they state is less than the number experienced during the development of other rocket engines.

NASA has not released official cost and schedule estimates to complete the Ares I program. NASA officials stated that these estimates will be made available when the project moves into implementation, or at the conclusion of the Constellation Program's non-advocate review. However, the value of various development contracts for the Ares I have increased by \$304 million since initial award, and the first manned launch has slipped from 2014 to 2015.

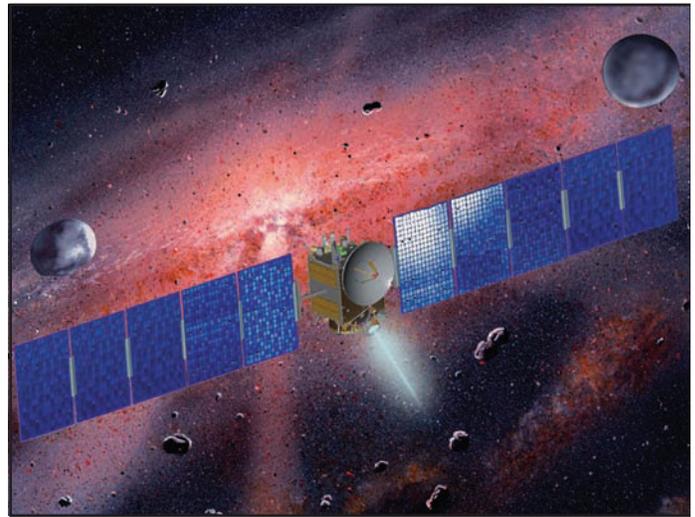
The project has already experienced schedule delays that they attribute to funding instability in fiscal years 2007 and 2008 and launch pad availability. Constellation's integrated risk management system also indicates there is a high risk that funding shortfalls could occur in fiscal years 2009 through 2012, resulting in planned work not being completed to support schedules and milestones. Further, the delayed Hubble Space Telescope servicing mission has caused the first planned Ares I developmental flight test—Ares I-X—to slip at least 3 months from April 2009 to July 2009. Since the Hubble mission will have a back up Shuttle for crew rescue purposes, thus utilizing both launch pads, the Ares I project cannot modify launch pad 39B for its use until the Hubble servicing mission is complete. NASA continues to develop an integrated schedule based on how the Hubble mission will impact pad modifications for the Ares I-X mission, as well as joint scheduling of a mobile launch platform and space in the Vertical Assembly Building.

Project Office Comments

The Ares I project office provided technical comments to a draft of this assessment, which were incorporated as appropriate. Project officials also commented that they believe the project has made progress in maturing the Ares I design and associated elements, and that all planned reviews have been executed on a schedule that supports the initial operating capability commitment. They added that the project is responding to technical and programmatic challenges, and they feel that all major element contracts are in place and are performing to plan.

Dawn

The Dawn mission is on a journey to the two largest asteroids in our solar system, Vesta and Ceres. Launched from Cape Canaveral in September 2007, the Dawn spacecraft will encounter and orbit Vesta 4 years later, then travel an additional three years to reach and orbit Ceres. The Dawn spacecraft will use solar-electric (ion) propulsion to reach and orbit Vesta for 7 months and Ceres for 5 months while performing scientific investigations at various altitudes and lighting conditions. Dawn will use imaging, spectroscopy, and gravity measurements to characterize the two asteroids—measuring their mass, gravity fields, principal axes, rotational axes, and moments of inertia.



Source: NASA/JPL/McREL; Background: William K. Hartmann, UCLA (artist depiction).



Project Essentials

NASA Center Lead: Jet Propulsion Laboratory
Partners: Los Alamos National Laboratories, German Aerospace Center (DLR) with the Max Planck Institute for Aeronomy, Agenzia Spaziale Italiana (ASI)

Major Contractors: Orbital Sciences Corporation

Launch Date: September 27, 2007
Launch Location: Cape Canaveral AFS, Fla.
Launch Vehicle: Delta II

Mission Duration: 8 Years

Project Performance
(then year dollars in millions)

	Baseline Est. (FY 2007)	Latest (Dec. 2008)	Change
Total Project Cost	\$460.4	\$465.0	1.0%
Formulation Cost	\$99.3	\$106.6	7.4%
Development Cost	\$273.7	\$269.4	-1.6%
Operations Cost	\$87.3	\$89.0	1.9%
Launch Schedule	9/2007	9/2007	none

Project Challenges

- > Complexity of Heritage Technology
- > Contractor Performance

Project Status

Dawn launched on September 27, 2007. The spacecraft is scheduled to begin the survey of Vesta on August 18, 2011 and then survey Ceres beginning February 18, 2015.

Dawn

Detailed Project Discussion

The Dawn project has been beset with funding issues. The project was approved for early formulation in January 2001, but was delayed nine months as NASA did not have the funds to proceed. Budget issues also caused a delay in the project as it moved through the formulation phase. The mission objectives were then modified to a baseline mission to Vesta with travel to Ceres as an extended mission. During the project's second confirmation review, NASA added the travel to Ceres as a primary mission objective. The project was also told to increase reserves to 25 percent to comply with JPL design principles which, according to project officials, were not written when the Dawn project was first proposed, causing the project to be de-scoped and under-funded at the beginning of implementation. Project management expended \$25 million in project reserves in the first year of implementation attempting to meet a June 2006 launch date, but the use of reserves was not conveyed to the mission directorate. In the subsequent year, the project experienced significant cost overruns. The project stopped development activities between October 2005 and January 2006 during a review by an Independent Assessment Team (IAT). The IAT reported technical issues with the project, recommended management changes, and stated a need for an additional \$57 million and a 12 to 18 month extension to complete implementation. According to project officials, NASA's Science Mission Directorate terminated the project in February 2006, but it was reinstated on appeal and resulted in a launch readiness date slip to June 2007. Ultimately, this one year launch delay cost the project an additional \$54 million.

JPL indicated that contractor performance led to several problems during Dawn's development, generally stemming from a lack of technical and corporate experience on the part of the prime contractor with regard to complex space systems, such as the ion propulsion system which contractor officials agreed was new to them. The IAT noted that JPL did not provide enough oversight of its contractor, which had no system-level planetary project implementation experience, to assure hardware delivery schedules would be met and software development activities could be accomplished on time and within budget. Project officials told us that other sub-contractors on the project also experienced development and testing issues. For example, a sub-contractor working on development of the ion propulsion system encountered problems that led to deficient workmanship and component failures, while another subcontractor had issues with development of the xenon tank for the ion propulsion system; both the flight tank and spare failed testing. As a result of these issues and other system level implementation issues, the project experienced cost overruns and the overall launch readiness date for the system slipped 15 months. Subsequently, the prime contractor suggested forfeiting part of their contract award fees to keep the project on cost and its mission intact, and NASA agreed.

The initial project proposal for Dawn assumed a high level of heritage technology for the ion propulsion system from the Deep Space One mission. According to project officials, inheritance reviews were conducted early in the life cycle for Dawn and the design was generally correct. A study performed during formulation should have derived that the cost and schedule assumptions of using heritage technology were not valid, but officials told us the study was not accurate. Problems with the heritage technology, however, were discovered in implementation, resulting in significant cost growth.

Project Office Comments

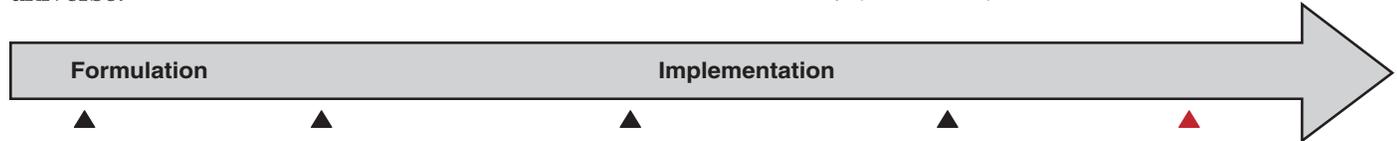
The Dawn project office provided technical comments to a draft of this assessment, which were incorporated as appropriate. Project officials said that NASA agrees that there were funding issues but points out that they were initially externally driven, which necessitated changes to project scope during the project life cycle and resulted in the prime contractor giving up their fee prior to confirmation. Project officials also agreed that there were technical challenges faced by both prime and by some sub-contractors, some of which were due to a higher expectation of heritage hardware than was actually the case.

Gamma-ray Large Area Space Telescope (GLAST)

The Gamma-ray Large Area Space Telescope (GLAST) seeks to improve understanding of the structure of the universe. By measuring the direction, energy, and arrival time of celestial high-energy gamma rays, GLAST will map the sky with 50 times the sensitivity of previous missions. GLAST's scientific payload includes two instruments: the Large Area Telescope (LAT) and the Gamma-ray Burst Monitor (GBM). The mission has four objectives: (1) understanding the mechanisms of particle acceleration in astrophysical environments; (2) determining the high-energy behavior of gamma-ray bursts; (3) resolving and identifying point sources with known objects; and (4) probing dark matter and the extra galactic background light in the early universe.



Source: Kennedy Space Center, Cape Canaveral, FL IMG RSC-08PD-1637.



Project Essentials

NASA Center Lead: Goddard Space Flight Center
Partners: U.S. Department of Energy, France, Germany, Japan, Italy and Sweden

Major Contractors: Stanford University, General Dynamics

Launch Date: June 11, 2008
Launch Location: Cape Canaveral AFS, Fla.
Launch Vehicle: Delta II

Mission Duration: 5 years (10 year goal)

Project Performance

(then year dollars in millions)

	Baseline Est. (FY 2007)	Latest (Dec 2008)	Change
Total Project Cost	\$723.3	\$774.5	7.1%
Formulation Cost	\$97.4	\$98.7	1.3%
Development Cost	\$403.3	\$423.0	4.9%
Operations Cost	\$222.5	\$252.8	13.6%
Launch Schedule	9/2007	6/2008	9 months

- ### Project Challenges
- Design Stability
 - Complexity of Heritage Technology
 - Contractor Performance
 - Development Partner Performance

Project Status

GLAST successfully launched into low Earth orbit on June 11, 2008.

Gamma-ray Large Area Space Telescope (GLAST)

Detailed Project Discussion

Prior to launch in June 2008, the GLAST project experienced several schedule delays because of conflicts over test facilities, launch pad time, and engineering issues. These delays resulted in NASA's reporting to the Congress that the GLAST project exceeded its schedule baseline by 8 months. Project officials told us that the spacecraft vendor gave priority to Department of Defense projects for thermal vacuum testing at its test facility. This action forced GLAST to be moved to the Naval Research Labs for testing. In order to accommodate GLAST, the alternate test facility required some minor modification. According to NASA officials, this resulted in a 3-month delay. A busy launch schedule at Cape Canaveral then made it difficult for GLAST to re-schedule its launch date, contributing to the remainder of the project's overall schedule slip.

Project officials said schedule slippage can also be attributed to heritage technology engineering problems. At the project's preliminary design review, GLAST had matured its one critical technology, while the rest were considered heritage technologies. The project considers the Large Area Telescope (LAT) a new instrument, though it is made up of several heritage technologies. According to a project official, the LAT has experienced both engineering design and electrical parts problems that resulted in schedule delays and the need for additional funding. Likewise, officials told us that a component of GLAST's command and data-handling system also features a new combination of heritage technology. Because of software and hardware problems, project officials said that the prime contractor had to bring this work, which had been outsourced to a sub-contractor, back in-house.

The project also identified partner issues that contributed to an increase in project cost. According to project officials, France initially was responsible for significant instrument integration work; however, the French were unable to complete that work and, as a result, the project office transferred it to the Naval Research Laboratory. This transfer increased costs by about \$5 million. In addition, officials said that Italy originally was supposed to supply the GLAST ground station with X-band communications. However, in 2003, Italian officials informed the project they could not keep this commitment. The antenna on the GLAST spacecraft now uses Ku-band communications instead. Italy also used an inexperienced contractor to produce GLAST's tracking towers, a situation that resulted in contamination problems. Project officials stated that these partner issues combined to increase the cost of the GLAST project and contributed to the \$45 million increase.

The GLAST project's design was not stable at critical design review as the project had released only 76 percent of its drawings and experienced a 31 percent growth in the number of drawings after the critical design review. Project officials attributed the growth to the withdrawal of the French partners, the change to a Ku-band transmitter and ground system, and the change in facility for producing the solar arrays.

Project Office Comments

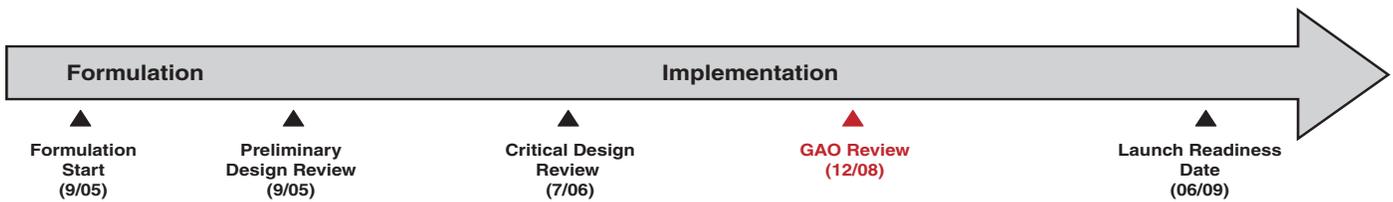
The GLAST project office provided technical comments on a draft of this assessment, which were incorporated as appropriate. Project officials also commented that they believe the principal project challenge was the loss of development partners, and that the eight month launch slip was caused by contractor performance and launch vehicle development issues. They did not consider design stability or the complexity of heritage technology as issues for this project.

Glory

The Glory project is a low-Earth orbit satellite that will contribute to the U.S. Climate Change Science Program. The satellite has two principal science objectives: (1) collect data on the properties of aerosols and black carbon in the Earth's atmosphere and climate systems and (2) collect data on solar irradiance. The satellite has two main instruments--the Aerosol Polarimetry Sensor (APS) and the Total Irradiance Monitor (TIM)--as well as two cloud cameras. The TIM will allow NASA to have uninterrupted solar irradiance data by bridging the gap between NASA's Solar Radiation and Climate Experiment and the National Polar Orbiting Environmental Satellite System (NPOESS) missions.



Source: Glory Project Office (artist depiction).



Project Essentials

NASA Center Lead: Goddard Space Flight Center
International Partner: None

Major Contractors: Raytheon Space and Airborne Systems, University of Colorado Laboratory for Atmospheric and Space Physics, Orbital Sciences Corporation

Projected Launch Date: June 2009
Launch Location: Vandenberg AFB, Calif.
Launch Vehicle: Taurus XL

Mission Duration: 3 years (5 year goal)

Project Performance
(then year dollars in millions)

	Baseline Est. (FY 2008)	Latest (Dec. 2008)	Change
Total Project Cost	\$266.1	\$347.9	30.7%
Formulation Cost	\$70.8	\$70.5	-0.4%
Development Cost	\$168.9	\$259.1	53.4%
Operations Cost	\$26.4	\$18.3	-30.7%

Launch Schedule	12/2008	6/2009	6 months
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- Project Challenges**
- Technology Maturity
 - Design Stability
 - Complexity of Heritage Technology
 - Contractor Performance

Project Status

The Glory project reported to the Congress that it exceeded its development cost threshold by 31 percent from its baseline, requiring the Congress to reauthorize Glory. The project is waiting for delivery of the APS, which is now projected for February 2009. The delivery of this instrument is over one year behind schedule. The launch date for Glory, originally scheduled for June 2008, is now scheduled for June 2009. The launch delay may require the project to report to the Congress that it will also exceed its development schedule baseline.

Glory

Detailed Project Discussion

The Glory project has experienced significant delays because of late delivery of the Aerosol Polarimetry Sensor (APS), which is based on heritage technology. At its preliminary design review in September 2005, the Glory project had one immature technology: the APS. At that review, the project estimated that the APS would be delivered by September 2007. According to the APS contractor, the instrument is now forecasted for delivery in February 2009—over one year behind schedule. The project identified contractor performance as the top risk facing the mission. Despite the contractor's performance, NASA has kept work on the APS with the company because the project believes it is more cost effective than starting a new in-house development project of this instrument. NASA estimated that an in-house development effort would cost an additional \$78 million and delay launch until February 2010. Glory project officials stated that the APS development problems do not stem from technical issues, but from the contractor's inability to plan and execute the work. The officials outlined several causes for the project's issues with the contractor, including the company consolidating its workforce and a resulting loss of APS corporate design knowledge. Contractor officials told us that along with moving the APS development effort from one facility to another, they made the decision to finish building the instrument with the new team rather than doing a complete design analysis. They said this led directly to cost and schedule increases as they had to perform more testing concurrent with the development of the instrument.

At the critical design review, the project's design was not stable as it had released only 70 percent of its drawings. As of GAO's review, 99 percent of total drawings have been released. However, Glory's drawing count increased by 27 percent after the critical design review. This increase is attributed to the modification of drawings for heritage parts for Glory's unique configuration.

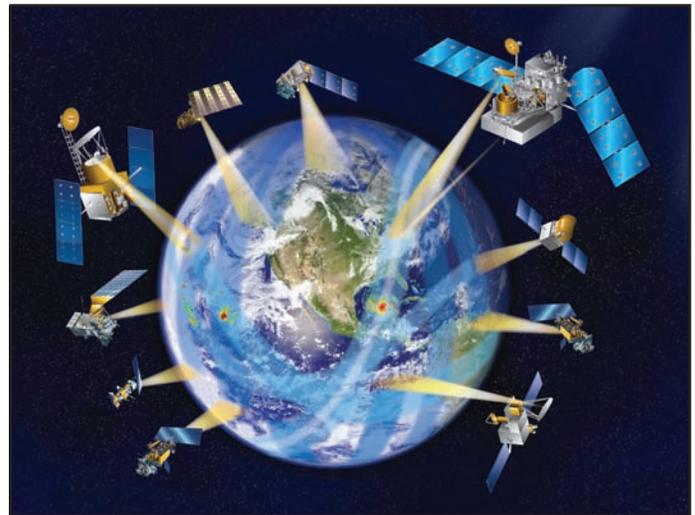
Since Glory was baselined in fiscal year 2008, the project's development costs have increased by 31 percent. As a result, NASA has reported to the Congress that Glory has exceeded its development cost threshold, requiring the Congress to reauthorize the project. Uncertainty in the project prior to its mission confirmation in 2005 delayed the launch readiness date from June 2008 to December 2008. More recently, the project's scheduled launch date has slipped from December 2008 to June 2009, which could cause the project to also have to report the slip to the Congress. According to project officials, Glory's recent cost and schedule issues are driven solely by the late delivery of the APS. The project has taken several steps to mitigate the cost increases caused by the delayed delivery of the APS and to improve the contractor's performance. The project has eliminated requirements, simplified the instrument design, provided NASA engineering and management resources to the contractor, and involved both NASA and contractor executives in addressing the problems. According to contractor officials, the company has used its award fee to cover the costs on this project. The company has also provided its own funding to help off-set cost overruns.

Project Office Comments

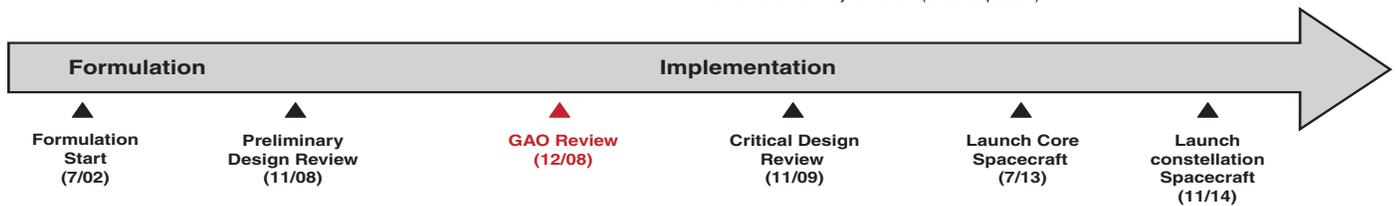
The project office provided technical comments to a draft of this assessment, which were incorporated as appropriate. Project officials also commented that since filing the threshold report, NASA has continued to pursue the baseline plan for the Glory implementation. They added that performance at the APS instrument supplier continues to be slow, but the instrument technical performance evaluated at each major developmental gate has been excellent. In addition, they believe the engineering design and the technical performance of the APS instrument have never been issues, and the programmatic issues have all been connected with the supplier's manufacturing and management.

Global Precipitation Measurement (GPM) Mission

The Global Precipitation Measurement (GPM) mission, a joint NASA and Japan Aerospace Exploration Agency (JAXA) project, seeks to improve the scientific understanding of the global water cycle and the accuracy of precipitation forecasts. The GPM is composed of a core spacecraft carrying two main instruments: a Dual-frequency Precipitation Radar (DPR) and a GPM Microwave Imager (GMI). In addition, the GPM project includes a second Low-Inclination spacecraft with a second GMI instrument. The GPM builds on the work of the Tropical Rainfall Measuring Mission, and will provide the first opportunity to calibrate measurements of global precipitation.



Source: GPM Project Office (artist depiction).



Project Essentials
<p>NASA Center: Goddard Space Flight Center International Partner: Japanese Aerospace Exploration Agency (JAXA)</p> <p>Major Contractors: Ball Aerospace</p> <p>Projected Launch Date: July 2013 Launch Location: Tanegashima Island, Japan Launch Vehicle: H-IIA (Japan)</p> <p>Mission Duration: 3 years (5 years consumables)</p>

Project Performance (then year dollars in millions)	
	Latest (Jan. 2009)
Preliminary Estimate of Project Life Cycle Cost*	not provided
<i>*NASA suggested it will provide baseline estimates for this project when it proceeds from formulation into implementation.</i>	
Launch Schedule	7/2013

Project Challenges
<ul style="list-style-type: none"> > None Currently Identified

Project Status

GPM is in the formulation phase and is expected to enter implementation after its mission confirmation review in the spring of 2009. Recent project budget changes show reductions in fiscal years 2009 and 2010. These reductions caused a project re-plan and delayed the scheduled development of the second GMI instrument by 1 year and delayed the launch of the Low-Inclination observatory by 5 months. The re-plan schedules a July 2013 launch of the core spacecraft at the latest as requested by JAXA.

Global Precipitation Measurement (GPM) Mission

Detailed Project Discussion

The GPM spacecraft and its components are being designed to be demisable—they will burn up during re-entry into the Earth's atmosphere to limit orbital debris—which poses a challenge for the project in the integration of the propellant management device with the craft's aluminum composite propulsion tanks. Neither the propellant management device nor the aluminum composite tanks are new technologies, but the integration of the two is the challenge. Currently, the integration of the propellant management device and the aluminum composite tank is not expected to be mature until after the preliminary design review. If the project is unable to sufficiently mature this technology, it will use a titanium propellant management device and/or tank that is less demisable.

The GPM project has not reached a design review where we could assess design stability based on our metric. The project currently has released 17 percent of its engineering drawings, but expects to have released only 70 percent of drawings at the critical design review. According to project officials, the two main instruments—the JAXA-supplied Dual-frequency Precipitation Radar (DPR) and the NASA-supplied GPM Microwave Imager (GMI)—are based on heritage technology and therefore are not considered critical technologies. However, the DPR and GMI will have to be adapted to the GPM spacecraft design for this mission. In addition, the DPR instrument includes a Ka-band radar that the project identified as a new design.

Project officials told us that JAXA has been frustrated by NASA's uncertainty over funding the GPM project and questioned NASA's commitment to the project. According to a March 2008 report from NASA's Inspector General, budget reductions to the GPM project in fiscal years 2005 through 2007 led to a 2-year delay in the contract for the development and delivery of the GMI. These reductions caused the launch of the core spacecraft to be delayed from 2007 to 2013 and the cost estimate to rise from \$600 million to over \$1 billion. In early 2008, NASA signed a launch vehicle agreement with JAXA. Subsequently, the preliminary design and critical design reviews were scheduled for the project.

The project's budget was recently reduced for fiscal years 2009 and 2010. Following these cuts, NASA directed the project to re-plan with two constraints: 1) maintain the core spacecraft launch date of June 2013 but let the Low-Inclination spacecraft slip as necessary and, 2) accept increased programmatic risk from low contingency funds in fiscal year 2009. The re-plan presented maintains the core spacecraft to a July 2013 launch date requested by JAXA, but the start of work on the second GMI instrument is delayed by one year and the launch of the Constellation observatory is delayed by 5 months. As a result of the reduction in funding levels, NASA considers fiscal year 2009 as a high-risk year for the project since it now has low contingency reserves of approximately 5 percent.

Project Office Comments

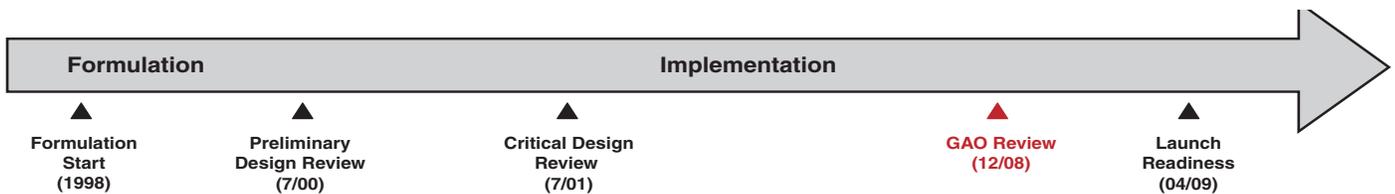
The project office provided technical comments to a draft of this assessment, which were incorporated as appropriate. Project officials said that following the numerous mission delays that drove the launch date from 2008 to the current July 2013, the sustained funding increases the GPM project has received since the fiscal year 2008 budget has enabled steady progress towards mission confirmation and implementation in fiscal year 2009. They added that JAXA has been satisfied with this progress, including the formal agreement concluded in early 2008 between NASA and JAXA on the use of the H-IIA launch vehicle to launch the Core Observatory. Project officials believe they will have a stable design since they plan to have necessary hardware manufacturing drawings released by the critical design review.

Herschel

The Herschel Space observatory, a collaborative project between NASA and the European Space Agency (ESA), will seek to discover how the first galaxies formed and how they evolved to give rise to present day galaxies like our own. Herschel has the largest mirror ever built for a space telescope. At 3.5 meters in diameter, the mirror will collect long-wavelength radiation from some of the coldest and most distant objects in the Universe. It will be able to observe dust-obscured and cold objects that are invisible to other telescopes. Additional targets for Herschel will include clouds of gas and dust where new stars are being born, disks out of which planets may form, and cometary atmospheres packed with complex organic molecules.



Source: ESA/AOES Medialab (artist depiction).



Project Essentials

NASA Center Lead: Jet Propulsion Laboratory
International Partner: European Space Agency (ESA)

Major Contractors: in-house development

Projected Launch Date: April 2009
Launch Location: Kourou, French Guiana
Launch Vehicle: Ariane 5 (ESA Supplied)

Mission Duration: 3 years (5 year goal)

Project Performance
(then year dollars in millions)

	Baseline Est. (FY 2007)	Latest (Dec. 2008)	Change
Total Project Cost	\$325.4	\$276.8	-14.9%
Formulation Cost	\$10.4	\$10.4	0.0%
Development Cost	\$117.0	\$131.7	12.6%
Operations Cost	\$198.0	\$134.7	-32.0%

	8/2007	4/2009	20 months
Launch Schedule			

Project Challenges

- Technology Maturity
- Design Stability
- Development Partner Performance

Project Status

Since Herschel's baseline was established in 2007, ESA slipped the Herschel launch schedule three times because of scope changes and challenges with integration of the instruments onto the spacecraft. A recent slip resulted in a project cost increase of \$43 million and required NASA to report to the Congress that it exceeded its schedule baseline. The project is currently behind schedule by about 50 days, a delay that has caused a fourth launch date slip from its current October 2008 date to April 2009.

Herschel

Detailed Project Discussion

NASA has completed the development of components for two Herschel instruments—the Heterodyne Instrument for the Far Infrared (HIFI) and the Spectral and Photometric Imaging Receiver (SPIRE) instrument—and delivered them to ESA. However, during both the preliminary and critical design reviews, some of the critical technologies for these elements were considered immature. At the preliminary design review (PDR) for HIFI, five of the eight critical technologies were immature. Later, at critical design review (CDR), two of the eight HIFI critical technologies were still assessed as immature. SPIRE had a similar record. At SPIRE's PDR, three of the five critical technologies were assessed as being immature. Two years later at CDR, two of five SPIRE critical technologies were still assessed as immature. Regardless of this, the project proceeded. After delivery of NASA's components, problems were found during testing of the equipment in Europe. According to the project office, the HIFI failed in thermal cycling during testing and SPIRE had problems with the wiring that connects its detectors. The technical issues with the two instruments cost \$3.9 million to resolve.

In addition to technology maturity issues, NASA committed to developing components for the HIFI and SPIRE instruments before achieving design stability for the instruments. At the CDR for both the HIFI and SPIRE instruments, NASA had released less than 10 percent of the engineering design drawings. According to the project office, this was primarily due to the fact that ESA's interface drawings were in preliminary format. The office also said that the lack of timeliness in the submission of design drawings is a challenge when the project has to depend on multiple partners for input.

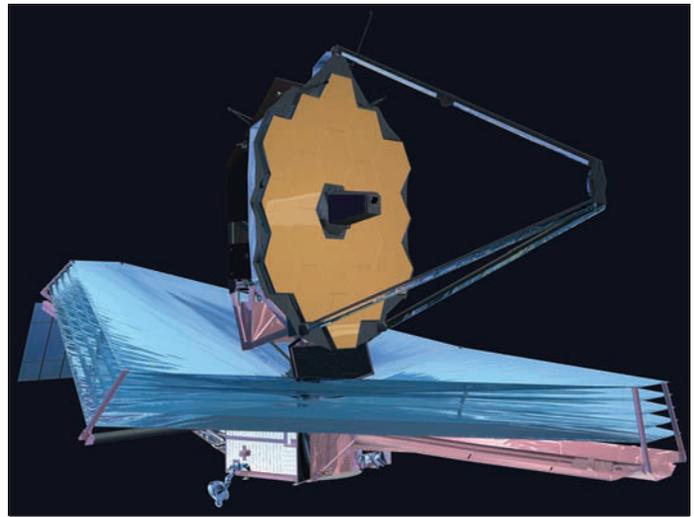
Herschel's \$43 million growth in life cycle costs can be largely attributed to technical integration problems, which resulted in launch delays. Those delays are also the primary cause of overall schedule slippage. ESA's contractor could not complete development of its instruments or integrate Herschel instruments in a timely manner, prompting ESA to pull the integration work in-house. While NASA faced some technical problems with development of components for the HIFI and SPIRE instruments, resulting in about \$3.9 million of cost growth, project officials said the remaining increase of about \$39 million is due to the three slips in Herschel's launch date since the project's baseline was established in February 2007 since the project must maintain a workforce to support testing and integration activities. Based on the 14-month delay in launch date, NASA reported to the Congress in February 2008 that the Herschel project has exceeded its schedule baseline. Herschel's launch schedule has now slipped even further. The project office stated that Herschel is currently behind schedule by about 50 days, which caused the launch date to slip from its current October 2008 date to early in calendar year 2009.

Project Office Comments

The Herschel project office provided technical comments to a draft of this assessment, which were incorporated as appropriate. Project officials also commented that although NASA did have some technical issues with their hardware contributions which did cause an increase to the NASA cost in order to correct the problems, the majority of the cost increase to NASA has been due to technical problems on the European side which have caused the launch to slip several times in the last several years.

James Webb Space Telescope (JWST)

The James Webb Space Telescope (JWST) is a large, infrared-optimized space telescope that is designed to find the first galaxies that formed in the early universe. The focus of scientific study will include first light, assembly of galaxies, origins of stars and planetary systems, and origins of the elements necessary for life. JWST's instruments will be designed to work primarily in the infrared range of the electromagnetic spectrum, with some capability in the visible range. JWST will have a large mirror, 6.5 meters (21.3 feet) in diameter and a sunshade the size of a tennis court. Both the mirror and sunshade will not fit onto the rocket fully open, so both will fold up and open once JWST is in outer space. JWST will reside in an orbit about 1.5 million kilometers (1 million miles) from the Earth.



Source: JWST Project Office (artist depiction).



Project Essentials

NASA Center Lead: Goddard Space Flight Center
International Partner: European Space Agency (ESA), Canadian Space Agency (CSA)

Major Contractors: Northrop Grumman

Projected Launch Date: June 2013
Launch Location: Kourou, French Guiana
Launch Vehicle: Ariane 5 (ESA Supplied)

Mission Duration: 5 years (10 year goal)

Project Performance

(then year dollars in millions)

	Latest* (Jan. 2009)
Total Project Cost	Not provided
Formulation Cost	Not provided
Development Cost	Not provided
Operations Cost	Not provided

**NASA suggested it will supply the baseline estimates for this project when it provides them to Congress in the FY10 Budget Request.*

Launch Schedule 6/2013

Project Challenges

- > None Currently Identified

Project Status

The JWST project was re-planned in fiscal year 2006 after a \$1 billion cost increase—\$3.5 billion to \$4.5 billion—and a 2-year schedule delay on the project. A major risk that continued to affect the project following this re-plan was the low level and late phasing of contingency funding budgeted, despite 12 percent of the \$1 billion cost growth being used to increase such funding. Although JWST passed its preliminary design review, the project still has to address several issues related to testing.

James Webb Space Telescope (JWST)

Detailed Project Discussion

The JWST project was re-planned in fiscal year 2006 after a \$1 billion cost increase and a 2-year schedule delay on the project. About half of the cost growth was because of a 1-year schedule slip, resulting from a delayed decision to use an ESA-supplied Ariane 5 launch vehicle and an additional 10-month slip caused by budget profile limitations in fiscal years 2006 and 2007. Changes in requirements and a 12 percent increase in the program's contingency funding accounted for the remainder of the growth. Despite this increase in contingency funding (i.e., reserves), the level and phasing of contingency funding budgeted for the project continues to be a major risk. An independent review team expressed concern over the contingency funding, stating that it is too low and phased in too late. Further, it stated that a contingency fund of 25 percent to 30 percent would be appropriate for a project through implementation. Goddard Space Flight Center policies also require reserves of 25 percent through Phase D, Implementation. NASA directed its Science Mission Directorate to address the JWST reserves issue at the project's confirmation reviews in the summer of 2008. The project budgeted for 5 years of operation for JWST, instead of 10 years of mission operations, which, according to the JWST Deputy Associate Director, saved the project approximately \$300 million.

Prior to the re-plan in fiscal year 2006, the JWST project was set to proceed into development with immature technologies. Because of substantial cost growth on the project and as part of the 2006 re-plan, NASA decided to invest additional time and resources in maturing JWST's critical technologies prior to the preliminary design review. JWST held a technology non advocate review in January 2007 to assess the maturity of its ten critical technologies. At that time, all but one of the critical technologies was assessed as mature, the remaining critical technology—the cryocooler—has since been matured. Maturing critical technologies on the project prior to entering implementation was a significant step to reducing risk. The JWST project office also had 53 percent of its design drawings released at its preliminary design review in March 2008 and anticipates that it will have 94 percent of its design drawings released by the critical design review in June 2009.

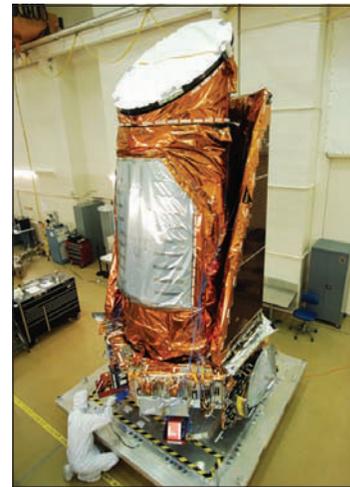
Although JWST passed its preliminary design review, the project still has to address several issues related to testing. One concern is that the project plans to do only one test at the highest level of assembly possible in the cryogenic vacuum chamber at the Johnson Space Center. The review panel advised JWST to add another test cycle to its schedule. Further, the board recommended the addition of a center of curvature test on the Optical Telescope Element and was also concerned that the project was not planning to test the sunshield at the highest level of assembly in the cryogenic vacuum chamber. The project is still working through how to address such testing issues.

Project Office Comments

The JWST project provided technical comments to a draft of this assessment, which were incorporated as appropriate. Project officials said they generally agree with the assessment as presented. Project officials commented that the specific concern expressed by the review team was that the project's baseline plan only included one cryogenic thermal vacuum test opportunity at the integrated level of assembly, but the officials added that the specific tests that will be conducted during that one cryogenic thermal vacuum test opportunity are numerous and comprehensive. Project officials said to address the review team's concern in this regard, the project has accounted for the cost of the additional cryogenic testing, should it eventually be required.

Kepler

The Kepler mission has been designed to discover Earth-like planets in orbit around stars in our galaxy. The goal is to detect tens or even hundreds of Earth-size planets in the habitable zones of stars similar to our own sun. The habitable zone is the region around a star where the temperature of a terrestrial-type planet can be expected to allow water to exist in liquid form on the planet's surface, thereby increasing the probability of life. Kepler will explore the structure and diversity of planetary systems by conducting a census of extra-solar terrestrial planets using a photometer in heliocentric orbit to observe the dimming of starlight caused by planetary transits.



Source: Ball Aerospace.



Project Essentials

NASA Center Lead: Jet Propulsion Laboratory
International Partner: None

Major Contractors: Ball Aerospace and Technologies Corp.

Projected Launch Date: March 2009
Launch Location: Cape Canaveral AFS, Fla.
Launch Vehicle: Delta II

Mission Duration: 3.5 years

Project Performance
(then year dollars in millions)

	Baseline Est. (FY 2007)	Latest (Dec. 2008)	Change
Total Project Cost	\$497.5	\$594.8	19.6%
Formulation Cost	\$138.1	\$141.2	2.2%
Development Cost	\$312.8	\$390.3	24.8%
Operations Cost	\$46.6	\$63.3	35.8%
Launch Schedule	6/2008	3/2009	9 months

- Project Challenges**
- > Complexity of Heritage Technology
 - > Contractor Performance

Project Status

Since being baselined in fiscal year 2007, NASA has reported to the Congress that both Kepler's development costs and schedule have exceeded the baseline. During that time, Kepler's development costs have increased by about \$78 million—or 25 percent—and its schedule has increased by 9 months, despite a reliance on heritage technologies. Kepler project officials attribute the cost and schedule growth to contractor performance problems, cost overruns, and the disruption caused by a \$35-million budget reduction in fiscal year 2005.

Kepler

Detailed Project Discussion

None of Kepler's technologies were identified as critical by the project management office because all of Kepler's technologies have flown on other missions and are therefore considered heritage. However, the project office acknowledged that the customization of some of Kepler's instruments, and the reliance on heritage technology has proven to be a challenge to Kepler's development. Project officials told us that Kepler's large photometry array added to the complexity of the project because photometers of Kepler's sensitivity have not flown before and proved more difficult to adapt than anticipated; an adaptation that contributed to cost growth. Officials added that the Kepler photometer requires a low noise level in its signal chain in order to detect changes in the brightness of stars. This made developing the electronics for the focal plane array a challenge. The focal plane array is the largest ever flown in space and has stringent requirements. Coupled with the high density of elements and electrical and thermal attachments, this makes the assembly and tests of this element a key challenge for the project.

We were unable to determine if Kepler's design was stable at its critical design review. According to the project office, the prime contractor, Ball Aerospace and Technologies Corporation, implemented a new drawing management system called Agile, and the project did not have any way to recover the forecast drawings count at the critical design phase in October 2006. However, the project reports that 96 percent of its engineering design drawings have been released to the manufacturer.

Kepler's total cost and overall schedule have increased significantly. Since being baselined in fiscal year 2007, Kepler's development costs have increased by about \$78 million—or 25 percent—and its schedule has increased by nine months. NASA has reported to the Congress that both Kepler's development costs and schedule have exceeded the baseline. The project office attributes the cost and schedule growth to contractor performance problems, which occurred because the prime contractor was unable to execute the project planned activities within the cost and schedule they proposed, despite a reliance on heritage technology. Contractor officials agreed that they underestimated the complexity and the effort required to modify the existing these technologies. Both the Kepler project manager and contractor officials also believe that a \$35 million funding cut in the program because of funding constraints in fiscal year 2005 was a significant contributor of the project's delays. This funding instability, according to a NASA project official, contributed to an overall 20-month delay in the project's schedule and about \$169 million in cost growth.

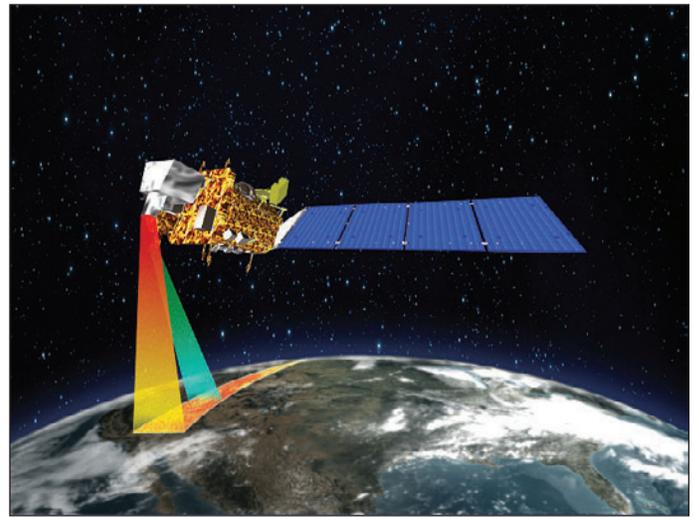
Both the project office and the prime contractor made changes to ensure that the project remained executable with sufficient reserves. The project office shortened the operations period by 6 months and accepted additional project risk when it cancelled or de-scoped several tests. For example, the flight segment vibration test was reduced to an acoustic test, and the vibration tests of the solar panel were removed. Additionally, the prime contractor put new management personnel in place and according to contractor officials, agreed to commit \$7 million of its projected award fee to a cost performance incentive that may allow the contractor to earn the fee later in the project's life cycle.

Project Office Comments

The Kepler project office provided technical comments to a draft of this assessment, which were incorporated as appropriate. Project officials also commented that Kepler instrument uses existing technology components in a new and complex instrument design, and that the contractor underestimated the complexity and effort required to develop the instrument system and subsystems. They added that after the 2006 re-baselining of the project, the contractor continued to have problems with the instrument development resulting in additional cost and schedule overruns. They said the project was able to absorb this cost increase by de-scoping elements of the program, delaying the guest observer science program and reducing the mission duration by 6 months.

Landsat Data Continuity Mission (LDCM)

The Landsat Data Continuity Mission (LDCM), a partnership between NASA and the U.S. Geological Service (USGS), seeks to extend the ability to detect and quantitatively characterize changes on the global land surface at a scale where natural and man-made causes of change can be detected and differentiated. It is the successor mission to Landsat 7. The Landsat data series, begun in 1972, is the longest continuous record of changes in the Earth's surface as seen from space. Landsat data is a unique resource for people who work in agriculture, geology, forestry, regional planning, education, mapping, and global change research.



Source: General Dynamics Advanced Information Systems (artist depiction).

Formulation		Implementation		
▲	▲	▲	▲	▲
Formulation Start (10/03)	Preliminary Design Review (11/08)	GAO Review (12/08)	Critical Design Review (8/09)	Launch Readiness Date (12/12)
<div style="border: 1px solid black; padding: 5px;"> <p style="text-align: center;">Project Essentials</p> <p>NASA Center: Goddard Space Flight Center Partner: U.S. Geological Service (USGS)</p> <p>Major Contractors: Ball Aerospace and Technologies Corp., General Dynamics Advanced Information Systems, The Hammers Company</p> <p>Projected Launch Date: December 2012 Launch Location: Vandenberg AFB, Calif. Launch Vehicle: Atlas V</p> <p>Mission Duration: 5 years (10 years propellant)</p> </div>		<div style="border: 1px solid black; padding: 5px;"> <p style="text-align: center;">Project Performance (then year dollars in millions)</p> <p style="text-align: right;">Latest* (Jan. 2009)</p> <p>Preliminary Estimate of Project Life Cycle Cost* \$730 to \$800</p> <p><i>*This estimate is preliminary, as the project is in formulation and there is still uncertainty in the value as design options, are explored. NASA uses these estimates for planning purposes.</i></p> <hr/> <p>Launch Schedule 12/2012</p> </div>		
<div style="border: 1px solid black; padding: 5px;"> <p style="text-align: center;">Project Challenges</p> <p>➤ None Currently Identified</p> </div>		<div style="border: 1px solid black; padding: 5px;"> <p style="text-align: center;">Project Status</p> <p>The LDCM project shifted its estimated launch date from July 2011 to December 2012 after it completed its Initial Mission Confirmation Review in September 2008. The LDCM project is on an aggressive 39-month development schedule for the main instrument. The LDCM instrument payload consists of a single science instrument, the Operational Land Imager (OLI); however, NASA is considering the addition of another science instrument—a decision that could exacerbate the already aggressive schedule and add cost.</p> </div>		

Landsat Data Continuity Mission (LDCM)

Detailed Project Discussion

The LDCM instrument payload consists of a single science instrument—the Operational Land Imager (OLI). The project considered the addition of two other science instruments—the Thermal Infrared Sensor (TIRS) and the Total Solar Irradiance Sensor (TSIS). The project has decided not to add TSIS, but will continue studying whether TIRS will be included. The project hopes to receive funding for completion of the TIRS instrument in spring 2009. The spacecraft is being designed to accommodate TIRS and both the spacecraft and OLI developers are studying the impacts of adding TIRS. According to a project official, Goddard Space Flight Center would develop and build TIRS in-house, a process that would take approximately 48 months. If TIRS is added to the LDCM mission, however, it could delay launch by over a year and, according to a project official, cost about \$5 million for the redesign of the spacecraft to accommodate the instrument. This design cost does not include the cost of integrating the instrument onto the spacecraft. Project officials have indicated that LDCM has already undertaken an aggressive 39-month OLI development schedule. According to the contractor for the OLI instrument, this aggressive schedule was necessary because of delays in the procurement process. The LDCM project delayed its estimated launch date from July 2011 to December 2012 after it completed its Initial Mission Confirmation Review in September 2008. While a launch after January 2012 could jeopardize the continuity of Landsat data, project officials said recent reliability analyses show that the Landsat 7 satellite may be operational until 2017, lessening the likelihood of a data gap.

The project office has identified four critical technologies for the OLI instrument. Three of the four critical technologies—the wide field of view optics, linear arrays, and modular sensor chip assemblies—are considered fully mature as they have been fully validated by the Earth Observing Satellite (EO-1) mission through scene comparisons with Landsat 7. The sensor assembly chips for the OLI are considered mature since prototypes were included on the Advanced Land Imager that flew on EO-1. The project does not anticipate that there will be any additional critical technologies for the spacecraft because most of the technology used to build the spacecraft will be commercial off-the-shelf items that have flown on other missions.

Because LDCM has not yet reached its critical design review, we were unable to assess design stability of the project at this time. The project office anticipates having over 95 percent of the flight design and manufacturing drawings complete by the critical design review currently scheduled for August 2009. The spacecraft contract was awarded in April 2008, and the project office anticipates releasing the spacecraft drawings after design maturation. Formal cost and schedule baselines will be established for the project at the Mission Confirmation Review in 2009.

Project Office Comments

The project office provided technical comments to a draft of this assessment, which were incorporated as appropriate. The project office also commented that NASA and the OLI instrument vendor are making steady progress on the OLI instrument on the planned schedule. The project is developing detailed schedules now to ensure sufficient schedule reserve is applied to the critical hardware developments.

Lunar Reconnaissance Orbiter (LRO)

The Lunar Reconnaissance Orbiter (LRO) is NASA's first mission in the implementation of the Vision for Space Exploration, the plan to return to the moon and beyond. LRO's mission is to orbit the moon for one year measuring lunar topography, resources, and thermal and radiation environments. This data will be used to select a landing site for future manned missions to the moon and to ensure astronaut safety. The LRO has a scientific payload of six main instruments and one technology demonstration instrument. LRO's launch vehicle contains a secondary payload, the Lunar Crater Observation and Sensing Satellite (LCROSS), which will investigate lunar surface volatiles such as water.



Source: LRO Project Office.



Project Essentials

NASA Center Lead: Goddard Space Flight Center
Partner: Boston University, University of California Los Angeles, Southwest Research Institute, Russian Institute for Space Research, Arizona State University, Naval Air Warfare Center
Prime Contractors: in-house development

Projected Launch Date: April 24, 2009
Launch Location: Cape Canaveral AFS, Fla.
Launch Vehicle: Atlas V

Mission Duration: 1 year (then science mission)

Project Performance
(then year dollars in millions)

	Baseline Est. (FY 2008)	Latest (Dec. 2008)	Change
Total Project Cost	\$540.1	\$540.1	0.0%
Formulation Cost	\$93.3	\$94.8	1.6%
Development Cost	\$420.8	\$422.4	0.4%
Operations Cost	\$25.8	\$22.9	-11.2%

Launch Schedule 10/2008 4/2009 6 months*

**Actual launch delay is currently 5 months and 25 days.*

Project Challenges

- > Complexity of Heritage Technology

Project Status

LRO's original schedule with a launch date by the end of 2008 placed the project on a challenging and aggressive development schedule. This schedule is driven by the need to provide data for the Orion and Ares I hardware designs and mission planning efforts for a human lunar mission by 2020. The project experienced challenges modifying instruments for the moon's thermal environment. These challenges, along with a decision by the launch authority to re-prioritize the LRO launch on its manifest, contributed to a launch slip to April 2009.

Lunar Reconnaissance Orbiter (LRO)

Detailed Project Discussion

The project did not identify any critical technologies. Each of the project's major instruments is based significantly on heritage technology. However, the project manager said the project had underestimated the difficulty of the modifications needed. For example, the project manager said the Lunar Reconnaissance Orbiter Cameras needed some technical work to adapt their designs for the lunar thermal environment as well as some redesign when areas needing reinforcement were found during testing. The Lunar Orbiter Laser Altimeter, while similar to laser altimeters that have flown on previous Mars and Mercury missions, had issues with the electronics that time the laser pulses of the altimeter, which, according to the project manager, took more time to resolve than originally expected. The Diviner Lunar Radiometer Experiment instrument is almost a copy of an instrument on Mars now, but experienced motor failures, which the project manager said took extra time and money to recover from. Finally, the Lyman-Alpha Mapping Project instrument, a copy of the Pluto Alice instrument, was slightly delayed because of a detector failure during thermal vacuum testing. According to the project manager, most instruments required additional design and analysis of their thermal control designs to operate reliably on the mission. Redesign was necessary because the lunar environment presents a harsher thermal environment than the environment faced by earth-orbiting missions.

The project did not measure design stability by percentage of drawings completed at the critical design review (CDR), and therefore was not assessed according to this metric.

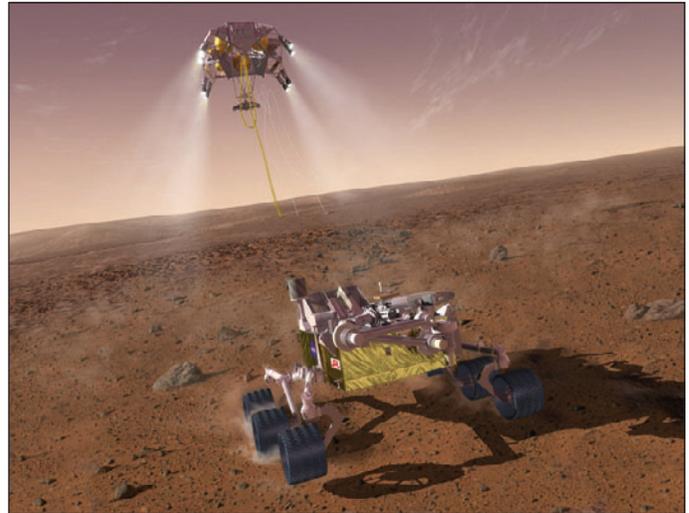
Project officials said NASA gave LRO more reserve funding because of the aggressive schedule on the project to compensate for schedule slippages. Most challenges faced by the project occurred prior to the confirmation review, so officials stated that the project will probably finish at about only 3 percent above the confirmation cost estimate. However, late delivery of instruments from project partners and a decision by the launch authority to slip the LRO launch date both contributed to the project's launch date being delayed 6 months from October 2008 to April 2009.

Project Office Comments

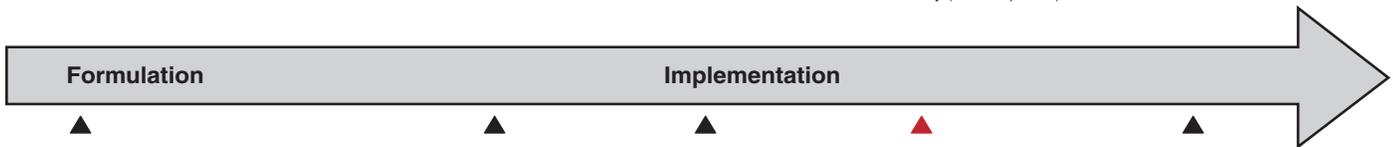
The LRO project office provided technical comments to a draft of this assessment, which were incorporated as appropriate. Project officials also commented that the change in launch date from December 2008 to April 2009 was made to accommodate other launch priorities and as well as technical problems with the launch vehicle. Project officials noted that, while LRO's schedule was aggressive, schedule reserve had been built in to accommodate late instrument deliveries and the project was on track for a December 2008 launch. They added that the additional time afforded by the new April 2009 launch date is being used by the project to perform additional testing and mission simulations.

Mars Science Laboratory (MSL)

The Mars Science Laboratory (MSL) is part of the Mars Exploration Program (MEP). The MEP seeks to understand whether Mars was, is, or can be a habitable world. To answer this question the MSL project will investigate how geologic, climatic, and other processes have worked to shape Mars and its environment over time, as well as how they interact today. The MSL will continue this systematic exploration by placing a mobile science laboratory on the Mars surface to quantitatively assess a local site as a potential habitat for life, past or present. The MSL is considered one of NASA's flagship projects and will be the most advanced rover ever sent to explore the surface of Mars.



Source: Mars Science Laboratory (artist depiction).



Project Essentials

NASA Center Lead: Jet Propulsion Laboratory
Partners: U.S. Department of Energy, Centre Nationale d'Etude Spatiale (France), Russian Federal Space Agency, Centro de Astrobiologia (Spain), Canadian Space Agency

Major Contractors: none — in-house development

Projected Launch Date: October, 2011
Launch Location: Cape Canaveral AFS, Fla.
Launch Vehicle: Atlas V

Mission Duration: 1 year - travel, 2 years - operations

Project Performance

(then year dollars in millions)

	Baseline Est. (FY 2008)	Latest (Dec. 2008)	Change
Total Project Cost	\$1642.2	\$1899.6	15.7%
Formulation Cost	\$515.1	\$515.5	0.1%
Development Cost	\$968.6	\$1225.0	26.5%
Operations Cost	\$158.5	\$159.1	0.4%
Launch Schedule	9/2009	10/2011	25 months

Project Challenges

- Technology Maturity
- Design Stability
- Complexity of Heritage Technology

Project Status

Since the project was baselined, MSL has experienced significant cost growth—over \$200 million thus far, or more than a 26 percent increase in development costs—because of technological and engineering problems. While the project has overcome design and weight growth issues, it continues to face other technical challenges that contributed to MSL's launch delay from October 2009 to October 2011. This launch delay will result in about \$400 million in cost growth as the project works to resolve its remaining technical risks.

Mars Science Laboratory (MSL)

Detailed Project Discussion

At the project's preliminary design review, the project assessed all seven of critical technologies as immature resulting from late development challenges encountered. At the critical design review a year later, three of the seven critical technologies had been replaced by backup technologies with two of the seven still assessed as immature, including one of the replacement technologies. In addition, MSL's design was never stabilized at the critical design review. Several design changes were required to address various issues. For example, the plumbing for the propulsion system was redesigned because it was determined that MSL needed larger, rigid lines for the system than were previously used on smaller Mars rovers. These thicker lines inadvertently became load-bearing components, which caused the project to redesign part of the structure to account for the loads and shift them to MSL's primary structure.

MSL has relied on several heritage technologies that have had to be re-designed, re-engineered, or replaced for use on the lab. For example, the heatshield made of a super light-weight ablator that had flown on previous missions was considered nearly ready at the critical design review, but it suffered a significant setback in testing and could not be proved for use on MSL. The project had to select a new and less mature technology—phenolic impregnated carbon ablator (PICA). According to the MSL project office, the impact of this change was approximately \$30 million in cost growth and a nine-month delay in delivery of the heat shield.

Significant weight growth has occurred during MSL's development bringing the spacecraft to 90 percent of its mass threshold according to MSL project officials. For example, MSL's project manager said that the project wanted to implement a dry lubrication scheme with lightweight titanium gears for the actuators, or motors that allow the lab to function autonomously. During fabrication, however, it was discovered that the lightweight titanium gears did not provide the durability needed for MSL, causing the project to revert to the heavier stainless steel gear system with wet lubricant used by prior projects. To keep the lubricant from freezing in Martian temperatures, the project also had to add heaters to the actuators, adding even more mass to the rover.

The project cost has grown by over \$200 million in the last year—more than a 26 percent increase in development costs—and will increase even more due to the launch delay from October 2009 to 2011. The project could not meet its original schedule due to difficulty in meeting delivery milestones for actuators, key avionics, and flight software while maintaining its full testing program. Since Mars launch windows are optimally aligned every 26 months, the project has to delay its planned launch to October 2011. As a result of the launch delay, project officials state that costs will likely grow by an estimated \$400 million bringing the project's life-cycle cost to \$2.2 to \$2.3 billion.

Project Office Comments

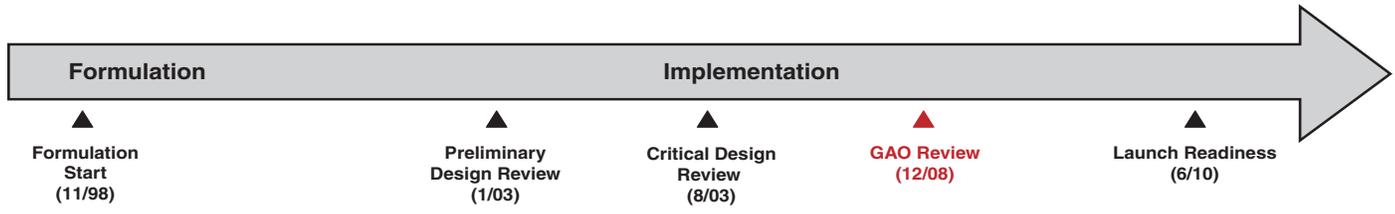
The MSL project office provided technical comments on a draft of this assessment, which were incorporated as appropriate. The project also commented that while most of the system development is on track, MSL cannot meet its October 2009 launch date due to a few critical elements that are lagging. Project officials said the MSL launch is now scheduled for the fall of 2011, which is the next opportunity for an optimally aligned Earth-Mars transit.

NPOESS Preparatory Project (NPP)

The NPOESS Preparatory Project (NPP) is a joint mission with the National Oceanic and Atmospheric Administration and the U.S. Air Force. The satellite will measure ozone, atmospheric and sea surface temperatures, land and ocean biological productivity, and cloud and aerosol properties. The NPP mission has two objectives. First, NPP will provide a continuation of global observations following the Earth Observing System missions Terra and Aqua. Second, NPP will provide the National Polar-orbiting Operational Environmental Satellite System (NPOESS) with risk-reduction demonstration and validation for the critical NPOESS sensors, algorithms, and ground data processing.



Source: Ball Aerospace.



Project Essentials

NASA Center Lead: Goddard Space Flight Center
Partner: National Atmospheric and Oceanic Administration and U.S. Air Force

Major Contractors: Northrop Grumman Electrical Systems and Ball Aerospace and Technologies Corp.

Projected Launch Date: June 2, 2010
Launch Location: Vandenberg AFB, Calif.
Launch Vehicle: Delta II

Mission Duration: 5 years

Project Performance

(then year dollars in millions)

	Baseline Est. (FY 2007)	Latest (Dec. 2008)	Change
Total Project Cost	\$672.8	\$794.6	18.1%
Formulation Cost	\$47.3	\$47.0	-0.6%
Development Cost	\$593.0	\$703.7	18.7%
Operations Cost	\$32.5	\$43.9	35.1%
Launch Schedule	4/2008	6/2010	26 months

- ### Project Challenges
- Technology Maturity
 - Design Stability
 - Complexity of Heritage Technology
 - Development Partner Performance

Project Status

Due primarily to the late delivery of a key instrument being developed by project partners, the NPP project has experienced nearly \$111 million in development cost growth and a 26-month delay in its launch readiness date since being baselined in fiscal year 2007. As a result, NASA has reported to the Congress that the NPP project has exceeded both its cost and schedule thresholds. The NPP project office is monitoring the risk of further instrument delivery delays.

NPOESS Preparatory Project (NPP)

Detailed Project Discussion

The NPP project office identified six critical technologies for the project—the spacecraft and all five instruments. Five of the six critical technologies were assessed as immature at the preliminary and critical design reviews. The Clouds' and the Earth's Radiant Energy System (CERES) instrument was the only mature technology, and according to project officials this instrument was only added back to the mission when it was determined that development of other instruments would cause a significant launch delay. Many of the spacecraft's components and subsystems have flown on previous missions and are therefore mature. The NPP project office now considers all critical technologies to be mature.

The project's design was unstable at the critical design review (CDR). Two instruments being developed by the Integrated Program Office (IPO), which is composed of National Oceanic and Atmospheric Administration and Department of Defense officials, are the Cross-track Infrared Sounder (CrIS) and the Visible Infrared Imaging Radiometer Suite (VIIRS). Both had to be redesigned because of failures that were detected during testing after the CDR. The project office said a 31 percent increase in new engineering drawings was largely attributed to the redesign of the VIIRS and CrIS stemming from testing failures. According to a project official, the CrIS structure development multiple fractures during testing and needed to be stripped to its components and rebuilt. The project official also said the VIIRS could not meet its science requirement of detecting ocean color because of the poor quality of its filters. The official indicated a problem exists with the system's requirements and not the ability of the contractor to produce the correct filters. An official for the contractor building the VIIRS instrument said the original requirement was unachievable and the filters will be improved for the second VIIRS instrument, which will be a part of the NPOESS mission.

Since NPP was baselined in fiscal year 2007, the project's development costs increased by about \$111 million, or almost 19 percent, and its schedule has increased by 26 months. As a result, NASA has reported to the Congress that the NPP project has exceeded both its cost and schedule thresholds. The project office attributes almost all of the cost and schedule changes to the late delivery of the VIIRS instrument by the project partners. The instrument is now scheduled to be delivered in April 2009. An official for the VIIRS instrument contractor cites the presence of multiple government customers and ongoing requirements changes as the reasons for the delay and increase in cost. Neither the IPO nor the NPOESS prime contractor, according to NASA's NPP project manager, provided adequate oversight of the VIIRS contractor during the development of VIIRS. While there is no contractual relationship between NASA and the VIIRS contractor, project officials told us NASA now has two engineers at the prime contractor's facility to oversee the design and development of the instrument. Additional delay in instrument delivery could result in observatory integration delays, cost increases, schedule slips, and possible gaps in data continuity.

Project Office Comments

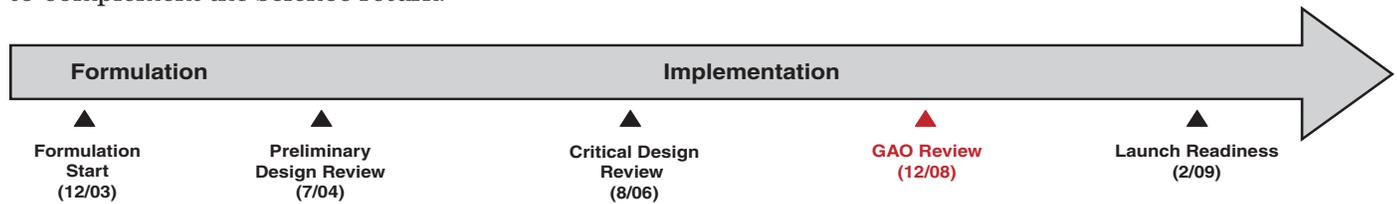
The NPP project office provided technical comments on a draft of this assessment, which were incorporated as appropriate. The project also commented that the NASA-developed instruments did not experience challenges with design stability, rather it was NASA's partners' instruments. They added that the VIIRS performance requirements have remained stable since the critical design review and the primary drivers of the schedule delay are issues found during fabrication and testing of the engineering and flight models. Project officials said the VIIRS instrument continues to incur delays during environmental testing which will likely result in a delay in NPP launch readiness beyond June 2010. NASA has provided the NPOESS IPO additional expertise to help provide more oversight to attempt to minimize additional delays and increase the likelihood of VIIRS meeting performance goals.

Orbiting Carbon Observatory (OCO)

NASA's Orbiting Carbon Observatory (OCO) seeks to enable more reliable forecasts of climate change. It will make the first global measurements of atmospheric carbon dioxide with the precision and resolution needed to characterize production and loss rates. These measurements will improve mankind's understanding of the processes that regulate atmospheric carbon dioxide. The OCO payload consists of a single unit instrument with three high resolution grating spectrometers. Each of these spectrometers records the intensity of radiation over one of three very narrow Near Infrared bands that are sensitive to the presence of carbon dioxide and oxygen. The observatory will fly in loose formation with other satellites to enable synergy and to complement the science return.



Source: Jet Propulsion Laboratory (artist depiction).



Project Essentials

NASA Center Lead: Jet Propulsion Laboratory
International Partner: None

Major Contractors: Hamilton Sundstrand Corp. and Orbital Sciences Corp.

Projected Launch Date: February 23, 2009
Launch Location: Vandenberg AFB, Calif.
Launch Vehicle: Taurus XL

Mission Duration: 2 years

Project Performance (then year dollars in millions)

	Baseline Est. (FY 2008)	Latest (Dec. 2008)	Change
Total Project Cost	\$235.2	\$273.1	16.1%
Formulation Cost	\$31.0	\$32.5	4.8%
Development Cost	\$186.4	\$219.7	17.9%
Operations Cost	\$17.8	\$20.9	17.4%
<hr/>			
Launch Schedule	9/2008	2/2009	5 months

Project Challenges

- Design Stability
- Contractor Performance

Project Status

OCO's launch date slipped from September 2008 to February 2009, and NASA reported to the Congress that the project's development cost increased 18 percent from the baseline established in fiscal year 2008. On February 24, 2009, OCO launched but failed to reach orbit.

Orbiting Carbon Observatory (OCO)

Detailed Project Discussion

The only critical technology for OCO, its three-channel grating spectrometer, was considered mature at the mission's preliminary design review. However, technical problems arose for the instrument after its critical design review (CDR) in August 2006. Testing results showed that the detectors used in the instrument suffer from a residual image problem when they transition from a bright-to-dark image. This is an inherent characteristic of the detectors and the error in data will be corrected by ground-based software. In addition, OCO's design was not stable at CDR as the project reported that it had only released 66 percent of its engineering drawings. Following CDR, the project also experienced a 15 percent increase in the total number of drawings expected. According to project officials, the increase was attributed to the changes made in the system design to address structural issues. The project has since released all of its engineering drawings.

According to project officials, the contractor developing the three-channel spectrometer underestimated the cost to develop the instrument. In December 2005, OCO project management began providing its own personnel to augment the contractor's workforce in order to mitigate schedule slippage. Reviews of the instrument design identified areas that would not withstand launch and/or flight forces—a finding that necessitated a redesign of the instrument structure. According to the deputy project manager, the contract was modified to bring responsibility for the instrument's integration and testing activity in house. Project management stated that the contractor did not receive its award fee because of its poor performance, but will still be eligible for on-orbit award fees.

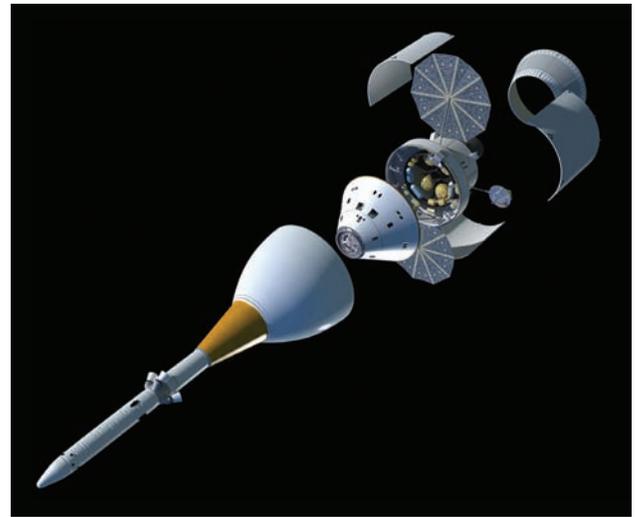
OCO has experienced cost increases and schedule delays, and NASA has reported to the Congress that OCO has exceeded its development cost baseline. According to project officials, the project did not receive funding to begin its preliminary design phase in 2003, resulting in a one year schedule delay and an increase to the estimated mission cost of approximately \$60 million. In addition, the movement of the instrument work in-house in October 2006 led to an increase in development costs and an inability to maintain the planned September 2008 launch date. NASA recently reported to the Congress an 18 percent increase in development cost from the baseline established in fiscal year 2008 and a schedule slip to December 2008. OCO was ready to launch in December but a delay at Vandenberg Air Force Base pushed the launch into 2009.

Project Office Comments

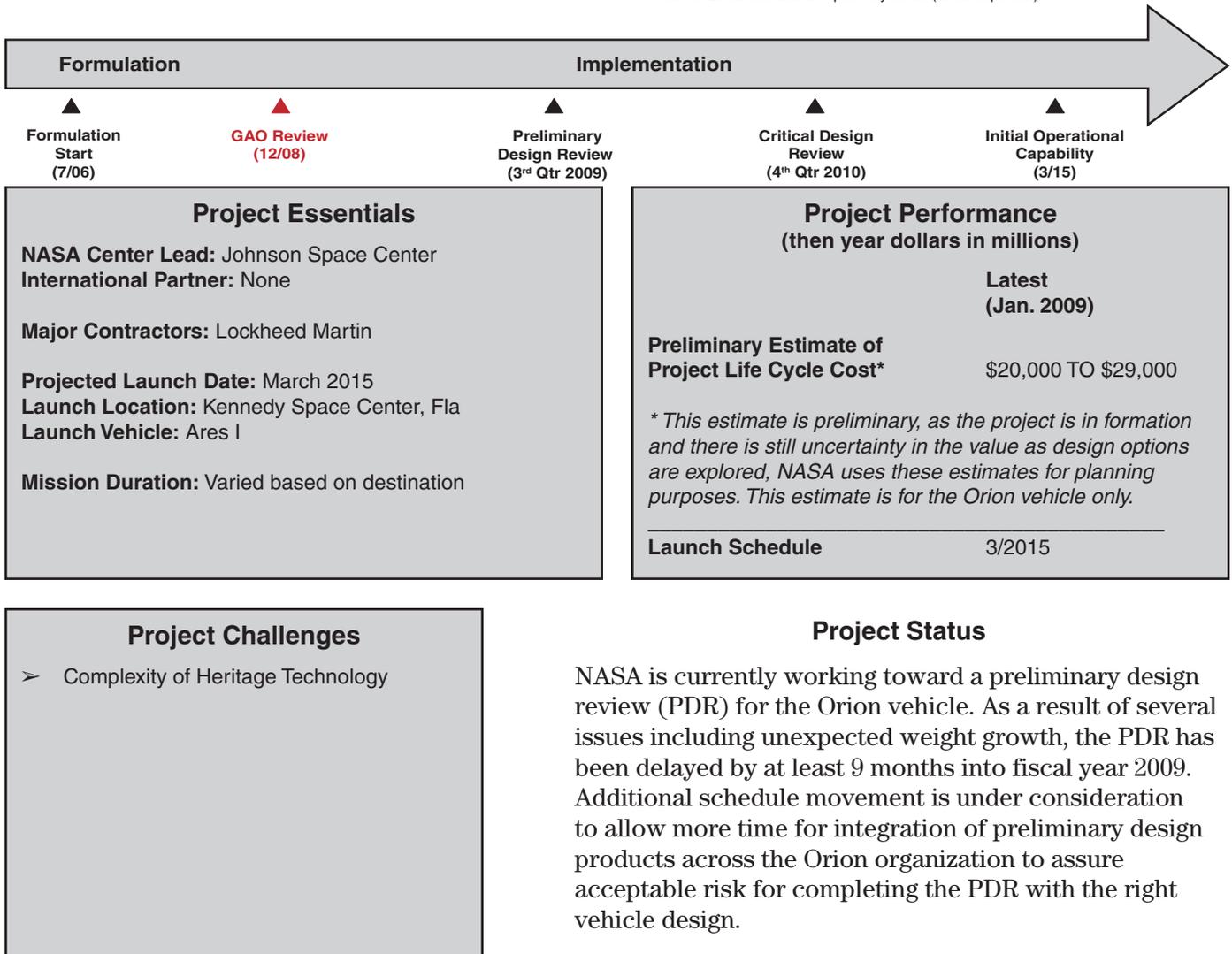
The OCO project office provided technical comments to a draft of this assessment, which were incorporated as appropriate. In addition, project officials commented that they believe the instrument and mission design were stable at the critical design review and neither have experienced significant changes to the CDR-approved design. They added that the project did experience problems during instrument development, assembly, and testing which prompted the project to be rebaselined. Since then, they stated that the project has stayed within its planned cost and schedule and was prepared to launch in December 2008, but was delayed because of unavailability of the launch range and launch vehicle certification issues.

Orion Crew Exploration Vehicle (CEV)

NASA's Orion Crew Exploration Vehicle (CEV), as part of the Constellation Program, is the next-generation spacecraft to carry crew and cargo to the International Space Station and to the Moon. The Constellation Program includes the CEV and a launch system that will replace the Space Shuttle, which is slated to retire in 2010. The five-meter diameter Orion capsule is to be launched by the Ares I Crew Launch Vehicle. Orion will carry up to six astronauts to the International Space Station or four astronauts to the Moon after linking up with a lunar lander. The capsule will return to Earth and descend on parachutes to the surface. Orion has three main elements—the crew module (capsule), service module/spacecraft adapter, and launch abort system.



Source: Lockheed Martin Space Systems (artist depiction).



Orion Crew Exploration Vehicle (CEV)

Detailed Project Discussion

The Orion project identified three critical technologies for the spacecraft: the phenolic impregnated carbon ablator (PICA) heat shield, which was used on Stardust, NASA's comet sample return mission, landing airbags, and landing parachutes. The project identified a backup heat shield technology for PICA. Project officials said that both heat shield technologies have some heritage to earlier NASA missions, but both technologies have distinct risks. According to officials, PICA must be built and applied to Orion in sections creating gaps between the sections that need to be filled, similar to Space Shuttle tiles. The backup is lighter than PICA, but more difficult to manufacture. The PICA material is the chosen technology for the thermal protection system, but project officials said that they will select a single technology at PDR based on performance, how difficult it is to produce, weight, and cost. The project expects that all technologies will be mature by the preliminary design review. We found, however, that the heat shield development and manufacturing schedule is at risk and may impact Orion's test schedule. In addition, Orion faces challenges in the development of the attitude control motor for the launch abort system. While similar attitude control motors have been demonstrated before, Orion's motor design is complex, and any failures during developmental testing may cause unexpected delays.

Although the Orion project has not reached a design review where we could assess design stability based on our metric, NASA recognizes that continued weight growth and requirements changes are contributing to instability in the Orion design. For example, according to agency officials, continuing Orion weight growth led NASA to redesign the Orion vehicle in fall 2007. As a result of engineering trade-offs that were made during this process, NASA modified the requirement for landing on land to landing in water, which would reduce vehicle mass. The Orion project is still working on these issues and has not yet finalized requirements or design.

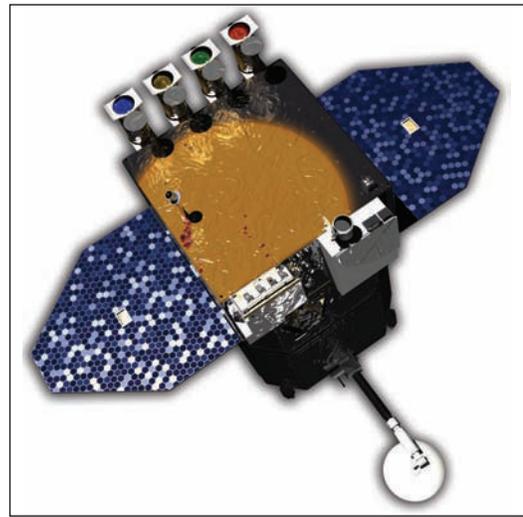
At the time of our review, NASA had not released cost and schedule estimates for completing the Orion project. NASA officials stated that these estimates will be made available at the conclusion of the Constellation Program non-advocate review, which takes place after PDR, when all NASA projects establish an integrated cost and schedule baseline. According to the Constellation program's risk database, there is a high risk that Orion could face funding shortfalls in fiscal years 2009 through 2012, resulting in planned testing not being completed in time to support schedule and milestones. Furthermore, schedule delays have already occurred as a result of unexpected efforts to resolve mass, power, and other architecture issues and because the project needed sufficient time to attain an acceptable level of design risk.

Project Office Comments

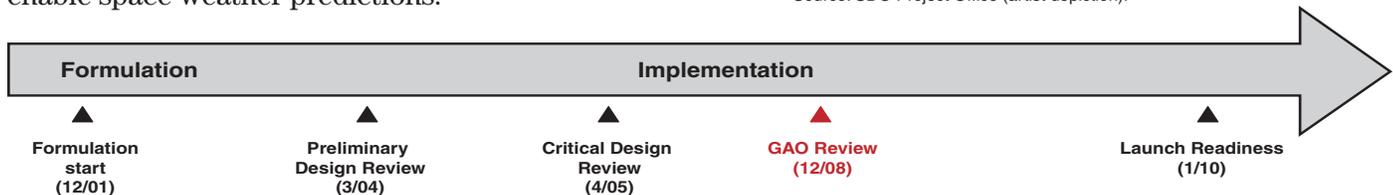
The Orion project office provided technical comments to a draft of this assessment, which were incorporated as appropriate. The project office also commented that they believe steady progress has been made in all technology areas and appropriate technology readiness will be achieved prior to PDR in late summer 2009. They also believe that the Orion project has achieved stability in requirements growth and that NASA will continue to narrow design options as the project moves toward a confirmed baseline design. Project officials added the project is on schedule to finalize the choice of material for the heat shield by March 2009.

Solar Dynamics Observatory (SDO)

NASA's Solar Dynamics Observatory (SDO) will investigate how the Sun's magnetic field is structured and how its energy is converted and released into the heliosphere in the forms of solar wind, energetic particles, and variations in solar irradiance. The primary goal of the SDO mission is to understand the solar variations that influence life on Earth and humanity's technological systems. It seeks to do this by determining how the Sun's magnetic field is generated and structured, and how this stored magnetic energy is released. Analysis of data from SDO's three instruments—Atmospheric Imaging Assembly (AIA), Extreme Ultraviolet Variability Experiment (EVE), and Helioseismic and Magnetic Imager (HMI)—will improve the science needed to enable space weather predictions.



Source: SDO Project Office (artist depiction).



Project Essentials
NASA Center Lead: Goddard Space Flight Center
International Partner: None
Major Contractors: Stanford University, Lockheed Martin Solar Astrophysics Laboratory, University of Colorado
Projected Launch Date: January 2010
Launch Location: Kennedy Space Center, Fla.
Launch Vehicle: Atlas V
Mission Duration: 5 years (10 year goal)

Project Performance (then year dollars in millions)			
	Baseline Est. (FY 2007)	Latest (Dec. 2008)	Change
Total Project Cost	\$785.5	\$817.0	4.0%
Formulation Cost	\$78.0	\$85.8	10.0%
Development Cost	\$623.7	\$629.6	0.9%
Operations Cost	\$83.8	\$101.6	21.2%
Launch Schedule	8/2008	1/2010	17 months

Project Challenges
➤ Design Stability
➤ Contractor Performance
➤ Development Partner Performance

Project Status

SDO has experienced significant launch schedule delays. Funding cuts in fiscal year 2005 caused the project to slip SDO's launch date from April to August 2008. Subsequent test scheduling issues and spacecraft parts problems caused a further delay until December 2008. A crowded launch manifest has now forced a 13-month delay to January 2010.

Solar Dynamics Observatory (SDO)

Detailed Project Discussion

The SDO project reported that its only critical technology—a 4K x 4K array of charge-coupled devices (CCD) to be used in both the HMI and AIA instruments—was mature at the project’s preliminary design review. The United Kingdom originally led development of the CCD camera systems, but dropped out of the project before the preliminary design review. Project officials also stated that SDO was purposefully designed to use existing technology components, but recognized that some technologies—such as the Ka-band transmitter, high-speed bus, and high-gain antenna system—required modifications to be used on SDO. For example, the existing technology for the Ka-band transmitter required a new design for integration with SDO. Project officials told us that originally Northrop Grumman was to build the Ka-band transmitter, but its development was brought in house after contractor performance issues arose.

SDO’s design was not stable at the critical design review (CDR). Following this review, the project experienced nearly a 1,200 percent increase in the number of releasable drawings expected. Project officials said only drawings for in-house structures such as propulsion systems, electronics, instrument ports, the high-gain antenna system, and the spacecraft were considered at CDR. Drawings for the instruments were not included and flight drawings were only in draft form at CDR. Project officials indicated that flight drawings did not need to be ready so far in advance of the project’s launch readiness date since there was enough time to build these components.

SDO also experienced several problems during testing of flight hardware. The project suffered a technical setback in 2007 when the thermal vacuum chamber being used to test the high gain antenna overheated, resulting in the need to completely rebuild the antenna. Several other risks to the project were identified during testing. For example, testing identified a part on the spacecraft’s high-speed bus that, under certain circumstances, could cause the spacecraft to reset itself, which could mean failure to meet science data quality and completeness requirements.

At the time of its critical design review in April 2005, the SDO project budget was reduced by one third for fiscal year 2005 because of other funding priorities. As a result, the project underwent a replan that delayed the project’s launch readiness date from April 2008 to August 2008. Subsequent scheduling issues for testing of the AIA instrument and other spacecraft parts problems caused further delays and cost increases: the launch date slipped to December 2008 resulting in a cost increase of \$18.1 million. Because of launch manifest issues, SDO’s launch date has since slipped to January 2010.

Project Office Comments

The SDO project office provided technical comments to a draft of this assessment, which were incorporated as appropriate. The project office commented that all of the problems they found during testing have been corrected, and that they believe the SDO design has been relatively stable and drawing releases occurred as planned. Project officials also said the project combined technology components in new ways in a new type of design, but the technologies themselves were not modified. They reported that SDO has been integrated and tested and is awaiting launch. Officials said the current delay and resulting cost increase is due to a crowded launch manifest.

Stratospheric Observatory for Infrared Astronomy (SOFIA)

SOFIA is a joint project between NASA and the German Space Agency (DLR) to install a 2.5 meter telescope in a specially modified Boeing 747SP aircraft. This airborne observatory is designed to provide routine access to the visual, infrared, far-infrared, and sub-millimeter parts of the spectrum. Its mission objectives include studying many different kinds of astronomical objects and phenomena, including star birth and death; the formation of new solar systems; planets, comets, and asteroids in our solar system; and black holes at the center of galaxies. Interchangeable instruments for the observatory are being developed to allow a range of scientific measurement to be taken by SOFIA.



Source: SOFIA Program Office.



Project Essentials

NASA Center Lead: Dryden Flight Research Center
International Partner: German Space Agency (DLR)

Major Contractors: L3 Communications, MPC Products Corporation, University Space Research Association

Projected Operational Capability: August 2009
Aircraft: Modified 747SP
Sortie Location: Dryden Flight Research Center, Calif.

Mission Duration: 20 years of science mission flights

Project Performance
(then year dollars in millions)

	Baseline Est. (FY 2007)	Latest (Dec. 2008)	Change
Total Project Cost	\$2954.5	\$2580.8	-12.6%
Formulation Cost	\$35.0	\$35.0	0.0%
Development Cost	\$919.5	\$946.4	2.9%
Operations Cost	\$2000.0	\$1599.4	-20.0%

Launch Schedule	12/2013	9/2014	9 months
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- Project Challenges**
- Complexity of Heritage Technology
 - Contractor Performance

Project Status

SOFIA plans to have its first science flight in 2009. The SOFIA project was rebaselined in fiscal year 2007; its development costs have grown to almost four times its original estimate. The rebaseline sought to achieve science objectives earlier than previously planned, but resulted in a 9 month delay in full operational capability. Cost growth is in part because of challenges with the modification of the aircraft used as the platform for SOFIA. Project officials said the aircraft modification proved to be more complex job than anticipated.

Stratospheric Observatory for Infrared Astronomy (SOFIA)

Detailed Project Discussion

We could not assess the technology maturity or the design stability of the overall project as NASA did not provide information related to the aircraft modification. Data provided for development of the instruments that will fly on SOFIA generally indicates a high level of technology maturity. Many of these technologies have already been used on ground-based telescopes, and the early instruments are essentially finished and have been waiting for the observatory to be completed. Similarly, we could not assess design stability of the instruments since the drawings were still preliminary at the critical design review.

NASA experienced challenges with the modification of the aircraft used as the platform for the SOFIA project, which led to significant cost overruns. Contributing to this challenge, according to project officials, was the aircraft manufacturer's refusal to provide the blueprints for the 747SP. The plane had to be reverse engineered, making the modifications more difficult. Project officials also said that the contractor responsible for the aircraft's modification and integration had limited experience with this type of work and did not fully understand the statement of work, further contributing to cost overruns.

The SOFIA project also experienced problems related to the original prime contractor's performance earlier in development. The SOFIA program manager said the original prime contractor was tasked to lead the project and NASA would purchase the raw data collected by SOFIA from the contractor. According to another NASA official, that contractor had neither the project management experience nor the design-build expertise necessary for the project—a situation that contributed to some of the SOFIA project's problems. Consequently, NASA brought overall management of both development and operations of SOFIA in-house to achieve stronger technical, cost, and schedule controls. Project management was restructured and operational responsibility now resides with NASA's Dryden Flight Research Center, while NASA's Ames Research Center manages the project's science. The original contractor is still under contract for some science operations and instrument development.

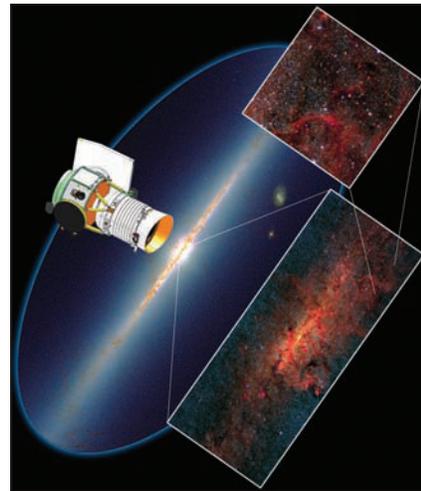
As a result of ongoing cost growth early in development, the SOFIA project underwent a review in 2006. The project was slated for cancellation in 2006, and no funds were allocated to it in that fiscal year. However, later that year, SOFIA was reinstated. In 2007, it was redesigned and, in July of that year, rebaselined. This new plan sought to be more responsive to the science community and achieve science objectives earlier than previously planned by performing science flights while still maturing the aircraft and telescope, but resulted in a 9-month delay in full operational capability. SOFIA's current development costs are estimated to be about \$950 million, almost four times the estimated development costs in 1997.

Project Office Comments

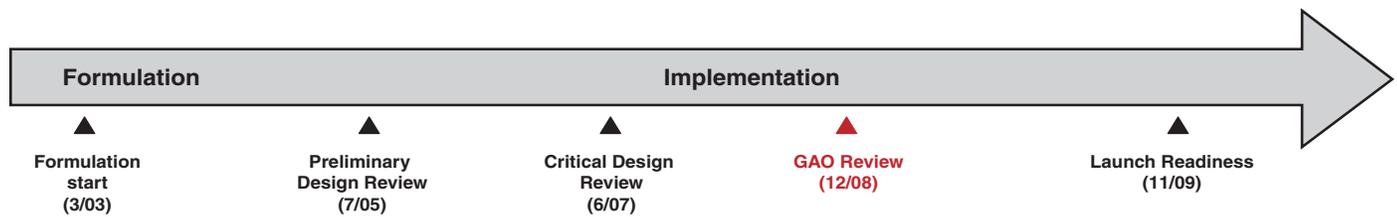
The project office provided technical comments to a draft of this assessment, which were incorporated as appropriate. The project office also commented that since its rebaselining in July 2007, the SOFIA project has not experienced cost or schedule growth.

Wide-field Infrared Survey Explorer (WISE)

The WISE mission is designed to map the sky in infrared light and search for the nearest and coolest stars, the origins of stellar and planetary systems, the most luminous galaxies in the universe, and most main-belt asteroids larger than 3 kilometers. It is also intended to create a catalog of over 300 million sources that will be of interest to future infrared studies, including the upcoming James Webb Space Telescope mission. During its 6-month mission, WISE will use a four-channel imager to take overlapping snapshots of the sky. The WISE telescope optics will be cooled below 20 degrees Kelvin to keep it colder than the objects in space it will observe so that WISE can see the dim infrared emission from them rather than from the telescope itself.



Source: NASA/JPL-Caltech (artist depiction).



Project Essentials

NASA Center Lead: Jet Propulsion Laboratory
International Partner: None

Major Contractors: Ball Aerospace and Technologies Corporation, Space Dynamics Laboratory

Projected Launch Date: November 1, 2009
Launch Location: Vandenberg AFB, Calif.
Launch Vehicle: Delta II

Mission Duration: 6 months

Project Performance
(then year dollars in millions)

	Baseline Est. (FY 2008)	Latest (Dec. 2008)	Change
Total Project Cost	\$311.4	\$310.5	-0.3%
Formulation Cost	\$99.5	\$99.6	0.1%
Development Cost	\$192.1	\$190.9	-0.6%
Operations Cost	\$19.8	\$20.0	1.0%
Launch Schedule	11/2009	11/2009	none

Project Challenges

- > Design Stability

Project Status

The WISE project is currently on schedule to meet its November 2009 launch date. However, the failure of a structural model of the flight cryostat during vibration testing prompted a design change to add a soft-ride system to the launch vehicle, a solution that cost about \$2.6 million. This failure has caused the project to de-scope some testing in order to regain lost cost and schedule margin.

Wide-field Infrared Survey Explorer (WISE)

Detailed Project Discussion

Though the project is currently on track to meet its launch readiness date, the WISE project encountered schedule delays early in its life cycle. According to a project official, the project was not initially confirmed to proceed because of cost and technical concerns. As a result, the official said the project designed a smaller telescope and matured the technology that had concerned the review board. The preliminary design review for WISE was held in July 2005, and the project had its initial confirmation review in November 2005; however, there was a lack of funding in the NASA budget for the WISE project at that time so the formulation phase was extended. At this point in the project, the launch readiness date had slipped from 2008 to June 2009. A second confirmation review was held in October 2006, at which time the launch readiness date was set for October 2009. Although the second confirmation review happened one year later, the launch readiness date set at the original confirmation review only slipped 4 months since, according to a project official, the project was able to make progress during that year.

WISE project officials identified two mission critical technologies—the solid hydrogen cryostat and the long wavelength infrared detector multiplexer—both of which were assessed as mature at the project's preliminary design review. The solid hydrogen cryostat is a modification of a heritage technology. It is of similar design and construction and manufactured by the same contractor that produced cryostats for previous NASA missions. A project official said the project did not encounter any challenges with the development of the cryostat. WISE's design, however, was not stable at the project's critical design review. At the time of that review, the project had released only 70 percent of its engineering drawings. A project official stated that the drawing count and additional analyses, prototypes, and engineering models were used at the critical design review to evaluate the project's design stability. The project has since released the remainder of the engineering drawings.

The project did encounter some challenges during testing, which impacted the spacecraft's design. The thermal-mass-dynamics-simulator, a structural model of the flight cryostat, failed during structural testing. According to a NASA official, analyses done by NASA and the cryostat's contractor did not predict this problem. To mitigate this problem, the project added a soft-ride system to the launch vehicle to reduce loads on the cryostat. The failure also caused the project to accept more project risk by de-scoping two test events in order to regain reserve margin. According to the project office, the remedy cost \$2.6 million, but the overall project schedule was not affected.

Project Office Comments

The WISE project office provided technical comments to a draft of this assessment, which were incorporated as appropriate. Project officials also commented that they believe that development of a complex cryogenic instrument from heritage technology was more challenging to the project than its design stability.

Agency Comments and Our Evaluation

We provided a draft of this report to NASA for review and comment. In written comments, NASA recognizes that its goal is to improve its cost estimating and schedule and indicates that it will work hard to improve its performance.

The actions NASA has taken to address our past recommendations are positive steps toward achieving successful project outcomes and ensuring that decision makers are appropriately investing the agency's resources. However, NASA asserts that its projects are typically high risk, one-of-a-kind missions that do not readily fit into the knowledge-based framework associated with best practices in system acquisition. NASA's own studies and those of others have shown that the challenges discussed in this report, as well as other project management challenges, have plagued the agency for decades. Given the fact that most of the projects we reviewed in this study breached congressional thresholds within a 2- to 3-year period, we remain convinced that NASA would benefit from a more disciplined, knowledge-based approach to its acquisitions.

NASA sought to provide clarification and additional context to the information we provided in our observations. The agency indicated that the growth we reported for the 10 projects in implementation was a forward-looking estimate, rather than actual growth. For this review, NASA provided us baseline cost and schedule estimates for most projects and then provided us updated estimates for those same projects. We assume that the estimates NASA provided are projections based on costs incurred and schedule completed to date, as well as realistic assumptions about future costs and schedule plans.

NASA also stated that cost and schedule growth for some projects was due to factors outside of the agency's control. Specifically:

1. Two NASA missions—the Lunar Reconnaissance Orbiter and Solar Dynamics Observatory—experienced delays to their launch dates due to U.S. launch manifest prioritization. While NASA maintains that the launch slips for LRO and SDO were beyond its control, we believe that greater discipline in these and other acquisitions can still alleviate the impact of these factors. Specifically, given the launch manifest constraints that the agency is and has been experiencing, it would be prudent to adequately plan for such launch delays when determining cost and schedule reserves.
2. NASA believes that Aquarius, NPP, and Herschel projects experienced cost growth and schedule delays due to partner performance beyond its

control. We believe that having the sufficient amount of insight into the partner's activities and schedules may have allowed NASA to become aware of the issues earlier and to actively manage the issues throughout the development process.

3. NASA stated in its comments that not all cost growth is reported from the time of the NASA commitment to Congress for the performance, cost and schedule of its projects, as is the case with the James Webb Space Telescope. This project was just confirmed in the fall of 2008. Nonetheless, NASA provided GAO data for projects as late as December 2008. Since NASA develops baseline estimates for its projects at the confirmation review that are formal commitments, we would have expected NASA to report that data to us in December 2008.
4. NASA stated that it underestimates the complexity of developing first-of-a-kind missions. While we recognize the nature of NASA projects, as stated in our report, we remain convinced that a knowledge-based approach will allow the agency to better plan for and address these complexities.

We are pleased that NASA recognizes our desire to assist the agency in improving its cost and schedule estimating and look forward to continuing to work with it to improve performance in these areas. NASA's comments are reprinted in appendix I. NASA also provided technical comments, which we addressed throughout the report as appropriate and where sufficient evidence was provided to support significant changes.

We will send copies of the report to NASA's Administrator and interested congressional committees. We will also make copies available to others upon request. In addition, the report will be available at no charge on GAO's Web site at <http://www.gao.gov>.

Should you or your staff have any questions on matters discussed in 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 are listed in appendix V.

Sincerely yours,

A handwritten signature in black ink, appearing to read 'Cristina Chaplain', with a stylized, cursive script.

Cristina Chaplain
Director
Acquisition and Sourcing Management

List of Congressional Committees

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Chairman

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

The Honorable Alan B. Mollohan
Chairman

The Honorable Frank R. Wolf
Ranking Member
Subcommittee on Commerce, Justice, Science,
and Related Agencies
Committee on Appropriations
House of Representatives

The Honorable Gabrielle Giffords
Chairwoman

The Honorable Pete Olson
Ranking Member
Subcommittee on Space and Aeronautics
Committee on Science and Technology
House of Representatives

Appendix I: Comments from the National Aeronautics and Space Administration

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



February 24, 2009

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

Dear Ms. Chaplain:

NASA appreciates the opportunity to comment on the draft Government Accountability Office (GAO) report, GAO-09-306, entitled "Assessments of Selected Large-Scale Projects." We are pleased that GAO recognizes NASA's efforts and the hard work of many people at NASA to mitigate acquisition management risk and lay a foundation to reduce project cost and schedule growth. NASA values the open and constructive communications between the NASA and GAO teams on this effort. NASA is dedicated to continuous improvement of its acquisition management processes and performance.

NASA has implemented improvement initiatives enumerated in the NASA response to the 2007 GAO High Risk Area of Contract Management. Specifically NASA has adopted a new acquisition strategy policy which improves its ability to manage performance risks (including adoption of probabilistic cost and schedule estimation methods); and has established a rigorous monthly internal Baseline Performance Review (BPR) to track program and institutional performance and identify corrective actions to allow performance to plan. These actions have allowed us to more clearly identify the causes of deviations from plan that can also be used by the GAO in future reporting.

While NASA practices many of the elements of GAO's stated business case approach, where applicable to the Agency's investment model, the essential attributes of NASA's project development differ from those of a commercial or production entity. NASA projects are typically high risk one-of-a-kind missions that require a knowledge-based approach where experience from previous missions are modified and adapted to the new mission. NASA's intent is to advance selected technologies and techniques to a level of maturity that would provide an acceptable balance of investment risk and return. This approach requires projects to develop a plan that meets system requirements within cost and schedule constraints and with acceptable risk by the confirmation review, called Key Decision Point C. Senior management reviews and assesses each project at this key decision point to determine readiness for the project to

proceed into the implementation phase and detailed design. As mentioned above, NASA management reviews projects monthly at the BPR to assess progress against cost, schedule, and technical commitments. This approach is outlined in NASA's policy directive and procedural requirements related to program/project management.

In its draft report, GAO asserts that NASA has had significant cost and/or schedule growth from the baseline estimate in 10 of the 13 projects on which NASA provided data, using GAO's definition of significant as "greater than the thresholds established for Congressional reporting." Among significant points of clarification that were not provided in the report is that the growth reported was a forward-looking estimate that included anticipated growth through launch, as well as actual growth to date. Based on this assumption, the projected growth indicated in the report is possible, but not yet the actual increase as GAO states.

Other GAO-quoted figures also require some additional context to provide the reader with an accurate view of the cost and schedule growth. NASA notes that the GAO report does not distinguish between factors that result in this growth and whether they are internal or external to NASA. Recognition of the factors that NASA controls, as well as those that are outside the control of the Agency, would best allow us to focus on those factors which NASA can address in order to improve the Agency's acquisition performance. Out of the 10 projects that exceeded Congressional growth thresholds, approximately half did so as a result of external factors. Further, it is also important to link specific instances of cost or schedule growth to factors that contributed to that growth. Some examples from the draft would include:

1. Slips in the launch dates for the Lunar Reconnaissance Orbiter (LRO) and the Solar Dynamics Observatory (SDO) are a result of delays in the U.S. launch manifest prioritization that rightly puts national security missions first. The launch manifest, while actively managed, is beyond the control of NASA.
2. Cost increases and delays to missions such as NPOESS Preparatory Project (NPP), Aquarius and Herschel are due to partner performance beyond the control of NASA.
3. Not all cost growth is reported from the time of the NASA commitment to Congress for the performance, cost, and schedule. This is the case for JWST which was just confirmed in the fall of 2008.
4. One of the most prevalent internal issues is underestimating the complexity of the development of first-of-a-kind missions, such as with MSL. In response to past history of these issues, NASA has adopted formal program reviews at key milestones and now includes probabilistic cost-estimating techniques to help address these uncertainties.

To ensure that NASA and GAO share a common data set for presentation to the Congress and the public, we have provided separate technical comments addressing the

3

accuracy and representation of data included in several of the Project Summary pages of the report.

NASA recognizes that the goal is to improve our performance in estimating cost and schedule so as to enhance our ability to explore and utilize space for the benefit of the Nation and the world. We are committed to continuous improvement and will work hard to continuously measure and improve our performance. To this end we welcome the comments from GAO regarding our performance.

Thank you for the opportunity to comment on this draft report. If you have any questions or require additional information, please contact Julie Pollitt at (202) 358-1580.

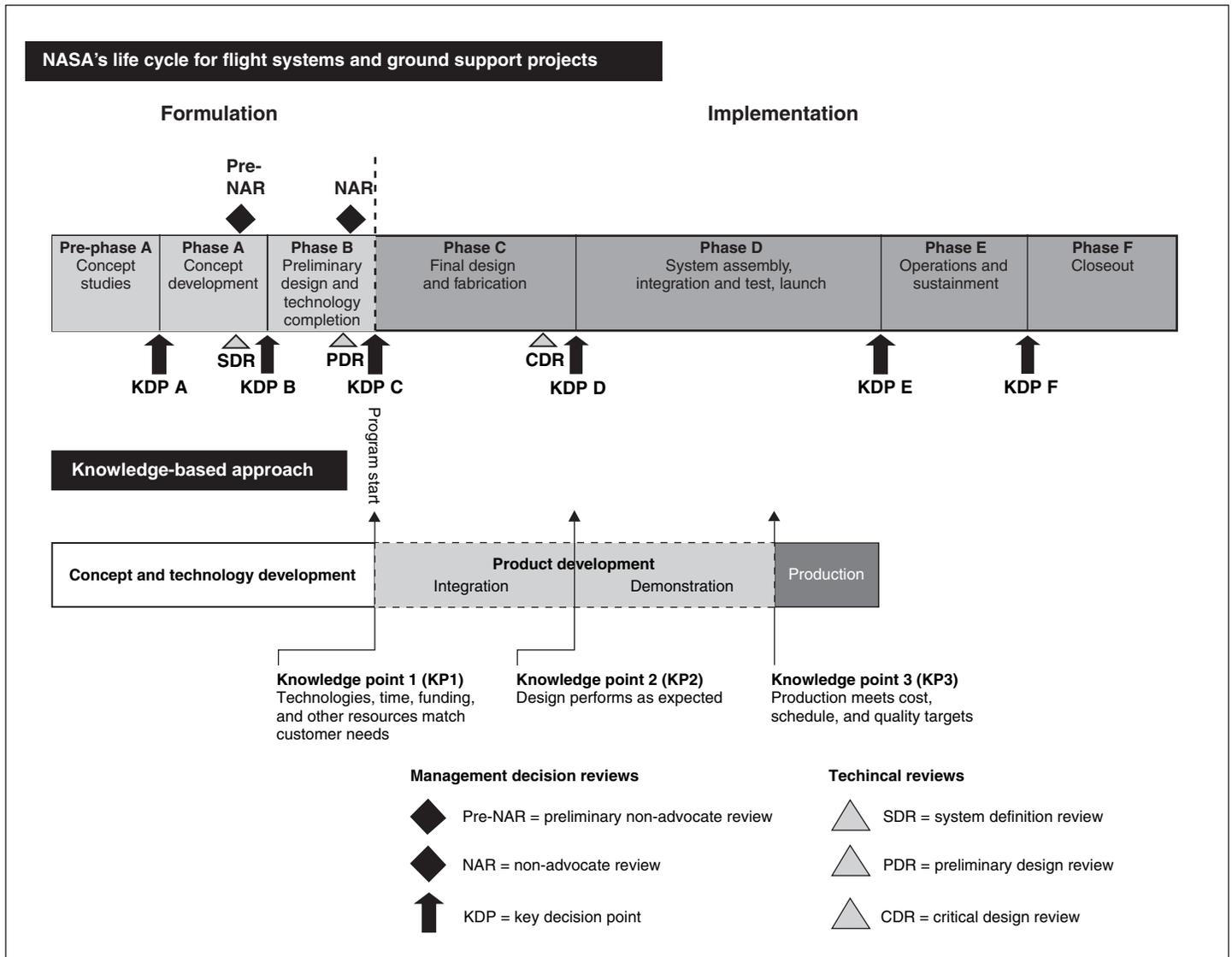
Sincerely,


Charles H. Spates
Associate Deputy Administrator

Appendix II: NASA Life Cycle For Flight Systems Compared to a Knowledge-Based Approach

GAO has previously conducted work on NASA's acquisition policy for space-flight systems, and in particular, on its alignment with a knowledge-based approach to system acquisitions. The figure below depicts this alignment.

Figure 1: NASA's Life Cycle for Flight Systems Compared to a Knowledge-Based Approach



Source: NASA data and GAO analysis.

As the figure shows, NASA's policy defines a project life cycle in two phases—the formulation¹⁴ and implementation¹⁵ phases, which are further divided into incremental pieces: phase A through phase F. Project formulation consists of phases A and B, during which time the projects develop and define the project requirements and cost/schedule basis and design for implementation, including an acquisition strategy. During the end of the formulation phase, leading up to the preliminary design review (PDR)¹⁶ and non-advocate review (NAR)¹⁷, the project team completes its preliminary design and technology development. NASA Procedural Requirements 7120.5D, NASA Space Flight Program and Project Management Requirements, specify that the project complete development of mission-critical or enabling technology, as needed, with demonstrated evidence of required technology qualification (i.e., component and/or breadboard validation in the relevant environment) documented in a technology readiness assessment report. The project must also develop, document, and maintain a project integrated baseline which includes the integrated master schedule and baseline life-cycle cost estimate. Implementing these requirements brings the project closer to ensuring that resources and needs match, but it is not fully consistent with knowledge point 1 of the knowledge-based acquisition life cycle. Our best practices show that demonstrating technology maturity at this point in the system life cycle should include a system or subsystem model or prototype demonstration in a relevant environment, not only component validation.

¹⁴ NASA defines formulation as the identification of how the program or project supports the Agency's strategic needs, goals, and objectives; the assessment of feasibility, technology and concepts; risk assessment, team building, development of operations concepts and acquisition strategies; establishment of high-level requirements and success criteria; the preparation of plans, budgets, and schedules essential to the success of a program or project; and the establishment of control systems to ensure performance to those plans and alignment with current Agency strategies. NPR 7120.5D, paragraph 1.2.1 a. (Mar. 6, 2007).

¹⁵ The implementation phase is defined as the execution of approved plans for the development and operation of the program/project, and the use of control systems to ensure performance to approved plans and continued alignment with the Agency's strategic needs, goals, and objectives. NPR 7120.5D, paragraph 1.2.1 c. (Mar. 6, 2007).

¹⁶ According to NPR 7120.5D, Table 2-6 (Mar. 6, 2007), the PDR demonstrates that the preliminary design meets all system requirements with acceptable risk and within the cost and schedule constraints and establishes the basis for proceeding with detailed design. It shows that the correct design option has been selected, interfaces have been identified, and verification methods have been described. Full baseline cost and schedules, as well as risk assessments, management systems, and metrics are presented.

¹⁷ According to NPR 7120.5D, Table 2-6 (Mar. 6, 2007), the PDR demonstrates that the preliminary design meets all system requirements with acceptable risk and within the cost and schedule constraints and establishes the basis for proceeding with detailed design. It shows that the correct design option has been selected, interfaces have been identified, and verification methods have been described. Full baseline cost and schedules, as well as risk assessments, management systems, and metrics are presented.

As written, NASA's policy does not require full technology maturity before a project enters the implementation phase.

After project confirmation, the project begins implementation, consisting of phases C, D, E, and F. During phases C and D, the project performs final design and fabrication as well as testing of components and system assembly, integration, test, and launch. Phases E and F consist of operations and sustainment and project closeout. A second design review, the critical design review (CDR),¹⁸ is held during the implementation phase toward the end of phase C. The purpose of the CDR is to demonstrate that the maturity of the design is appropriate to support proceeding with full scale fabrication, assembly, integration, and test. Though this review is not a formal decision review, its requirements for a mature design and ability to meet mission performance requirements within the identified cost and schedule constraints are similar to knowledge expected at knowledge point 2 of the knowledge-based acquisition life cycle. Furthermore, after CDR, the project must be approved at KDP D before continuing into the next phase.

The NASA acquisition life cycle lacks a major decision review at knowledge point 3 to demonstrate that production processes are mature. According to NASA officials, the agency rarely enters a formal production phase due to the small quantities of space systems that they build.

¹⁸ According to NPR 7120.5D, appendix A (Mar. 6, 2007), a non-advocate review (NAR) is comprised of the analysis of a proposed program or project by a (non-advocate) team composed of management, technical, and resources experts (personnel) from outside the advocacy chain of the proposed program or project. It provides agency management with an independent assessment of the readiness of the program/project to proceed into implementation.

Appendix III: Objectives, Scope, and Methodology

Our objectives were to report on the status and challenges faced by several NASA systems with life-cycle costs greater than \$250 million and to discuss broader trends faced by the agency in its management of system acquisitions.

In conducting our work, we evaluated performance and identified challenges for each of 18 major projects¹⁹ included in this report. We summarized our assessments of each individual project in two components—a project profile and a detailed discussion of project challenges. We did not validate the data provided by the National Aeronautics and Space Administration (NASA). However, we took appropriate steps to address data reliability. Specifically, we confirmed the accuracy of NASA-generated data with multiple sources within NASA and, in some cases, with external sources. Additionally, we corroborated data provided to us with published documentation. We determined that the data provided by NASA project offices were sufficiently reliable for our engagement purposes.

We developed a standardized data collection instrument (DCI) that was completed by each project office and returned by December 2008. Through the DCI, we gathered basic information about projects as well as current and projected development activities for those projects. The cost, schedule and performance data estimates that NASA inputted were the most recent updates as of December 2008. At the time we collected the data, 4 of the 18 projects were in formulation and 14 were in implementation. However, NASA only provided cost and schedule data for 13 of the projects. To further understand performance issues, we talked with officials from each project office and NASA's Office of Program Analysis and Evaluation (PA&E).

The results collected from each project office, Mission Directorate, and PA&E were summarized in a two-page report format providing a project overview; key cost, contract, and schedule data; and a discussion of the challenges associated with the deviation from relevant indicators from best practice standards. The aggregate measures and averages calculated were analyzed for meaningful relationships, e.g. relationship between cost growth and schedule slippage and knowledge maturity attained both at critical milestones and through the various stages of the project life cycle.

¹⁹ According to NPR 7120.5D, Table 2-6 (Mar. 6, 2007), the CDR demonstrates that the maturity of the design is appropriate to support proceeding with full scale fabrication, assembly, integration, and test, and that the technical effort is on track to complete the flight and ground system development and mission operations in order to meet mission performance requirements within the identified cost and schedule constraints. Progress against management plans, budget, and schedule, as well as risk assessments are presented.

We identified cost and/or schedule growth as significant where, in either case, a project's cost and/or its schedule exceeded the thresholds for the Congressional reporting requirement.

To supplement our analysis, we relied on GAO's body of work over the past years that has examined acquisition issues across multiple agencies. These reports cover such issues as contracting, program management, acquisition policy, and cost estimating. GAO also has an extensive body of work related to challenges NASA has faced with regard to specific system acquisitions, financial management, and cost estimating. This work provided the context and basis for much of the general observations we made with regard to the projects we reviewed. Additionally, the discussions with the individual NASA projects helped us identify further challenges faced by the projects. Together, this contributed to our development of a short list of challenges discussed for each project. The challenges we identified and discussed do not represent an exhaustive or exclusive list. They are subject to change and evolution as GAO continues this annual assessment in future years.

Our work was performed primarily at NASA headquarters in Washington, D.C. In addition, we visited NASA's Marshall Space Flight Center in Huntsville, Alabama, Dryden Flight Research Center at Edwards Air Force Base in California, and Goddard Space Flight Center in Greenbelt, Maryland to discuss individual projects. We also met with representatives from NASA's Jet Propulsion Lab in Pasadena, California and three NASA suppliers.

Data Limitations

NASA only provided specific cost and schedule estimates for 13 of the 18 projects in our review. Agency officials believe that because one project, the James Webb Space Telescope, will not formally release its baseline cost and schedule estimates until the fiscal year 2010 budget submission to Congress, they are not required to provide those estimates to GAO. For three of the projects that had not yet entered implementation, NASA provided internal preliminary estimated total (life-cycle) cost ranges and associated schedules, from key decision point B (KDP-B), solely for informational purposes.²⁰ NASA formally baselines and commits itself to cost and schedule targets for a project with a specific and aligned set of planned mission objectives at key decision point C (KDP-C), which follows a non-advocate review (NAR) and preliminary design review (PDR). 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

²⁰ These missions include: Ares I, Landsat Data Continuity Mission and Orion.

fiscal year budgeting purposes at KDP-B, which occurs mid-stream in the formulation phase, and hence, are not considered a formal commitment by the agency on cost and schedule for the mission deliverables. NASA officials contend that because of changes that occur to a project's scope and technologies between KDP-B and KDP-C, estimates of project cost and schedule can change significantly heading toward KDP-C. Finally, NASA did not provide data for the Global Precipitation Measurement mission because NASA officials said it did not have a requirement for a KDP-B review, because it was authorized to be formulated prior to the requirements of NPR 7120.5D were in place.

Project Profile Information on Each Individual Two-Page Assessment

This section of the two-page assessment outlines the essentials of the project, its cost and schedule performance and its status. Project essentials reflect pertinent information about each project, including, where applicable, the major contractors and partners involved in the project. These organizations have primary responsibility over a major segment of the project, or in some cases, the entire project.

Project performance is depicted 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 PA&E and from NASA's Integrated Budget and Performance documents. For systems in implementation, we compared the latest available information with baseline cost and schedule estimates set for each project in the fiscal year 2007 or 2008 budget request.

All cost information is presented in nominal "then year" dollars for consistency with budget data.²¹ Baseline costs 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.

The schedule assessment is based on acquisition cycle time, which is defined as the number of months between the project start, or formulation start, and projected or actual launch date.²² Formulation start generally refers to the initiation of a project; NASA refers to project start as key

²¹ Due to changes in NASA's accounting structure, its historical cost data is relatively inconsistent. As such, we used "then-year" dollars to report data consistent with the data that NASA reported to us.

²² Some projects reported that their spacecraft would be ready for launch sooner than the date that the launch authority could provide actual launch services. In these cases, we used the actual launch date for our analysis rather than the date that the project reported readiness.

decision point A, or the beginning of the formulation phase. The preliminary design review typically occurs during the end of the formulation phase, followed by a confirmation review which allows the project to move into the implementation phase. The critical design review is held during the final design period of implementation and demonstrates that the maturity of the design is appropriate to support proceeding with full scale fabrication, assembly, integration, and test. Launch readiness is determined through a launch readiness review which verifies that the launch system and spacecraft/payloads are ready for launch. The implementation phase includes the operations of the mission and concludes with project disposal.

We assessed the extent to which NASA projects exceeded their cost and schedule baselines. To do this, we compared the project baseline cost and schedule estimates with the current cost and schedule data reported by the project office in December 2008.

Project Challenges Discussion on Each Individual Two-Page Assessment

To assess the project challenges for each project, we submitted a data collection instrument to each project office. We also held interviews with each of the project offices to discuss the information on the data collection instrument. These discussions led to identification of further challenges faced by NASA projects. These challenges were largely apparent in the projects that had entered the implementation phase. We then reviewed pertinent project documentation, such as the project plan, schedule, risk assessments, and major project reviews.

To assess technology maturity, we asked project officials to assess the technology readiness levels (TRL) of each of the project's critical technologies at various stages of project development. Originally developed by NASA, TRLs are measured on a scale of one to nine, beginning with paper studies of a technology's feasibility and culminating with a technology fully integrated into a completed product. (See appendix IV for the definitions of technology readiness levels.) In most cases, we did not validate the project offices' selection of critical technologies or the determination of the demonstrated level of maturity. However, we sought to clarify the technology readiness levels in those cases where the information provided raised concerns, such as where a critical technology was reported as immature late in the project development cycle. Additionally, we asked project officials to explain the environments in which technologies were tested.

Our best practices work has shown that a technology readiness level of 6— demonstrating a technology as a fully integrated prototype in a realistic environment—is the level of maturity needed to minimize risks for space

systems entering product development. In our assessment, the technologies that have reached technology readiness level 6 are referred to as fully mature due to the difficulty of achieving technology readiness level 7, which is demonstrating maturity in an operational environment—space. Projects with critical technologies that did not achieve maturity by the preliminary design review were assessed as having a technology maturity project challenge. We did not assess technology maturity for those projects which had not yet reached the preliminary design review at the time of this assessment.²³

To assess design stability, we asked project officials to provide the percentage of engineering drawings completed or projected for completion by the preliminary and critical design reviews and as of our current assessment.²⁴ In most cases, we did not verify or validate the percentage of engineering drawings provided by the project office. However, we collected the project offices' rationale for cases where it appeared that only a small number of drawings were completed by the time of the design reviews or where the project office reported significant growth in the number of drawings released after CDR. In accordance with GAO best practices, projects were assessed as having achieved design stability if they had released at least 90 percent of all projected drawings by the critical design review. Projects which had not met this metric were determined to have a design stability project challenge. Though some projects used other methods to assess design stability, such as computer and engineering models and analyses, we did not analyze the use of these other methods and therefore could not assess the design stability of those projects. We could not assess design stability for those projects which had not yet reached the critical design review at the time of this assessment.

²³ According to NASA officials, projects that were in formulation at the time of the agency's 2007 revision of its project management policy are required to comply with that policy. Projects that had already entered implementation at the time of the revision were directed to implement those requirements which would not adversely affect the project's cost and schedule baselines.

²⁴ 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 drawing growth occurred. So, the denominator in the calculation may have been larger than what was projected at the critical design review. We felt that this more accurately reflected the design stability of the project.

To assess the complexity of heritage technology, we interviewed project officials about the use of heritage technologies in their projects.²⁵ We asked them what heritage technologies were being used, what effort was needed to modify the form, fit, and function of the technology for use in the new system, and whether the project encountered any problems in modifying the technology. Heritage technologies were not considered critical technologies by several of the projects we reviewed. Based on our interviews, review of cost and schedule data from the data collection instruments, and previous GAO work on space systems, we determined whether complexity of heritage technology was a challenge for a particular project.

To assess whether projects encountered challenges with contractor performance, we interviewed project officials about their interaction and experience with contractors. We also interviewed contractor officials from Orbital Sciences Corporation, Ball Aerospace and Technologies Corporation, and Raytheon Space Systems about their experiences contracting with NASA. We were informed about contractor performance problems pertaining to their workforce, the supplier base, and technical and corporate experience. We also discussed contract fees and situations in which NASA and a contractor agreed that the contractor would use their award fee to cover project cost overruns. We assessed a project as having this challenge if these contractor performance problems, as confirmed by NASA and, where possible, the project contractor, caused the project to experience a cost overrun, schedule delay, or decrease in mission capability. For projects which did not have a major contractor, we considered this challenge not applicable to the project.

To assess whether projects encountered challenges with development partner performance, we interviewed NASA project officials about their interaction with international or domestic partners during project development. Development partner performance was considered a challenge for the project if project officials indicated that domestic or foreign partners were experiencing problems with project development that impacted the cost, schedule, or performance of the project for NASA. These challenges were specific to the partner organization or caused by a contractor to that partner organization. For projects which did not have

²⁵ NASA distinguishes critical technologies from heritage technologies. NASA officials do not believe that heritage technologies are the same as critical technologies because they believe critical technology does not rely on existing technology. GAO best practices describe critical technologies as those that are required for the project to successfully meet customer requirements, regardless of whether or not they are based on existing or heritage technology. For the purposes of this review, we distinguish between the two types because NASA did not report heritage technologies as critical technologies in our data collection instrument.

an international or domestic development partner, we considered this challenge not applicable to the project.

The individual project offices were given an opportunity to comment on and provide technical clarifications to the two-page assessments prior to their inclusion in the final product.

We conducted this performance audit from February 2008 to March 2009 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 IV: 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.	Analytical 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.

Appendix IV: Technology Readiness Levels

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 TRL 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 an realistic environment.	Prototype near or at planned operational system. Represents a major step up from TRL 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 TRL 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	Development Test and Evaluation (DT&E) 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	Operational Test and Evaluation (OT&E) in operational mission conditions

Source: GAO and its analysis of National Aeronautics and Space Administration data.

Appendix V: GAO Contact and Staff Acknowledgments

GAO Contact

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

Acknowledgments

In addition to the contact named above, Jim Morrison, Assistant Director; Greg Campbell; Richard A. Cederholm; Brendan S. Culley; Neil D. Feldman; Leon S. Gill; Rachel L. Girshick; Kristine R. Heuwinkel; Deanna R. Laufer; Shelby S. Oakley; Kenneth E. Patton; Sylvia Schatz; and Letisha T. Watson made key contributions to this report.

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